Sea Level Rise Vulnerability Study for the City of Los Angeles

Prepared by the
University of Southern California Sea Grant Program

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Abstract

The City of Los Angeles (City of L.A. or the City) has initiated research to support planning for the impacts of climate change. The City, the University of Southern California Sea Grant Program (USC Sea Grant) and project partners developed a science-based and stakeholder-supported adaptation planning process to support research on the impacts of sea level rise on City assets, resources and communities. As a first step, this report, *Sea Level Rise Vulnerability Report for the City of Los Angeles*, is a summary of initial research on the potential impacts of sea level rise and associated flooding from storms for coastal communities in the City of L.A. The study concentrates on the City's three coastal regions: Pacific Palisades from Malibu to Santa Monica; Venice and Playa del Rey; and San Pedro, Wilmington and the Port of Los Angeles.

An interdisciplinary team of world-renowned experts was engaged to identify the City's potential exposure to sea level rise. A sophisticated model, developed by the U.S. Geological Survey (USGS), was used to examine the impacts from rising seas, as well as flood impacts from storms and high tides that could be exacerbated with those rising sea levels. The model is based on an *El Nino*-fueled storm that occurred in the Los Angeles region during January 2010, considered a moderately severe "10-year" storm (10% chance of occurring annually). As new data become available for the L.A. region, they can be applied to evaluate impacts of more severe storms, such as a 100-year event (1% chance of occurring annually).

In this study, we provide an initial report by Dr. Reinhard Flick focused on coastal vulnerabilities in locales within City boundaries, and provide recommendations for beach monitoring programs. We then highlight the findings of three vulnerability assessments that provide a preliminary examination of the physical, social, and economic impacts of sea level rise on the City's coastal assets, resources and communities, and include a summary discussion of ecological vulnerability at Ballona Wetlands. One of the next steps for the City will be to develop an Adaptation Plan. We help get this process started with a matrix of available adaptation measures the City can consider in planning for sea level rise as well as recommendations for moving forward with adaptation planning.

The summary of coastal issues and full texts of each vulnerability assessment are included as appendices to this report:

- Appendix 1 - *City of Los Angeles Coastal Issues Related to Future Mean Sea Level Rise*
- Appendix 2 - *Physical Vulnerability Assessment Findings for the City of Los Angeles*
- Appendix 3 - *Sea-Level Rise Impacts and Flooding Risks in the Context of Social Vulnerability: An Assessment for the City of Los Angeles*
- Appendix 4 - *Economic Impact of Sea Level Rise to the City of Los Angeles*

This report provides an initial and conservative assessment of the potential vulnerabilities the City may face due to rising sea levels. It draws attention to potentially vulnerable City assets (i.e. water and power infrastructure), possible building-related economic losses, and indicators of social vulnerability to begin to identify the most vulnerable communities in the City of L.A. It is not meant to be a comprehensive or regional review. It includes strategies the City may wish to consider; however this report in no way replaces the critical science and engineering studies that should be conducted as part of the development of any adaptation strategy or plan.

Executive Summary

Climate change is expected to usher in an era of higher temperatures, increased precipitation and/or severe drought, and increased rates of sea level rise around the world. According to the National Research Council (NRC), global sea level has risen at an increasing rate since the late 19th / early 20th Century, when global temperatures first started to rise. Climate researchers believe sea level rise will drive storm surge and wave run-up higher than current conditions, thereby causing more extensive and frequent coastal, storm-driven flooding.

Sea level rise in Los Angeles is expected to match global projections over the next century with an increase of 0.1 - 0.6 meters (m), or 0.3 - 2.0 feet (ft), from 2000 - 2050 and 0.4 - 1.7 m (or 1.3 - 5.6 ft) from 2000 - 2100 (NRC 2012). Tides, wave-driven run-up, and storm surge play critical roles in coastal flooding in Southern California, especially when big wave storms occur at or near peak high tides. Sea level rise will potentially exacerbate the damage from these events.

The City of Los Angeles (City of L.A. or the City) owns and maintains critical coastal infrastructure that includes two power plants and two wastewater treatment plants, and the Port of Los Angeles (Port), all of which are approximately 10 ft above sea level. Under current conditions, some of this infrastructure is vulnerable to flooding during high tide events and severe storms. This flooding is expected to worsen as sea level rise contributes to increased total water levels. The Port is among the busiest in the world, contributing more than $63 billion to the State of California, and more than $260 billion to the U.S. economy. More than 40% of all imports arriving in the U.S. comes through the Ports of Los Angeles and Long Beach, where it is loaded onto trucks and trains for overland shipping (Port of Los Angeles 2012).

Beyond these critical assets, a major component of Los Angeles' economy is dependent upon beach tourism. In 2012, the Los Angeles region attracted over 41 million tourists, who accounted for more than $16.5 billion in expenditures (Los Angeles Division of Tourism 2012).

The City recognizes that this is the time to begin planning for the impacts of climate change, not 20 or 30 years in the future when disruptions to business and damage to critical coastal infrastructure will prompt *ad hoc* and poorly coordinated responses. Because of the unprecedented degree of stakeholder collaboration and inter-agency cooperation required for large-scale regional adaptation, an extended timeframe for planning is critical.

The City of L.A. engaged the University of Southern California (USC) Sea Grant Program, along with the Los Angeles Regional Collaborative on Climate Action and Sustainability (LARC) and ICLEI – Local Governments for Sustainability, U.S.A. (ICLEI), to begin research into the impacts of sea level rise on the City's coastal assets, resources and communities. In December 2011, the City launched this project; a science-based and stakeholder-supported sea level rise adaptation planning effort. The methodology 1) supports the City in identifying the vulnerabilities of its coastal assets, resources and communities to sea level rise, 2) provides information for developing meaningful and effective adaptation strategies, and 3) builds on the City's ongoing environmental and climate policies.

Geographic Scope and Purpose of this Report

This report focuses on the potential impacts of sea level rise and associated coastal flooding for the coastal communities of the City of L.A. We highlight the findings of a coastal issues report; three vulnerability assessments that provide a preliminary examination of the physical, social, and economic impacts of sea level rise on the City of L. A.; and a discussion of ecological vulnerability at Ballona

Wetlands. We conclude the report with a set of guidelines for identifying and evaluating possible adaptation strategies and measures to address these potential vulnerabilities. This report is meant to provide a first glimpse into the vulnerabilities the City of L.A. may face under rising sea levels and to start building the capacity within the City to begin an adaptive approach to planning for sea level rise and other climate change impacts.

Sea Level Rise Exposure

For the vulnerability assessments, the City utilized a coastal impacts model developed by Dr. Patrick Barnard and colleagues at the United States Geological Survey (USGS). This model incorporates not only the impacts of rising sea levels, but also the impacts of waves and storm surge associated with coastal storms. The USGS model is based on a storm that occurred in the Los Angeles region during January 2010. The modelers applied two sea level rise scenarios using upper-end estimates of 0.5 meters (m) sea level rise between 2000 - 2050 and 1.4 m sea level rise between 2000 - 2100 (scenarios based on Rahmstorf 2007). The scenarios were added to the tide, wave and wind conditions of the January 2010 storm to project what could be expected for a similar type of storm event under conditions related to rising seas. While there are a number of sea level rise and coastal impact models available for use, it was determined at the time of this analysis that the USGS model provided the best available science.

Major Findings

Coastal and Shoreline Assets[1]

This section summarizes a preliminary report on coastal vulnerabilities for those beaches located within City boundaries, and provides recommendations for monitoring programs. This report provides a first glimpse into potential strategies the City may wish to consider, however this report in no way replaces the critical engineering studies that should be conducted before committing to any strategy or plan.

Physical Vulnerability Assessment[2]

The physical vulnerability assessment considers areas where important structural community assets are susceptible to and/or unable to accommodate adverse effects of sea level rise. The major findings include:

- The City's roads and water systems (wastewater, stormwater, potable water) are vulnerable to impacts from sea level rise and associated storm surge.

- The City's cultural assets are vulnerable to sea level rise. Museums and cultural centers are considered to be highly vulnerable because of the damages that can result to the physical buildings and resources. Parks and open space, while in vulnerable locations, are less vulnerable to flooding impacts since they can be restored relatively quickly.

- The Port and the City energy facilities have relatively low vulnerability to sea level rise.

Under current conditions, City assets are already vulnerable to damages that could occur during concurrent high tide and large storm events. Highlighting future possible vulnerabilities allows the City to start planning now on how to better address the potentially increasing frequency and severity of these events in the future.

It is also important to highlight that some agencies within the City have already begun planning for sea

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1. This report, funded by the City of L.A., was developed by Dr. Reinhard Flick (see Appendix 1).
2. This study, funded by the City of L.A., was conducted by ICLEI (see Appendix 2).

level rise, even prior to the initiation of this study. For instance, the Bureau of Sanitation has recognized that climate change effects may impact assets and operations and has developed strategic planning goals and outcomes to mitigate these impacts. The Bureau has commissioned engineering studies to plan for potential flooding at several critical locations. Since 2011, the Port has been working with the RAND Corporation to conduct a sea level rise vulnerability study. Similarly, in 2010, the Department of Water and Power conducted a tsunami study. Analyses from all of these studies have been incorporated in the sea level rise vulnerability study we discuss here.

Social Vulnerability Assessment[3]

The social vulnerability assessment describes the impacts that sea level rise and its associated effects may pose to the City's coastal residents. Demographic overviews of the three coastal areas within the City of L.A. that will experience direct impacts of sea level rise are followed by a description of population characteristics that help predict the degree of social vulnerability for certain segments of communities vulnerable to flooding. The characteristics examined in this assessment include: income, poverty, education, females as head of household, race, linguistic isolation, age, housing type and age, and physical and mental illnesses and disabilities. These characteristics are associated with higher sensitivity and/or lower adaptive capacity to flooding and sea level rise, and thus can be used to inform adaptation planning. Major findings include:

- Low-lying San Pedro and Wilmington, communities around the Port of Los Angeles, are more vulnerable to the impacts of sea level rise, due to lower per capita income, lower education levels and linguistic isolation.

- Venice, and low-lying San Pedro and Wilmington may also have reduced capacity to adapt to the impacts of sea level rise because of an older housing stock and a high percentage of renters.

- The Social Vulnerability Index (developed by Cutter et al. 2003), which calculates a vulnerability index based on a combination of 32 census-based population characteristics, corroborates findings that communities in Venice, San Pedro and Wilmington are the most socially vulnerable coastal communities in the City.

This assessment allows the City to begin identifying adaptation and communication strategies that target vulnerable populations. Strategies may include: documenting where vulnerable populations reside so first responders understand the extent of the need and can direct assistance appropriately when the time comes; conducting workshops and preparing other public outreach materials for non-English speakers; and, given low education and high poverty levels, using alternative educational/informational methods that do not require literacy or internet access.

Economic Vulnerability Assessment[4]

The economic impacts analyzed in this study include both property damage losses and direct and indirect business interruption losses due to sea level rise and associated storm surge. These findings present a "worst case" assumption if the City takes no action to plan for the potential impacts from these events.

Major findings include:

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3. This study, funded by the City of L.A., was conducted by Dr. Julie Ekstrom and Dr. Susanne Moser (see Appendix 3).

4. This study, funded by USC Sea Grant, was conducted by Dr. Dan Wei and Dr. Sam Chatterjee (see Appendix 4).

- For a 10-year flood event, the direct building losses are estimated to be $410.3 million with 0.5 m sea level rise, and nearly doubled with 1.4 m sea level rise. Losses to residential buildings comprise about 50% of the total losses. The other 50% of losses are split evenly between the commercial buildings and industrial buildings in most simulated scenarios.

- Business interruption losses are relatively small compared with the building stock losses. For a 10-year flood event, the total output losses in the City are expected to be $5.8 million to $9.1 million under the two simulated sea level rise scenarios.

- Simulations show that the transportation system and the utility system in the City would suffer very limited damages from flooding in the limited scenarios evaluated in this study.

Impacts caused by long-term and permanent coastal erosion and beach area losses of sea level rise are not covered in this study. The potential economic impacts of sea level rise to the City in this analysis should be considered to be conservative estimates. Further economic studies to assess potential impacts on tourism, transportation systems, goods movement, and the regional economy would help to elucidate a more robust picture of potential impacts. Identifying these vulnerabilities allows the City to identify where it should focus its adaptation efforts with respect to sea level rise to minimize the losses due to damage to its building stock and to minimize business interruption losses and the ensuing ripple effects.

Ecological Vulnerability Assessment
Most of the City's coastal zone is highly urbanized. The vulnerability of the less urbanized areas such as City beaches, open space areas, parks or recreation centers, was assessed in the physical vulnerability assessment conducted by ICLEI (Appendix 2). We do highlight one important ecological asset located within City boundaries: the Ballona Wetlands Ecological Reserve. This wetland provides a plethora of ecosystem services including, but not limited to, biological productivity energy flow, nutrient cycling, foraging, nursery, sheltering, and resting places for wildlife, sediment accretion, and wave attenuation.

We cite results from a recent sea level rise study conducted by researchers from Loyola Marymount University and the Santa Monica Bay Restoration Foundation, which indicate that Ballona is vulnerable to sea level rise and associated storm surge impacts (Bergquist et al. 2012). Even though the City does not manage Ballona Wetlands, it provides important ecosystem functions for the City, and therefore we suggest that it is in the interest of the City to participate in the development of sea level rise adaptation strategies and plans for this important ecological resource.

Moving Forward: Considerations for Identifying Appropriate Adaptation Strategies
In the final section, we identify a suite of adaptation measures the City can consider utilizing in planning for sea level rise. We also provide several recommendations for moving forward. These recommendations include:

- Continue the "adaptive adaptation planning" process that reassesses the City's vulnerabilities as scientific information and further vulnerability assessments evolve;

- Invest in a strong foundation for climate adaptation;

- Define clear adaptation goals;

- Develop clear prioritization and selection criteria for choosing among possible adaptation strategies;

- Expand partnerships in developing adaptation options, both within the City itself, as well as in the regional context;

- Invest in scientific and engineering studies and coastal monitoring efforts to clearly delineate the necessary modifications in physical assets and infrastructure, determine the time frame for responses, and begin constructing an estimate of financial needs; and,

- Conduct robust and thorough risk analyses.

Regional Stakeholder Participation

Stakeholder input is an invaluable part of the public process when planning for a future with potentially significant impacts on the public. A Regional Stakeholder Working Group (RSWG) was appointed early in the process. The group includes representatives from the Los Angeles City Council, Los Angeles County, State of California, the private sector, government associations, and non-governmental organizations. Through formal meetings and a review and comment process, the Regional Stakeholder Working Group (RSWG) provided critical input to the process and the final version of this study. RSWG members commented on the sea level rise report by providing suggestions on how to move forward in adaptation planning, expand this study in future iterations, and communicate the findings to wider audiences. While some comments were out of the scope and intent of this initial study, it is important to capture comments to assist the City as it moves to the next milestones of the process and updates this study as new science and information become available.

City Leadership Already Underway

Already, the City adaptation process is well underway to meeting, and exceeding, some of the recommendations listed above. The City has demonstrated proactive leadership in developing the process and undertaking this study to identify its potential vulnerabilities to sea level rise and associated flood impacts from storms. The City has engaged a team of world renowned experts to identify its potential exposure to sea level rise, using a sophisticated model that examines both the impacts from rising seas, as well as flood impacts from storms and high tides, which could be exacerbated with those rising sea levels. It has identified its potential vulnerabilities in order to begin planning now and not in 20 or 30 years.

Prior even to the recommendations of this study, agencies within the City were already commissioning studies to understand the impacts of sea level rise on critical infrastructure, as well as other climate change impacts. LARC commissioned a simulation of climate change by Dr. Alex Hall at the University of California, Los Angeles, to examine localized impacts such as temperature change, urban heat islands, fresh water supply, increased fire frequency, and human health impacts to the greater L.A. metropolis. Further results describing changes in precipitation, cloud cover, snowpack, winds, storms, and other patterns will be released in 2013 and 2014. Equally, the best adaptation strategy is mitigation, or the reduction of greenhouse gas (GHG) emissions. The City of L.A. has emerged as a leader in its varied and numerous mitigation strategies. Adaptation to current and potential impacts is the next important phase in tackling climate change head-on.

Sea Level Rise in Southern California

The Global Picture of Climate Change

Aside from a warmer planet, climate change is expected to usher in an era of higher winds, flooding and/or severe drought, and increased rates of sea level rise around the world. Caused by both the thermal expansion of seawater and the melting of land-based ice, global sea level rise is expected to accelerate due to increasing rates of ice cap and glacier melting and transfers of more heat from the atmosphere to the oceans. According to a recent report by the National Research Council (NRC) (NRC 2012), based on tide gage measurements from around the world, global sea level rose an average of 0.17 cm (or 0.07 in) per year, for a total of about 18 cm (7 in) over the entire 20th century. In comparison, global rates for 1993–2003 were almost double at 0.31 cm (or 0.12 inches) per year, based on precise satellite altimetry measurements and confirmed by tide gage records (Nicholls et al. 2011; NRC 2012). The most recent NRC report (2012) reports estimates global sea level will rise by as much as 8 - 23 cm (3 - 9 in) by 2030 relative to 2000; 18 - 48 cm (7 - 19 in) by 2050; and 50-140 cm (20-55 in) by 2100.

Many argue that we are already seeing evidence of this change. The fall of 2012, for example, witnessed "Superstorm Sandy" along the Eastern Seaboard of the U.S. The 14-foot storm surge at its peak washed away dozens of homes and destroyed entire neighborhoods; flooded streets, subways and other infrastructure, including a main substation of the power grid. Approximately 8.5 million people were without power, many without heat, refrigeration and communication for almost three weeks. All told, Sandy cost 159 lives and resulted in $65 billion in damages and economic loss, including significant business interruption (Hurricane Sandy Rebuilding Task Force 2013). While there is no definitive evidence that Sandy was a direct consequence of climate change, she left behind a path of devastation that demonstrates the damage that can accrue from major storms.

The Local Picture of Sea Level Rise

Although it is occurring around the globe, sea level rise is not uniform; it varies from place to place (NRC 2012). Along the West Coast, sea level is influenced by a number of regional factors, such as decadal (or about a 10 year cycle) ocean and atmospheric circulation patterns (Bromirski et al., 2011) and shorter-term heating and cooling effects, such as *El Niños* in the Pacific Ocean, as well as plate tectonics (NRC 2012).

Sea level rise in Los Angeles is expected to match global projections over the next century, despite the fact that local sea level has been relatively static for the past decade. For the Los Angeles region, the NRC report projects sea level rise of an increase of 0.1 - 0.6 m (or, 0.3 - 2.0 ft), from 2000 - 2050 and 0.4 - 1.7 m (or 1.3 - 5.6 ft) from 2000 - 2100 (NRC 2012).

Tides, wave-driven run-up, and storms play the most critical roles in coastal flooding in Southern California, especially when big wave storms occur at or near peak high tides. Sea level rise slowly but inexorably exacerbates these effects by making the occurrence of extreme total high water levels more and more frequent over time.

Image of the Hyperion Wastewater Treatment Plant and the Scattergood Generating Plant, two coastal assets in the City of Los Angeles. (Photo credit: Kenneth & Gabrielle Adelman, California Coastal Records Project, www.Californiacoastline.org).

As a result, climate researchers believe storms will impact the West Coast more powerfully in the future because sea level rise will raise wave run-up (or maximum vertical extent of wave up-rush on a beach) and storm surge, thereby causing more erosion and more extensive and frequent flooding and damages.

The Need for Sea Level Rise Adaptation Planning in Los Angeles

The City of L.A. owns and maintains critical coastal infrastructure that includes two power plants and two wastewater treatment plants that are approximately 10 feet above mean sea level. Under current conditions, some of this infrastructure is already vulnerable to flooding during high tide events and severe storms. This flooding is expected to worsen as sea level rise contributes to increased total extreme water levels.

Beyond these critical assets, beaches and beach tourism are major contributions to Los Angeles' economy. L.A. County attracted almost 27 million tourists who accounted for more than $15 billion in expenditures, and more than $8 billion in tax revenues in 2011, climbing to over 41 million tourists and $16.5 billion in expenditures in 2012 (Los Angeles Division of Tourism, 2011 and 2012). Many of these visitors were attracted to the region's wide sandy beaches and other attractions that make coastal communities special, such as piers, boardwalks and marinas.

Among the most famous of these beach communities in Los Angeles is Venice, whose natural beach has been altered significantly by coastal engineering and advantageous sand placement. Over the last five decades, sand has already been replenished at a cost of millions of dollars (Flick 2012). Like Venice, other coastal communities such as Pacific Palisades, Santa Monica and Malibu, are dependent upon their wide sandy beaches and other coastal assets for tourism and economic development. As sea level rise accelerates, more will have to be done to expand and stabilize beaches, perhaps including sand and dune replenishment and the construction of groins, jetties, and breakwaters to safeguard these world-famous tourist destinations for future generations.

Los Angeles Harbor/San Pedro and the Port of Los Angeles are two important economic engines for the City of Los Angeles. (Photo Credit Top to Bottom: California Coastal Records; Jim Fawcett).

South of Venice, on the southern side of the Palos Verdes Peninsula, the Port of Los Angeles is one of the busiest in the world, contributing more than $63 billion to the State of California, and more than $230 billion to the U.S. economy (Port of Los Angeles 2012). In fact, more than 40 percent of all imports arriving in the U.S. comes through the Ports of Los Angeles and Long Beach, where it is loaded onto trucks and trains for overland shipping.

These and other invaluable coastal assets and resources are all threatened by climate change and sea level rise. A recent study by King et al. (2011) modeled the economic impacts of 100-year floods (e.g., flooding, upland erosion and beach erosion) on five coastal California communities using baseline conditions compared to sea level rise scenarios of 1.0 m and 1.4 m. For iconic Venice Beach, King's study indicates that a 100-year storm under current conditions with no sea level rise would cause an estimated $7 million in damages. By contrast, a 100-year storm with a 1.4 m rise in sea level (projected by 2100) could potentially cause $15.1 million in damages, more than doubling the economic impact. In our study, we provide revised estimates of expected economic impacts through our Economic Vulnerability Assessment (Appendix 4).

Mitigation and Adaptation Planning Ongoing in Los Angeles

More than half of the world's population lives in urban areas, and as a result, cities have taken on the mantle of being the "first responders" to the coming climate crisis. As one of the largest cities in the world, Los Angeles has become a model for the rest of the global community in planning for climate change.

In 2007, then-Mayor Antonio Villaraigosa released *GreenLA: An Action Plan to Lead the Nation in Fighting Global Warming*, a mitigation strategy that laid out standards for reducing greenhouse gas emissions by restricting energy and land use. Among other objectives, the plan set forth a goal of reducing greenhouse gas emissions to 35 percent below 1990 levels by 2030, one of the most aggressive climate goals put forth by any city in the country. The voluntary plan identifies more than 50 action items, grouped into focus areas, to reduce emissions. ClimateLA is the implementation program that provides detailed information about each action item discussed in the GreenLA framework. Action items include harnessing wind power to generate electricity, retrofitting City buildings to make them more energy efficient, and converting the City's fleet vehicles to cleaner models.

In 2008, the City began conducting research on adaptation planning, working with the Los Angeles Regional Collaborative for Climate Action and Sustainability (LARC), the University of Southern California (USC) Sea Grant Program, and the University of California, Los Angeles (UCLA). Adaptation planning, in contrast to mitigation, focuses on planning for the projected impacts of climate change to minimize harm. Together, mitigation strategies and adaptation planning are tools that help to ensure community resilience.[5]

Through a federal Energy and Efficiency Community Block Grant to the City of L.A., LARC commissioned a simulation of climate change in Greater L.A. UCLA's Dr. Alex Hall, a leading climate scientist and member of the Intergovernmental Panel on Climate Change, is using the most scientifically advanced models in the world to simulate the impacts of climate change at an extremely high resolution. These climate change simulations will allow the City of L.A. and LARC to plan for adaptation to such impacts as temperature change, urban heat islands, increased fire frequency, and human health impacts. The research is also informative about the potential for development of local renewable energy resources that would also lead to GHG reductions. The first results of these models, describing possible temperature changes in communities across Southern California by mid-century, were released in June of 2012. Further results describing changes in precipitation, cloud cover, snowpack, winds, storms, and other patterns will be released in 2013 and 2014.

[5]. Resilience can be defined as the ability of a system to absorb some amount of change, including shocks from extreme events, bounce back and recover from that change, and, if necessary, transform itself to continue to be able to function and provide essential services and amenities that it has been designed to provide (California Natural Resources Agency, 2009).

Geographic Scope of this Study

The configuration of municipal boundaries in the City of L.A. reflects the history of the City as a collection of what were once separate municipalities. As a result, the City's coastal boundaries are discontiguous; and each region displays a variety of geomorphological and demographic traits. This plan focuses on the City's three coastal reaches: Pacific Palisades from Malibu to Santa Monica; Venice, Playa Del Rey and LAX; and San Pedro, Wilmington, and the Port of Los Angeles (Figure 1).

In the north, the coastal boundary of the City of L.A. begins in the hillside community of Pacific Palisades, an area distinguished by coastal canyons and high bluffs above a narrow coastal shelf. The Pacific Coast Highway runs along the narrow margin between Santa Monica Bay and already eroding coastal bluffs.

The community of Venice lies at low elevation along the Santa Monica Bay coastline, adjacent to the L.A. County enclave of Marina del Rey. A renowned beach destination, Venice occupies the northern side of the former Los Angeles River basin as it makes its way to the ocean.

The Playa del Rey and Playa Vista communities occupy a broad coastal plain, the former riverbed and delta of the Los Angeles River, now channelized 15 miles east and redirected to San Pedro Bay. Further south along the coast, LAX, and the community of Westchester occupy a coastal bluff bounded by wide beaches that have received significant sand nourishment during the last half century.

In the south, the coast has an east-west orientation, with south-facing beaches fronting San Pedro Bay, and a hillside community built on the eastern side of the Palos Verdes promontory. The Port of Los Angeles is built at its base and extends onto the western side of Terminal Island, a human-made island whose eastern half is part of the City of Long Beach. Wilmington lies on the north side of the Port of Los Angeles. Wilmington is a lower-income neighborhood, many of whose residents work in harbor-related businesses. To the west of Wilmington is the Harbor City community, a business area serving San Pedro and Wilmington.

Coastal Regions in the City of Los Angeles

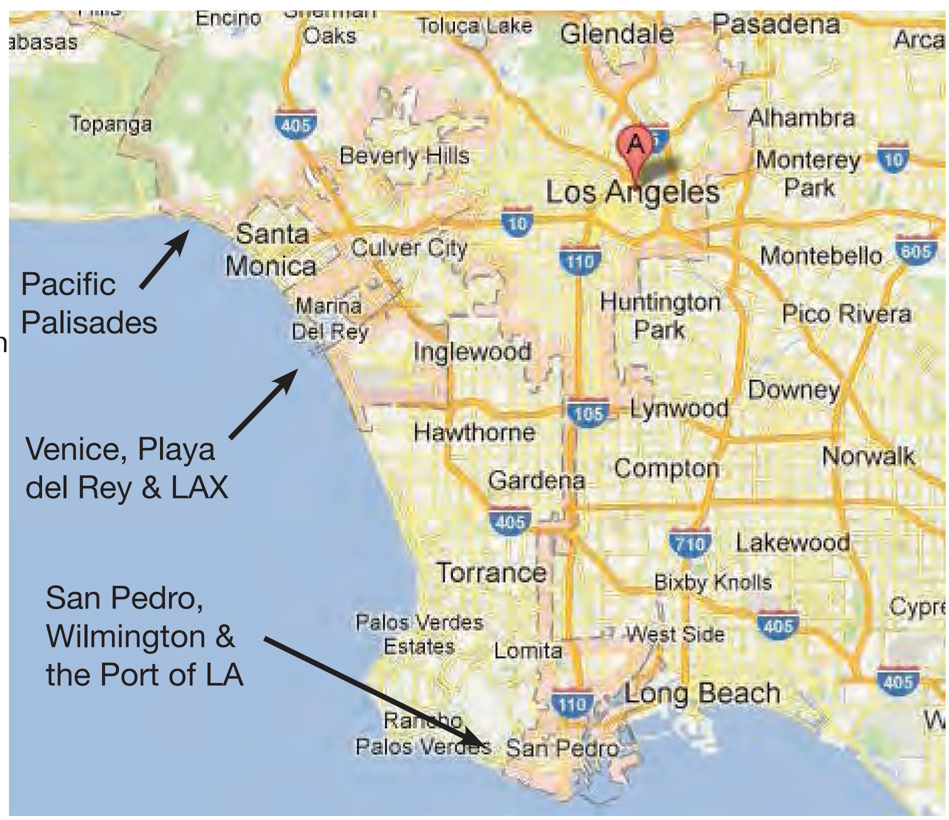

Figure 1: Google Maps image showing the boundaries of the City of Los Angeles with the major coastal regions indicated.

Adaptation Planning Process

The time to begin planning for the impacts of climate change is now, not 20 or 30 years in the future when these effects will already have begun to disrupt business and damage critical coastal infrastructure, prompting *ad hoc* and poorly coordinated responses. Because of the unprecedented degree of stakeholder collaboration and inter-agency cooperation required for regional-scale planning, an extended time frame for taking action is critical. Understanding this urgency, the City of L.A. has decided to commence proactive planning now.

The USC Sea Grant Program worked with the City, LARC and ICLEI - Local Governments for Sustainability, USA (ICLEI), to develop an adaptation planning process. This process is collaborative, science-based, and participatory. It provides a methodology to help the City identify the vulnerabilities to sea level rise of its assets, resources and communities, and establish mechanisms for moving forward with developing adaptation strategies. This methodology draws heavily from a variety of adaptation planning guides and resources (NRC 2010, Snover et al. 2007, Russell and Griggs, 2012), as well as the considerable on-the-ground experience of the project partners.

The project began with the development of three teams, which will be key to its long-term success: an Adaptation Planning Team; the City Adaptation Leadership Team (CAL); and a Regional Stakeholder Working Group (RSWG).

The Adaptation Planning Team is comprised of Mayor's office staff and representatives from USC Sea Grant, LARC, and ICLEI. This group oversees and coordinates the process.

The CAL brings together City department principals who will be at the forefront of facing the impacts of accelerating sea level rise. Departments include: Department of Water and Power; Department of Public Works; Bureau of Sanitation; Harbor Department; Planning Department; Department of Recreation and Parks; and Emergency Management Services.

City Adaptation Leadership members at a meeting to discuss current known vulnerabilities. (Photo credit: Marika Schulhof).

The RSWG includes Los Angeles City Council staff, Los Angeles County representatives, State of California representatives, business, industry, government associations, and non-governmental organizations. The City maintains close relationships with L.A. County, which manages several important facilities in its jurisdiction (i.e., waste treatment facilities, numerous roads, the 800-acre yacht harbor and residential enclave at Marina del Rey, and County-managed beaches), and neighboring cities such as Santa Monica, Malibu, and the South Bay beach cities of Manhattan Beach, Hermosa Beach and Redondo Beach. These communities are represented in the RSWG.

There are four major milestones in the process for sea level rise adaptation planning:

1. *Identification of Current Observed Vulnerabilities*: This entails identifying City assets, resources and communities located in the coastal zone. Since many of the impacts the City will feel from sea level rise are ones the City already experiences, effort was placed towards identifying current vulnerabilities and impacts from coastal storms and extreme high tides (e.g. flooding of major infrastructure).

2. *Sea Level Rise Vulnerability Assessments*: A sea level rise vulnerability assessment evaluates the degree to which important community assets are susceptible to, and unable to accommodate, the adverse effects of climate change. In this effort, partners have examined the physical, social, economic and ecological vulnerabilities the City may face under sea level rise.

3. *Identification of Sea Level Rise Adaptation Measures*: Once vulnerabilities are understood, the City can then begin to assess how best to manage the expected impacts. There are a number of tools available for the City to consider.

4. *Development of Sea Level Rise Adaptation Plan*: This is a long-term milestone that entails the development of a sea level rise adaptation plan that is approved by the Mayor and City Council. Using the strategies and guidance put forth in this study, the City can move forward with developing site-specific adaptation and financial strategies for implementation.

While the milestones above describe a linear process that culminates in an adaptation plan, adaptation planning is indeed far from complete once a plan has been developed and approved. Scientific information is always being updated and improved and this new information should be called upon to reassess the City's vulnerabilities, plans and actions. Moreover, any action to provide adaptation will trigger other changes and will require monitoring of effectiveness. We refer to this notion as "adaptive adaptation planning." The model has been developed with this concept in mind (Figure 2).

Sea level rise is one of many climate change impacts to be addressed using this iterative and adaptive planning process. It is hoped that the process developed for sea level rise will be useful in planning for other impacts of climate change, and that the City of L.A. will be a model for the region, as well as the rest of the country, in developing climate change adaptation strategies. The City looks to LARC to transfer the knowledge gained and lessons learned from this pilot sea level rise effort within the City.

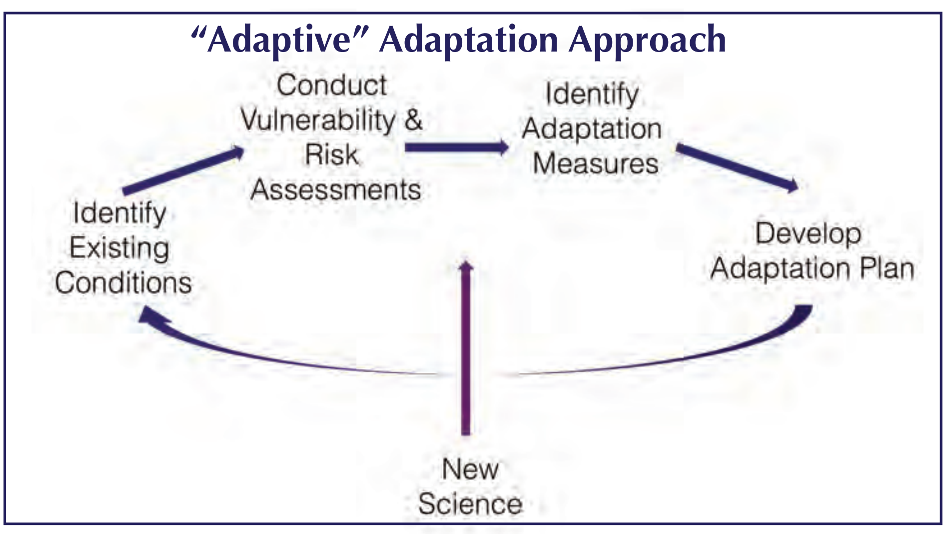

Figure 2: This schematic describes the "adaptive" adaptation planning approach. The four milestones do not describe a linear process, but rather, an iterative process that incorporates new science and information as it becomes available.

Regional Stakeholder Working Group Participation and Review

Stakeholder input is an invaluable part of the public process and particularly so when planning for a future with potentially significant impacts on the public. A Regional Stakeholder Working Group (RSWG)[1] was appointed early in the process. Through formal meetings and a review and comment process, the RSWG provided critical input to the draft and final versions of this study. RSWG members commented on the sea level rise report by providing suggestions on how to move forward in adaptation planning, expand this study in future iterations, and communicate the findings to wider audiences. While some comments were out of the scope and intent of this initial study, it is important to capture comments to assist the City as it moves to the next milestones of the process and updates this study as new science and information become available.

Comments from the RSWG include:

- It is important to look at how the methodology could be applied to regional or statewide efforts. Lessons learned would be valuable for other cities or regions undergoing vulnerability assessments.

- It may be disadvantageous to assume that the 10-year storm of the last fifty years will be the 10-year storm of the future. It is important to examine changes in strength and frequency of storm events.

- While not directly managed by the City, certain assets and resources should be closely examined and considered for further engineering studies. A few mentioned include: critical roads (i.e. PCH); seawater barriers in the County; breakwaters; piers (i.e. Santa Monica); and current or pending construction (i.e. the City's Temescal Canyon Park stormwater project).

- Consider conducting a full ecological vulnerability assessment to include all ecological resources in the City such as beaches, wetlands, open spaces and other coastal habitats.

- Consider including the impact to tourist resources and other indirect economic impacts in the analysis of economic vulnerability.

- Recommend including business continuity planning, insurance industry, risk management, emergency planning, and building design groups among groups to communicate study results and consider involving representatives in the planning process.

- An important next step would be to conduct a quantitative physical vulnerability and risk assessment to go beyond the qualitative assessment conducted in this study.

Climate Change Planning is Already Underway in the City of L.A.

By commissioning this study and by initiating this participatory process, the City of L.A. has shown tremendous leadership in proactively confronting climate change, rather than responding reactively. This study is part of a series of efforts on different aspects of climate change – heat, fresh water, fires, and human health impacts.

This preliminary sea level rise vulnerability assessment provides a first glimpse into the challenges the City may expect due to sea level rise (and other associated impacts) on its infrastructure assets, resources, and communities. The City has engaged a team of world renowned experts to identify its potential exposure to sea level rise, using a sophisticated model that examines both the impacts from rising seas, as well as flood impacts from storms and high tides, which could be exacerbated with

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6. Members are listed on page 65.

rising sea levels. It has identified its potential vulnerabilities in order to begin planning now. Due to the participatory nature of the planning process, the City recognizes the importance of community stakeholders in identifying appropriate adaptation measures to increase its resilience and is actively engaging them in their planning process.

Prior even to the recommendations of this study, agencies within the City were already commissioning studies to understand the impacts of sea level rise on critical infrastructure. For instance, the Bureau of Sanitation, the Port of Los Angeles and the Department of Water and Power have already commissioned independent studies to assess their vulnerability to sea level rise, climate change, and tsunami risks. These studies will serve to bolster the resilience already built into many of the agencies' operations and planning.

An important adaptation strategy is mitigation through the reduction of greenhouse gas (GHG) emissions. In any sea level rise, or climate change, model, much of the uncertainty lies in not knowing which way society as a whole will move with respect to limiting its GHG emissions. Under business as usual scenarios in which we continue to emit greenhouse gases at current rates, climate change impacts will be far more severe than if we work to limit our emissions. Through its GreenLA and ClimateLA plans, the City of L.A. has emerged as a leader in its varied and numerous mitigation strategies.

The Purpose of this Document

This report contains the results of the coastal vulnerabilities report, the current observed vulnerabilities identification exercise and the physical, social and economic vulnerability assessment studies that were commissioned by the City and USC Sea Grant. In addition, a discussion of the ecological vulnerability of Ballona Creek, the City's major remaining natural coastal feature, is included. This report is meant to inform policymaking by identifying the systems and sectors most likely to be affected by sea level rise, and by furthering an understanding of each sector's vulnerabilities. Understanding these vulnerabilities will enable the City to develop strategies that increase its resilience to accelerated sea level rise and other impacts of coastal change. In the final section of the report, we identify a broad range of adaptation strategies that can serve as a foundation for future adaptation planning.

This document is one of the first tangible products of the adaptation planning effort. It represents a preliminary and first step in an ongoing process to assess the City's vulnerability and work to increase its resilience to climate change impacts. Because the science of climate change is advancing so rapidly, it is vitally important to build flexibility into the City's efforts. The result is this living document that must be continually updated to integrate new science; iterative and collaborative "adaptive adaptation planning" process is as important as the document itself.

Coastal and Shoreline Assets

Dr. Reinhard Flick, Scripps Institution of Oceanography, has developed a preliminary review of the major geographic regions within the City of L.A. and provides a brief overview of the potential adaptation strategies and next steps the City can consider in planning for sea level rise (see Appendix 1 for full report). Dr. Flick's report provides a first glimpse into potential strategies the City may wish to consider; however this report in no way replaces the critical engineering studies that should be conducted before committing to any strategy or plan. We summarize some of the key recommendations from that report below.

Pacific Palisades (Topanga Canyon Boulevard to Santa Monica)

This reach, or section of coastline, presents mainly major geotechnical and coastal engineering challenges, as well as complex societal and legal issues. The inland stretch along PCH is heavily developed with few or no good options for retreat of the highway. Since PCH is not likely to be moved, continued and improved armoring is the most realistic choice for avoiding undermining the roadway by wave-driven erosion. This seems to be the most vulnerable part of the entire City shoreline. Heavily-used PCH has occasionally been undermined in some spots and has required attention since it was first constructed, and will continue to do so in the future. L.A. City, County, and Caltrans highway engineers are aware of these problems, and are in the best position to suggest solutions once the future vulnerabilities are better defined. Careful quantification of the times, locations, and extent of future overtopping; ocean flooding; and undermining of PCH and other infrastructure due to erosion can eventually form the basis for a phased and ongoing plan to address geotechnical needs.

As sea level rise accelerates, it would be wise to initiate a storm watch and notification program using standard available weather and wave forecast products to provide warnings several days in advance of dangerous wave and tide combination conditions. This would facilitate traffic management, increase safety, and provide engineering data that will be useful once adaptation measures become necessary.

Beaches show a typical configuration with wave-driven sand transport predominantly to the east; that is, they are narrow or non-existent upcoast (west) where headlands block the flow of sand or divert it offshore, and widen downcoast, reaching maximum width just west of the next headland. At least annual monitoring beach widths will eventually provide the history that will be necessary to address the issues of stabilization with groins or other measures, and periodic nourishment that will almost certainly be needed in the future to maintain a sandy beach.

Will Rogers State Beach is highly instructive in that it illustrates successful and relatively unobtrusive groin beach width stabilization structures that will almost certainly become increasingly necessary if area beaches are to be preserved in the future. Everts Coastal (2002) provides quantitative assessments of major shoreline sand retention structures and guidelines that will be helpful for engineers planning future structures. As with the beaches to the west, at least annual systematic monitoring of beach width should be conducted.

Google Earth image of Will Rogers State Beach with effective groin beach stabilization.

Venice-Marina Peninsula-Playa Del Rey-LAX

This reach is a central part of Santa Monica Bay's iconic "Bay Watch" beach system that extends from Malibu to Redondo Beach and provides major economic benefits from recreation, boating, utility siting, and tourism. It has mostly wide to very wide beaches that were largely created by sand supplied as a by-product of coastal construction activity, including LAX, Marina Del Rey, and the Hyperion Wastewater Treatment Plant (Flick 1993; Leidersdorf and Woodell 1993, 1994).

View south of iconic beaches of central Santa Monica Bay: from Venice (pier, lower right) past Marina Del Rey jetties and west end of LAX runways, toward Redondo Beach (Wikimedia Commons photo, 2007).

While these beaches have been wide and stable for many decades, gradual retreat is already in progress. The main concern for the future is that sand is not being provided at nearly the rate it was up until the 1960s. As sea level rise accelerates in the future, these iconic L.A. beaches will undoubtedly narrow at an even faster rate. It is unlikely that any storm-wave driven flooding or property damage will occur in the foreseeable future, but if sea level rise takes one of the higher trajectories, problems would become evident around mid-century.

To maintain the property protection and recreational benefits of these beaches, sand nourishment will be necessary at some point in the future. To enable sound engineering benefit/cost analyses for these inevitable projects, it will be necessary to monitor the beach width going forward, in a manner similar to that discussed in the context of the beaches in the Pacific Palisades reach. The Venice-Marina Peninsula-Playa Del Rey-LAX reach is ripe for wave- and sea level rise-driven beach retreat modeling, since a wealth of historical beach profile, shoreline position, and wave data already exists. Such work could help to narrow the uncertainty of future rates of beach loss due to sea level rise using empirical models currently under development. This is of course a regional, and in fact a state-wide necessity, and not only a City of L.A. concern. However, the City can play a vital role in highlighting the need for monitoring and coordination of local, regional, state, and federal constituencies.

San Pedro-Wilmington-Terminal Island-L.A. Harbor Exposed Coast

The San Pedro part of L.A. has a south-facing exposed open-coast portion, and an east-facing section sheltered behind the L.A.-Long Beach outer breakwater. Both sections are heavily suburbanized atop a flat coastal terrace that has a 35 m (115 ft) high sea cliff at its seaward edge. The geology suggests relatively resistant formations at sea level near Cabrillo Point, but more erodible material to the west toward Point Fermin. As sea level rise accelerates, the weaker cliff sections will be subject to more undermining from wave action and eventual collapse than the more resistant sections. Ongoing — at least annual — monitoring of cliff retreat is recommended.

Inspection of aerial photos (Google Earth) shows that about 25% of the cliff edge in San Pedro is occupied by park or other open space, which minimizes the vulnerability of property loss from cliff failure. Cliff-top development on the other 75% of the exposed western end of San Pedro has substantial setback from the edge of the cliff. Therefore, few if any developments will be immediately threatened. However, several areas of geotechnical instability are evident, especially related to land sliding. Some

residential development on the cliff top at the eastern end of the exposed section of San Pedro has little setback and may be threatened if cliff retreat resumes or accelerates in response to sea level rise.

L.A. Harbor

The L.A.-Long Beach outer breakwater starts at Cabrillo Beach and protects everything behind it (to the north) from wave attack. Components of harbor infrastructure and Port of Los Angeles operations may be vulnerable to sea level rise. But this again presents mostly a major harbor engineering project that will have to be undertaken in stages as problems become apparent. For example, the outer breakwater is highly effective at sheltering the harbor and adjacent coast from wave action, but it is frequently overtopped during high wave events coinciding with high tides. If wave climate becomes more severe, more damage to the breakwater itself is likely and may require elevation.

View north over L.A.-Long beach outer breakwater Angel's Gate toward Port of Los Angeles and Terminal Island (lower right) Wilmington is visible in the distance (Port of Los Angeles photo).

Anecdotal evidence suggests that the Port infrastructure can accommodate even mid-to high-range sea level rise scenarios by periodically being raised during major refitting construction projects. A study by the RAND Corporation was conducted to determine the Port's vulnerabilities and what accommodation and adaptation strategies will be needed (Lempert et al. 2012).

Immediate Sea Level Rise Adaptation Actions

Each coastal community within the City of L.A. will require its own specific adaptation strategies. In the cases of the need for geoengineering solutions, these strategies will require the accompanying engineering and geotechnical studies. There are, however, several important actions that can be taken immediately, requiring minimal financial expenditures, that would serve to advance the City's efforts to prepare for the impacts of sea level rise. These include:

- Storm watch and notification;
- Semi-annual beach width monitoring;
- Annual monitoring of cliff retreat;
- Use of historical beach profiles and existing wave data to develop predictions; and
- Coordination with local, regional, state and federal agencies, especially Los Angeles County (Public Works and the Department of Beaches and Harbors) and the U.S. Army Corps of Engineers.

Current Observed Vulnerabilities and Physical Vulnerability Assessment

This section provides an overview of current observed vulnerabilities conducted by USC Sea Grant and the physical vulnerability assessment survey conducted by ICLEI – Local Governments for Sustainability, U.S.A. (ICLEI). The ICLEI report is presented in its entirety in Appendix 2. All of the information on the City's assets is presented in a series of matrices in this section that include a description of the asset, an overview of current observed vulnerabilities to storms and high tide events, and a description of its potential physical vulnerabilities due to rising sea levels as described by ICLEI.

Current Observed Vulnerabilities

The first step in the adaptation planning process, conducted during the winter of 2012, was to work with City staff from the City Adaptation Leadership team (CAL) to identify and examine current observed vulnerabilities and existing conditions. Members of the CAL were asked to:

- Identify their major assets within the coastal zone;
- Provide a brief description of the asset; and,
- Provide a description of the current known vulnerabilities and environmental issues related to maintenance and functioning of these assets.

The assets and observed conditions were identified in a two-fold process. First, we developed a series of maps on which City officials identified coastal assets and known vulnerabilities. This was followed by a worksheet in which officials provided more detailed information about the asset and its current vulnerabilities. We also include a replacement value, where that information is available, for some of the City assets. It should be noted that these replacement values were not derived from the economic study described in Appendix 4, but rather were self-reported by City agency officials. Information gathered during this exercise is summarized in the asset matrices presented at the end of this section (pages 20-48).

Members of the CAL during a mapping exercise in which members were asked to identify coastal assets and their current vulnerabilities. (Photo credit: Marika Schulhof).

Physical Vulnerability Assessment

Overview on Physical Vulnerability Assessments

A sea level rise physical vulnerability assessment considers areas where important community assets are susceptible to, and unable to accommodate, the adverse effects of sea level rise. Four factors are generally considered in vulnerability assessments: *exposure*, *sensitivity*, *adaptive capacity* and *consequences*.

Exposure is defined as the nature and degree to which a system experiences a stress or hazard. In the case of sea level rise, this would entail identifying which assets, resources or communities may be vulnerable to impacts from sea level rise. This includes examining both flooding (defined as land that was once dry that becomes *temporarily* wet either periodically or episodically) and inundation (defined as land that was once dry that becomes *permanently* wet or underwater), (Flick et al. 2012).

Sensitivity is defined as the degree to which exposed assets would be impaired by sea level rise. Assets that are greatly impaired by sea level rise have a *high* sensitivity, whereas assets that are minimally impaired by the same change in sea level have a *low* sensitivity.

Adaptive capacity is the ability of an asset to make adjustments in response to a climate impact to maintain its primary functions. This does not mean that the asset must look the same as before the impact, but it must provide the same services and functions as it did before the impact occurred.

Consequences are the adverse effects that occur as a result of an asset being impaired by a climate impact. City officials were asked to describe consequences for the economy, environment, and communities and populations. They were also asked to consider the magnitude of the consequence, such as a size of the population, land area, or resources that would be affected.

Identifying the City's Exposure

While the exercise conducted to identify current observed vulnerabilities served as guidance for preliminary analysis, it was imperative to use the best available science when focusing in on the City's potential vulnerabilities to sea level rise. This was determined to be a coastal impacts model developed by Dr. Patrick Barnard and colleagues from the U.S. Geological Survey (USGS). This model incorporates not only the impacts of a rising sea, but also the impacts of tides, and extreme waves and storm surge associated with severe coastal storms.

Image of flooding in San Pedro (5th St. and Pacific Ave.) during the January 2010 storm. (Photo credit: Robert Casillas, http://lapd.com/news/headlines/torrential_rains_pound_san_pedro/).

The USGS model is based on a storm that occurred in the Los Angeles region during January 2010. This El Niño-fueled storm produced large waves (with a maximum wave height offshore of Los Angeles of 7.5 m, or 25 ft) that remained elevated for a week, producing some of the most extreme coastal erosion observed for several decades in Southern California and causing severe flooding in some coastal communities.

Once the model appropriately recreated, or hindcast, the impacts from this 2010 storm, the modelers applied two sea level rise

Components of Total Water Predictions

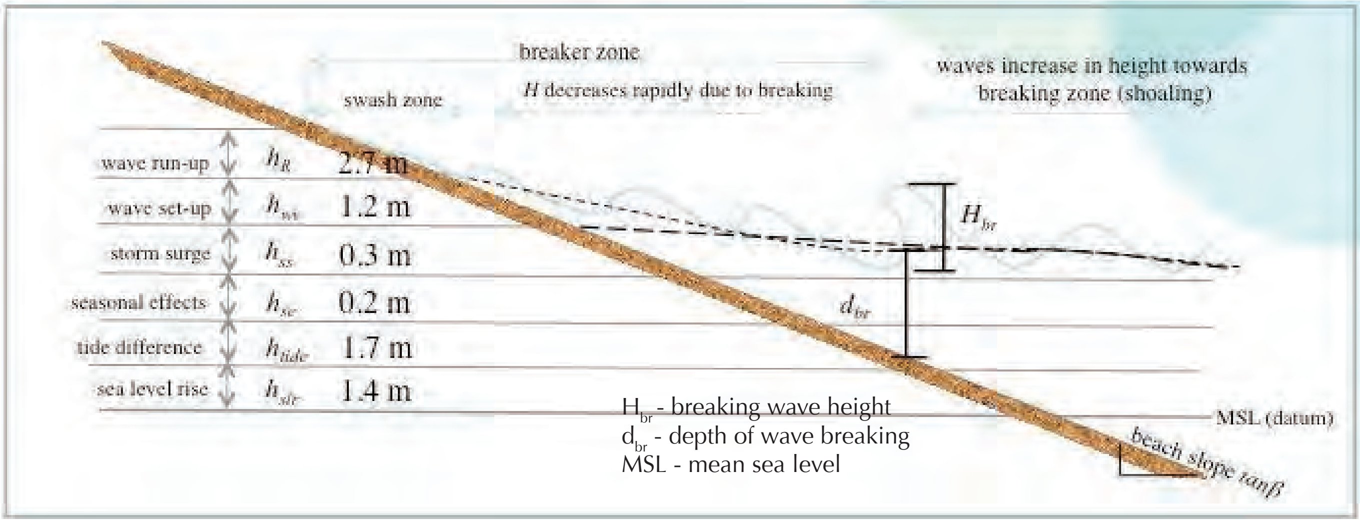


Figure 3: This diagram depicts the total coastal water level components caused by both sea level rise and storms driven by climate change that are used in the coastal impacts model to predict coastal flooding. The diagram includes the upper-end sea level rise scenario predicted between 2000-2100 and the wave height, surge and tidal ranges predicted for Southern California under a 10-year storm scenario. (Source: Patrick Barnard, USGS).

scenarios using the upper-end sea level rise scenarios of 0.5 m (1.6 ft) between 2000 - 2050 and 1.4 m (4.6 ft) between 2000 - 2100 based on Rahmstorf (2007). These sea levels were added to the tide, wave, and wind conditions of the January 2010 storm to project the potential for increased flooding that could result from various sea level rise scenarios under a similar storm event (Figure 3).

The City used these scenarios to identify the exposure of its assets to sea level rise. The maps used by the City to assess vulnerability are presented in subsequent pages of this report (Figures 4-6, pages 17 - 19).

While there are a number of coastal impact and sea level rise models available for use, it was determined at the time of this analysis that the USGS model provides the best scientific description of what could be expected from the combination of sea level rise and a moderately severe winter storm. However, there are two important caveats that should be noted:

- The January 2010 storm is considered a moderately severe "10-year" storm, which means it has a 10% chance of occurring on a yearly basis. Most planning departments and insurance estimates base their analyses on the "100-year" storm, or a storm that has a 1% chance of occurring in a single year. This model therefore provides a conservative estimate of flooding.

- As the science advances, sea level rise scenarios and the ranges and average rates of sea level rise associated with those scenarios will continue to be updated and modified. For this report, the USGS model used sea level rise scenarios based on a highly-respected and cited report published in 2007 (Rahmstorf 2007). Since then, a study by the NRC has refined these scenarios specifically for the West Coast of the U.S. This new study suggests that Southern California should plan for a range of sea level rise of 0.1 - 0.6 m between 2000 - 2050 and 0.4 – 1.7 m between 2000 - 2100. The difference in these scenarios (recent NRC study vs. Rahmstorf's estimates) does not invalidate the results of our preliminary vulnerability assessment, but rather underscores the need to continually reassess vulnerabilities based on the best available science. Sea level rise, and climate change, vulnerability assessment is an iterative process and it is critical to allow for the "adaptive adaptation planning" approach we advocate in this report. We strongly recommend that as more information becomes available, the City incorporate this new information and reassess their assets' vulnerabilities.

Analysis of the City's Assets Exposure

Based on the exposure of City assets identified by the USGS model, ICLEI employed a qualitative and participatory methodology to gauge the sensitivity and adaptive capacity of the systems addressed in this report. Specifically, ICLEI developed a detailed survey that required respondents to consider a system's sensitivity, adaptive capacity, and consequences of not protecting these assets from accelerated sea level rise. The vulnerabilities for each asset were determined using answers to the survey and subsequent follow-up conversations with City staff.

The ICLEI report revealed vulnerabilities in wastewater management, stormwater management, potable water systems, and roads. Within the City's wastewater management system, collection systems in low-lying areas are particularly vulnerable to flooding, tidal and groundwater inflow, which cause wastewater to discharge into the ocean. Wastewater treatment plants also are vulnerable to inundation and flooding, which could damage systems and impact operations, and also result in wastewater being discharged into the ocean.

The ICLEI report found that the City's stormwater management system is vulnerable to flooding and inundation, potentially causing flooding in low-lying areas. Likewise, the potable water system is vulnerable to flooding, inundation and groundwater intrusion, making access to underground infrastructure difficult and thereby posing a risk to public health. The City's roads are also vulnerable to flooding, inundation, and groundwater inflow, potentially putting access to transportation and emergency services at risk. Coastal buildings, especially in Venice, which is near sea level, are vulnerable to flooding and inundation.

In contrast, the ICLEI report revealed that the Port and City energy facilities have relatively low vulnerability to sea level rise. The Port, although susceptible to flooding and inundation because of its low elevation, was found to have a high capacity to adapt, as it plans to build future infrastructure at higher elevations. However, the vulnerability of roadways surrounding the Port needs to be a consideration in future assessments due to the potential to interrupt the movement of goods. Energy systems have low vulnerability because of replacement schedules and built-in system redundancies.

A sand dune protects a L.A. power generation plant while residents enjoy coastal recreation. (Photo credit: Marika Schulhof)

City parks and open areas were determined to have moderate vulnerability to flooding because they can be restored relatively quickly. On the other hand, museums and other structures have higher vulnerability because of the damage that would be incurred by flooding or inundation.

Identifying components of the City's infrastructure that are at risk is the first step toward building future resilience for sensitive assets. It also helps educate the public about potential risks and opportunities to manage those risks. Proactive planning at this relatively early juncture will increase the City and region's capacity for building the Los Angeles of the future.

It is important to highlight, however, that many of the City's agencies had already begun planning for climate change prior to the initiation of this study. For instance, the Bureau of Sanitation (BOS) has

recognized that climate change effects may impact assets and operations and has developed strategic planning goals and outcomes to lessen these impacts. Additionally, the BOS includes capabilities for upgrades and replacement of equipment, facilities and infrastructure in its planning and capital improvement programs. They have already commissioned engineering studies to address potential flooding at several critical locations. Since 2011, the Port has been working with the RAND Corporation to conduct a sea level rise vulnerability study. Similarly, in 2010, the Department of Water and Power conducted a tsunami study. While tsunamis are not directly related to sea level rise and climate change, wave run-up and surge from a tsunami provide a good, if extreme, corollary to what could be expected in the future with higher sea levels and a major storm. Analyses from all of these studies have been incorporated in the sea level rise vulnerability study we discuss here.

Sea Level Rise Exposure Maps
Pacific Palisades Area

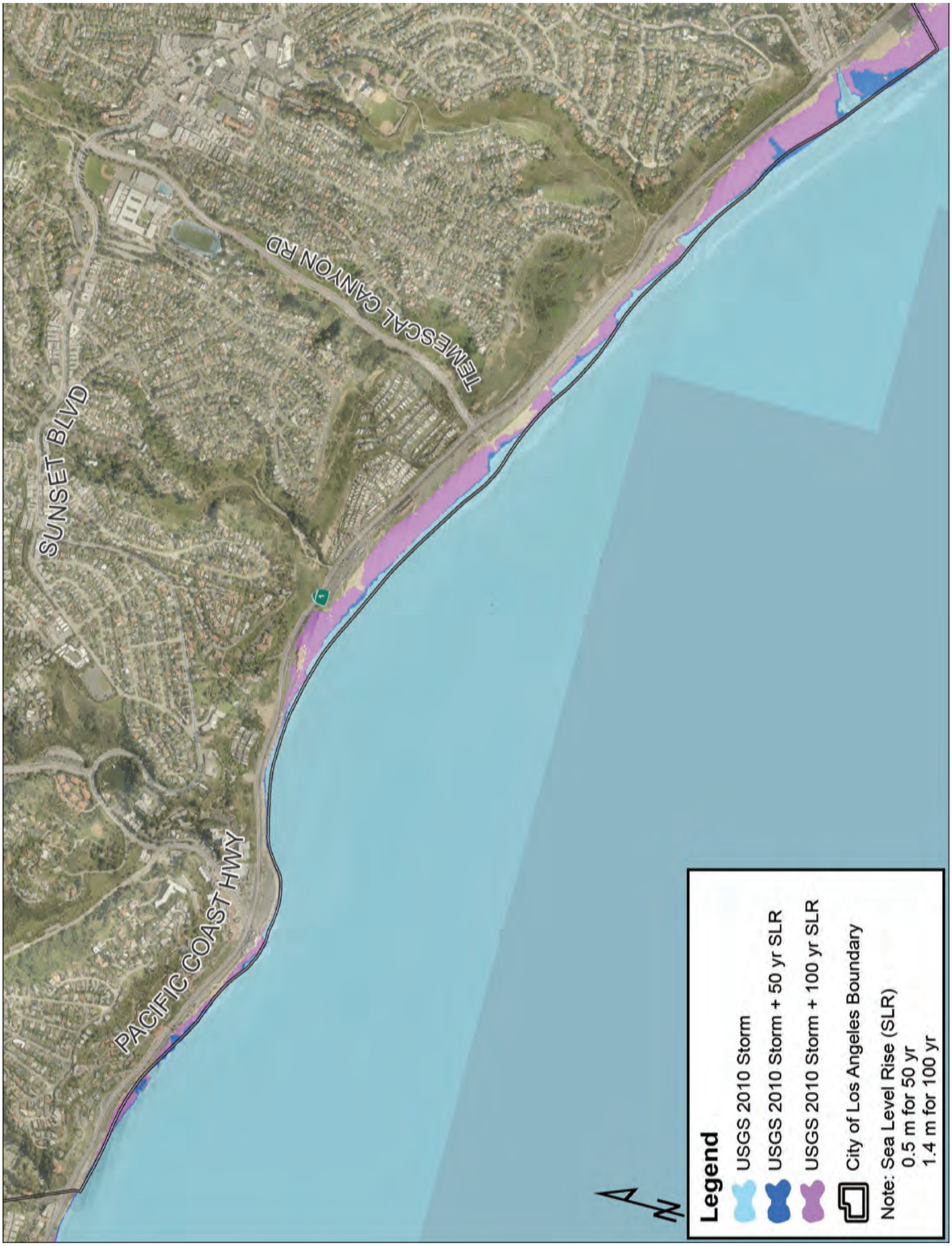


Figure 4

Sea Level Rise Exposure Maps
Venice Area

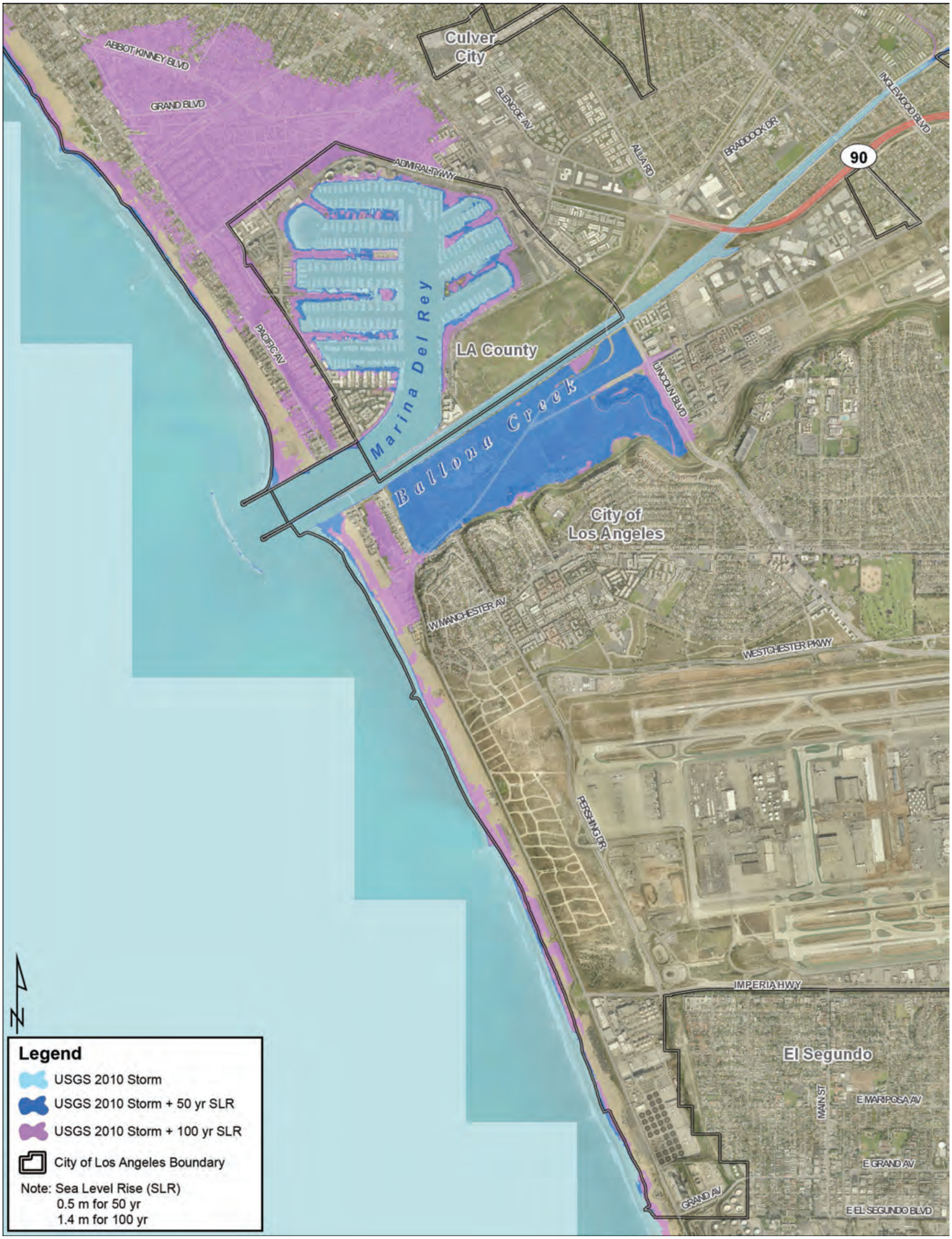


Figure 5

Sea Level Rise Exposure Maps
Harbor Area

Figure 6

City Asset Matrices: Current Observed and Expected Physical Vulnerabilities

In the subsequent pages, we provide matrices for each asset by City sector. These matrices provide:

1. An overview of the asset that describes the function of the asset, the responsible City department/ point of contact, the associated regulatory oversight and a description of the asset;

2. Current, known vulnerabilities (e.g., does the asset currently flood under extreme high tides or severe storms?);

3. A summary of the asset's sensitivity and adaptive capacity in response to sea level rise associated impacts, along with the consequences of inaction; and,

4. An estimate of replacement value. It should be noted that these values are self-reported by the responsible City department and are not correlated with the economic vulnerability assessment described below (see also Appendix 4).

In some of the matrices, a unique asset is described (e.g., Hyperion Wastewater Treatment Plant). For these, exposure maps are included that demonstrate the potential flooding due to both 0.5 m and 1.4 m sea level rise. In other instances, assets are grouped by type (e.g., fire hydrants). In these matrices, maps are not included because the assets cover too broad of a geographic region. The number of assets for each sub-region (Pacific Palisades, Venice/LAX, and San Pedro/Harbor) are included.

Hyperion Wastewater Treatment Plant (HTP)
12000 Vista Del Mar Blvd
Playa Del Rey, CA 90293

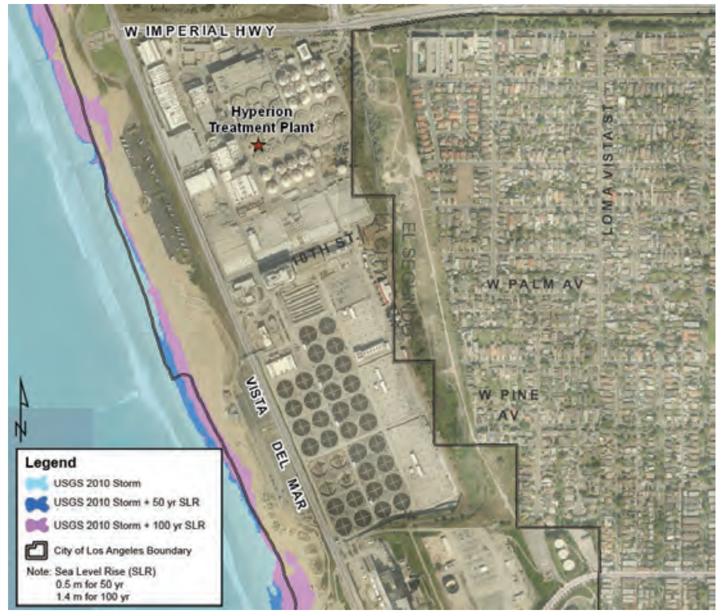
Asset Overview

Owner:
City of Los Angeles

City Department and Point of Contact:
Department of Public Works, Bureau of Sanitation

Regulatory Oversight:
Regional Water Quality Control Board
State Water Resources Control Board
Environmental Protection Agency
South Coast Air Quality Management District

Summary of Asset:
HTP is located next to Dockweiler State Beach at approximately 32 feet above sea level. The major treatment processes at this plant include screening, grit removal, primary sedimentation, and secondary treatment. After secondary treatment, the wastewater is discharged into Santa Monica Bay through the five-mile submerged outfall.



Current Observed Vulnerabilities

Localized flooding and damage to equipment and structure of facility is possible due to extreme wet weather, if there are failure(s) to critical individual unit processes (facilities), failure of effluent pumping, or failure of influent bypass pumping of influent sewer flow. Damage to process control operations (secondary treatment) is possible from extreme wet weather washout.

Possible structural damage from seismic or tsunami events, combined with extreme wet weather, could result in failure of critical plant process equipment and/or inability to transport biosolids to reuse sites, due to restricted local road and interstate highway access.

Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis

Sensitivity (LOW)	Adaptive Capacity (HIGH)	Consequences (MEDIUM)
HTP is sensitive to storm-related flooding which could cause equipment and operations failures due to damage of electrical pumps and panels from exposure to water. A dramatic increase in sea level could reduce the plant's efficiency in the discharge of effluent, because the pumped flow would be met with more water pressure. While erosion could result in some loss of the beach in front of the plant, the plant itself is not very sensitive to erosion or interaction with the groundwater because it is built on top of a large cement catacomb.	The plant's ability to continue to function if it is partially disabled depends on the severity of the impact. The plant maintains additional flow capacity, so if one part of it becomes impaired, the plant will continue to treat and handle the quantity of wastewater entering the plant. The plant is equipped with pumps that could remove water relatively quickly and has a redundant 1-mile outfall. Emergency generators have been placed at all critical facilities. The Bureau of Sanitation is securing an on-site renewable energy power source to maintain service in case of grid failure.	The primary economic consequences would be repairing the plant. Impacts to individual pieces of equipment would cost significantly less than the loss of the entire facility. The primary environmental consequence would be the discharge of partially treated wastewater into Santa Monica Bay which would be temporary in nature and therefore may impact habitat and wildlife.

Replacement value (i.e., cost of inaction):	$3 billion

Terminal Island Water Reclamation Plant (TIWRP)
445 Ferry Street, San Pedro, CA 90731

Asset Overview

Owner:
City of Los Angeles

City Department and Point of Contact:
Department of Public Works, Bureau of Sanitation

Regulatory Oversight:
Regional Water Quality Control Board
State Water Resources Control Board
Environmental Protection Agency
South Coast Air Quality Management District

Summary of Asset:
TIWRP is a tertiary/advanced water reclamation plant that treats municipal and industrial wastewater. It is located on Terminal Island, and is situated on a 19.8-acre site, parts of which are located below sea level. Raw wastewater reaches the plant through a series of pumping plants and force mains. The plant provides preliminary, primary, secondary, tertiary, advanced and solids handling and treatment facilities. The TIWRP currently discharges tertiary effluent to the Los Angeles Harbor.

Current Observed Vulnerabilities

Localized flooding and damage to equipment and structure of facility is possible due to extreme wet weather, possibly resulting in failure(s) to critical individual unit processes (facilities), failure of effluent pumping, or failure of influent bypass pumping of influent sewer flow. Damage may occur to process control operations (secondary treatment) from extreme wet weather washout and gallery flooding.

Possible structural damage from seismic or tsunami events, combined with extreme wet weather, could result in failure of critical plant process equipment and/or inability to transport biosolids to reuse sites, due to weather related road closures and interstate highway access.

Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis

Sensitivity (MEDIUM)	Adaptive Capacity (MEDIUM)	Consequences (MEDIUM)
Terminal Island Reclamation Plant is sensitive to storm-related and tidal flooding, which could cause equipment damage and operations failures. The property is impacted by extreme high tides during which it pumps out seawater. With sea level rise, king high tides could pass through the gates at the rear of the plant, inundating some facilities. A storm-related event could exceed the design capacity of the plant, flooding galleries and damaging equipment. As a result, partially treated wastewater could be discharged into the Los Angeles Harbor.	The plant would continue to function if partially disabled. At the current flow of 15 MGD the plant has some additional capacity to handle increased flow during storm events. Depending on the equipment damage caused by a storm event, the plant may be temporarily or partially disabled and may require emergency generators or pumps to be used to ensure that wastewater continues to be discharged to the outfall. Engineering studies that include assumptions about flood depth and duration would help to refine an evaluation of adaptive capacity.	The economic consequences of impairment of TIWRP are medium. If the pumps fail, emergency response actions would be needed to remove the water to return the plant to service. Impacts to individual pieces of equipment would cost significantly less than the loss of the entire facility. Damage to processes could result in partially treated wastewater discharges, with public health impacts and environmental consequences that would be localized and temporary. Partially treated wastewater could spill into the San Pedro Harbor, affecting fishing communities, recreational opportunities and habitat.

Replacement value (i.e., cost of inaction):	None provided

Venice Collection System
Coastal Interceptor Sewer runs along the coastline; the south end begins at the Hyperion Treatment Plant.

Asset Overview
Owner: City of Los Angeles
City Department and Point of Contact: Department of Public Works, Bureau of Sanitation
Regulatory Oversight: Regional Water Quality Control Board State Water Resources Control Board Environmental Protection Agency
Summary of Asset: The Venice Collection System is part of the Coastal Interceptor Sewer, which runs along the coast from West Los Angeles to the Hyperion Treatment Plant.

Current Observed Vulnerabilities
Structural damage possible from seismic or tsunami, combined with Extreme Wet Weather, could result in failure of critical conveyance equipment.

Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis

Sensitivity (MEDIUM)	Adaptive Capacity (MEDIUM)	Consequences (HIGH)
The Venice collection system is sensitive to interaction with groundwater, storm-related and tidal flooding, because water entering the collection system reduces its capacity. Erosion could also potentially damage the pipes.	The collection system can continue to function if partially disabled, because it will continue to convey wastewater into the Hyperion Treatment plant at reduced capacity. The BOS is upgrading the system to be more resilient to storm-related flooding through proactive maintenance and functional improvements and has emergency response plans to control overflows and maintain the integrity of the collection system.	The economic consequences of impairment of this asset include the costs of repairing the system. Damage to the system could also cause wastewater spills in the Santa Monica Bay, which would have environmental, public health and economic impacts.

Replacement value (i.e., cost of inaction):	None provided

Venice Storm Water / Urban Runoff Pumping Plant (VSPP)
1600 Main Street
Venice, CA 90291

Asset Overview

Owner:
City of Los Angeles

City Department and Point of Contact:
Department of Public Works, Bureau of Sanitation

Regulatory Oversight:
Regional Water Quality Control Board
State Water Resources Control Board
Environmental Protection Agency

Summary of Asset:
The Venice Storm Water / Urban Runoff Pumping plant is a low flow diversion pump designed to move urban runoff and, in the wet season, stormwater flows from a lower elevation up to a higher one, so that it can be transported through pipelines by gravity for eventual processing at a treatment plant during low flows and discharge into the ocean during storm flows.

Current Observed Vulnerabilities

Pumping plant may be damaged if an extreme wet weather event floods electrical components. It is in the Tsunami Warning Area. Severe tidal condition could flood the plant.

Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis

Sensitivity (LOW)	Adaptive Capacity (HIGH)	Consequences (LOW)
The VSPP is not sensitive to storm-related flooding, tidal flooding, and erosion. Discharge during each storm season continues as designed and does not impact pumping capacity. The pump does not operate during rain events and the flow is conveyed to the discharge locations by gravity. The plant is located between the beach and a channel, so the plant could potentially be inundated by sea level rise from both sides.	The plant has been identified as an asset that is functioning as intended. Any flooding would not be related to function of the low flow pump. The BOS is evaluating the need to make the plant more resilient to storm-related flooding through functional and reliability improvements. The BOS has emergency plans in place to restore function. A study to better understand the impacts of groundwater and seawater intrusion into the VSPP is underway.	Any localized flooding would not be related to function of the low flow urban runoff diversion pump. Flooding would have high social consequences including displacement and public health concerns. The replacement value of the plant itself is ten million dollars however impacts to individual pieces of equipment would cost significantly less than the loss of the entire facility.

Replacement value (e.g., cost of inaction):	$10 million

San Pedro Storm Water Collection System
San Pedro Storm Drain Network
Harbor Area, Terminal Island Basin

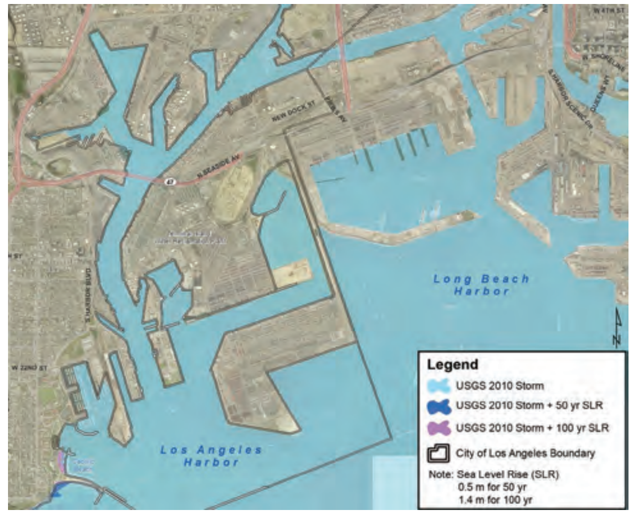
Asset Overview

Owner:
City of Los Angeles

City Department and Point of Contact:
Department of Public Works, Bureau of Sanitation

Regulatory Oversight:
Regional Water Quality Control Board
State Water Resources Control Board
Environmental Protection Agency

Summary of Asset:
The San Pedro storm water collection system includes the storm drain network in the San Pedro area. Many lines are located below sea level.



Current Observed Vulnerabilities

The stormwater management system is vulnerable to extreme weather, flooding, and inundation, which could exacerbate flooding in low-lying areas.

Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis

Sensitivity (MEDIUM)	Adaptive Capacity (MEDIUM)	Consequences (MEDIUM)
This system is sensitive to storm-related and tidal flooding. Large amounts of water may enter the system, either through storm-water or high tides, exceeding the capacity of the system and causing neighborhoods to flood.	The system is able to function if partially disabled and will continue to convey storm water at a reduced capacity. The ability of the system to be quickly restored depends on the severity of the storm and the functionality of other connected facilities in the system. This system has been impacted by storm-related flooding and the Department of Public Works was able to reroute, relocate and resize the pipes, as well as remove some turns which had constrained the flow to eliminate the localized flooding.	The consequences of an impaired system are medium related to the economic impacts of flooded homes and streets.

Replacement value (e.g., cost of inaction):	None provided

Wastewater Pumping Plants

Asset Overview		
Location and Number of Assets*		
Pacific Palisades Sub-Region: Pacific Palisades (4)	**Venice/LAX Sub-Region:** Los Angeles (1) Venice (1) Playa del Rey (1)	**San Pedro/Harbor Sub-Region:** Wilmington (6) Terminal Island (4) San Pedro (6)
Owner: City of Los Angeles		
City Department and Point of Contact: Department of Public Works, Bureau of Sanitation		
Regulatory Oversight: Regional Water Quality Control Board State Water Resources Control Board Environmental Protection Agency		
Description of Assets: Wastewater pumping plants are located underground and move wastewater from a lower elevation up to a higher one, so that it can be transported through municipal sewer lines for eventual processing at a treatment plant. There are approximately 21 plants located in the exposure zone.		
Current Observed Vulnerabilities		
Pumping plants may be damaged if an extreme wet weather event floods electrical components and there is no emergency generator on site. The pumping plants are located in a Tsunami Warning Area. Severe tidal conditions could flood plants causing a wastewater spill.		
Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis		
Sensitivity (HIGH)	**Adaptive Capacity (MEDIUM)**	**Consequences (HIGH)**
The wastewater pumping plants are taxed by storm-related flooding and the impacts of sea level rise would only exacerbate those problems. Storm-related and daily tidal flooding could cause electrical equipment to fail or flood the plant.	Many locations have backup generators on site. The BOS has plans to be able to get to these plants so they could be quickly and easily restored if impaired. This depends on the severity of the event. The BOS is undertaking efforts to make these plants more resilient to flooding.	Impairment of these plants would have significant economic consequences. Each of these 21 plants has an approximate two million dollar replacement value. In addition, damage to these plants could result in wastewater spills resulting in negative economic and environmental impacts.
Replacement value (e.g., cost of inaction)	$2 million/per plant (21 plants in exposure zone)	

* Please refer to subregional maps on pages 17-19.

Low Flow Diversion Pumps

Asset Overview		
Location and Number of Assets*		
Pacific Palisades Sub-Region: Pacific Palisades (3)	Venice/LAX Sub-Region: Venice (1)	San Pedro/Harbor Sub-Region: none in coastal zone
Owner: City of Los Angeles		
City Department and Point of Contact: Department of Public Works, Bureau of Sanitation		
Regulatory Oversight: Regional Water Quality Control Board State Water Resources Control Board Environmental Protection Agency		
Description of Assets: There are four low flow diversion pumping plants located in the exposure zone, and they are designed to move water during low flow periods from lower to higher elevation, so it can be transported through pipes by gravity for eventual processing and cleaning at a treatment plant. They do not usually operate during storm events.		
Current Observed Vulnerabilities		
Pumping plant may be damaged if extreme wet weather event floods electrical components. Located in a Tsunami Warning Area. Severe tidal condition could flood the plant causing inability to divert storm water. Severe tidal condition could flood the plant causing wastewater spill.		
Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis		
Sensitivity (LOW)	Adaptive Capacity (HIGH)	Consequences (LOW)
Discharge during each storm season continues as designed and does not impact pumping capacity as the pump does not operate during rain events and the flow is conveyed to the discharge locations by gravity.	The pumps can be restored to operation prior to the dry season if they are impaired by storm-related flooding.	The primary economic consequence would be repair or replacement of the plants, which have a million dollar replacement value each.
Replacement value (e.g., cost of inaction)	$1 million/per plant (4 plants in exposure zone)	

* Please refer to subregional maps on pages 17-19.

Harbor Generating Station
161 N Island Ave
Wilmington, CA 90744

Asset Overview

Owner:
City of Los Angeles

City Department and Point of Contact:
Department of Water and Power

Regulatory Oversight:
North American Electric Reliability Corporation (NERC), Western Electricity Coordination Council (WECC), Southern California Air Quality Management District (SCAQMD)

Summary of Asset:
The Harbor Generation Station is a natural gas fired steam electric generating facility located in the Wilmington area. The facility's total capacity is 472 megawatts and it occupies approximately 20 acres.

Current Observed Vulnerabilities

Energy facilities have low vulnerability to the impacts of sea level rise, because all coastal assets were designed to withstand exposure to water. In addition, replacement schedules and system redundancies reduce vulnerability.

Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis

Sensitivity (LOW)	Adaptive Capacity (HIGH)	Consequences (MEDIUM)
The Harbor Generation Station is not sensitive to the impacts of sea level rise, such as storm-related flooding, tidal flooding, erosion, and interaction with groundwater, because, as a coastal asset, it was designed to be able to cope with these impacts.	This asset can continue to function if partially disabled and its functionality can be restored quickly if impaired. Outdoor components are designed for water resistance and exposure. Indoor components are designed for water to drain into sumps and are also equipped with pumps to quickly remove the water from the sumps.	Impacts would be equally distributed to the immediate area.

Replacement value (e.g., cost of inaction):	None provided

Haynes Generating Station
6801 E 2nd Street
Long Beach CA 90803

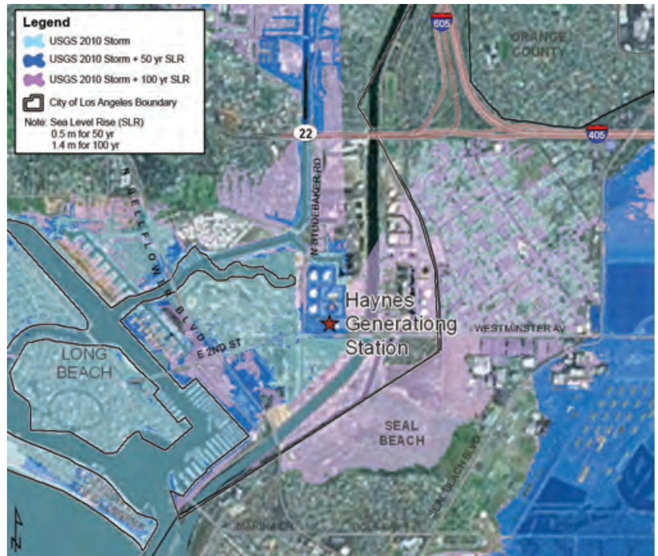
Asset Overview

Owner:
City of Los Angeles

City Department and Point of Contact:
Department of Water and Power

Regulatory Oversight:
North American Electric Reliability Corporation (NERC), Western Electricity Coordination Council (WECC), Southern California Air Quality Management District (SCAQMD), California State Water Resources Control Board (SWRCB)

Summary of Asset:
Haynes Generation Station is a natural gas fired power plant located in the Long Beach area with a capacity of 1556 megawatts.



Current Observed Vulnerabilities

Energy facilities have low vulnerability to the impacts of sea level rise, because all coastal assets were designed to withstand exposure to water. In addition, replacement schedules and system redundancies reduce vulnerability.

Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis

Sensitivity (LOW)	Adaptive Capacity (HIGH)	Consequences (MEDIUM)
This asset is not sensitive to the impacts of sea level rise, such as storm-related flooding, tidal flooding, erosion, and interaction with groundwater because, as a coastal asset, it was designed to be able to cope with these impacts.	This asset can continue to function if partially disabled and its functionality can be restored quickly, because outdoor assets are designed for water resistance and exposure. Indoor assets are designed for water to drain into sumps and are also equipped with pumps to quickly remove the water from the sumps.	Impairment of Haynes would have moderate economic consequences, because clean-up could take time, potentially affecting the power supply to other parts of Los Angeles. The disruption of power supply could have environmental consequences, because it could impact power supply to waste water treatment plants, potentially resulting in sewage spills.

Replacement value (e.g., cost of inaction):	None provided

Receiving Station Q (RSQ)
150 N Island Ave
Wilmington, CA 90744

Asset Overview

Owner:
City of Los Angeles

City Department and Point of Contact:
Department of Water and Power

Regulatory Oversight:
North American Electric Reliability Corporation (NERC) and Western Electricity Coordination Council (WECC) Reliability Standards. California Public Utilities Commission (CPUC) claims jurisdiction over matters of safety.

Summary of Asset:
Receiving Station (RS) Q is located in the Wilmington area and is comprised of equipment that receives power from generation, transforms the voltage, and distributes the power out again into the distribution network. Specifically, it has underground transmission connections to RS-C and Harbor Generation stations and connection to distribution stations that serve the San Pedro and Wilmington areas.

Current Observed Vulnerabilities

Energy facilities have low vulnerability to the impacts of sea level rise, because all coastal assets were designed to withstand exposure to water. In addition, replacement schedules and system redundancies reduce vulnerability.

Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis

Sensitivity (LOW)	Adaptive Capacity (HIGH)	Consequences (MEDIUM)
This asset is not sensitive to the impacts of sea level rise, such as storm-related flooding, tidal flooding, erosion, and interaction with groundwater, because as a coastal asset, it was designed to be able to cope with these impacts.	This asset can continue to function if partially disabled and its functionality can be restored quickly, because outdoor assets are designed for water resistance and exposure. Indoor assets are designed for water to drain into sumps and are also equipped with pumps to quickly evacuate the water from the sumps.	The DWP reports minor economic consequences from the potential impairment of RS-Q, because impacts would be distributed equally in the immediate area. Impairment of RS-Q could have moderate environmental consequences, however, because it could impact power supply to wastewater treatment plants, potentially resulting in a sewage spill.

Replacement value (e.g., cost of inaction):	None provided

230 KV Scattergood-Olympic Cable
Dockweiler Beach/Venice Area

Asset Overview
Owner: City of Los Angeles
City Department and Point of Contact: Department of Water and Power
Regulatory Oversight: North American Electric Reliability Corporation (NERC) and Western Electricity Coordination Council (WECC) Reliability Standards.
Summary of Asset: This is an underground cable in the Dockweiler Beach/Venice area that connects to a high voltage interstate line.

Current Observed Vulnerabilities
None identified

Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis		
Sensitivity (MEDIUM)	Adaptive Capacity (HIGH)	Consequences (MEDIUM)
This asset is potentially sensitive to daily tidal flooding, because flooding of low-lying areas around the cable could make maintenance and repair difficult.	This asset can continue to function if partially disabled. Outdoor assets are designed for water resistance and exterior exposure. Their function can also be restored quickly.	The DWP reports minor consequences from the potential impairment of this asset, because impacts would be distributed equally in the immediate area.

Replacement value (e.g., cost of inaction):	None provided

Electrode Vault
17300 Pacific Coast Highway
Pacific Palisades, 90272

Asset Overview
Owner: City of Los Angeles
City Department and Point of Contact: Department of Water and Power
Regulatory Oversight: California Public Utilities Commission (CPUC) claims jurisdiction over power equipment based on safety matters.
Summary of Asset: This is an underground vault. It is currently being redesigned and moved for reasons unrelated to sea level rise.

Current Observed Vulnerabilities

Energy facilities have low vulnerability to the impacts of sea level rise, because all coastal assets were designed to withstand exposure to water. In addition, replacement schedules and system redundancies reduce vulnerability.

Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis

Sensitivity (LOW)	Adaptive Capacity (HIGH)	Consequences (MEDIUM)
This asset is not sensitive to the impacts of sea level rise, such as storm-related flooding, tidal flooding, erosion, and interaction with groundwater, because, as a coastal asset, it was designed to deal with these impacts.	This asset can continue to function if partially disabled. Outdoor assets are designed for water resistance and exterior exposure. Their function can also be restored quickly.	The DWP reports minor consequences from the potential impairment of this asset, because impacts would be distributed equally in the immediate area.

Replacement value (i.e., cost of inaction):	None provided

Local Electricity Distribution Assets

Asset Overview		
Location and Number of Assets*		
Pacific Palisades Sub-Region: Poles (multiple) Transformers (multiple) Wires (multiple)	Venice/LAX Sub-Region: Poles (multiple) Transformers (multiple) Wires (multiple)	San Pedro/Harbor Sub-Region: Distribution Stations (3) Poles (multiple) Transformers (multiple) Wires (multiple)
Owner: City of Los Angeles		
City Department and Point of Contact: Department of Water and Power		
Regulatory Oversight: California Public Utilities Commission (CPUC) claims jurisdiction over power equipment based on safety matters.		
Description of Assets: Local electricity distribution assets include three distribution stations, poles, transformers, wires, vaults, and cables. These assets help deliver electricity at relatively low voltages to customers.		

Current Observed Vulnerabilities
Energy facilities have low vulnerability to the impacts of sea level rise, because all coastal assets were designed to withstand exposure to water. In addition, replacement schedules and system redundancies reduce vulnerability.

Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis		
Sensitivity (LOW)	Adaptive Capacity (HIGH)	Consequences (MEDIUM)
These assets are not sensitive to the impacts of sea level rise, such as storm-related flooding, tidal flooding, erosion, and interaction with groundwater, because, as coastal assets, they were designed to be able to cope with these impacts.	These assets can continue to function if partially disabled. Outdoor assets are designed for water resistance and exterior exposure. Indoor assets are designed for water to drain into sumps and are also equipped with pumps to quickly evacuate the water from the sumps. In addition, assets are laid out in a manner that is easily reparable and their function can also be restored quickly. Lastly, if needed, power can be re-routed to other parts of the network.	The DWP reports minor consequences from the potential impairment of these assets, because impacts would be distributed equally in the immediate area.

Replacement value (e.g., cost of inaction)	None provided

* Please refer to subregional maps on pages 17-19.

Water Pipes

Asset Overview		
Location and Number of Assets*		
Pacific Palisades Sub-Region: 1919 feet	Venice/LAX Sub-Region: 186,961 feet	San Pedro/Harbor Sub-Region: 10,632 feet
Owner: City of Los Angeles		
City Department and Point of Contact: Department of Water and Power		
Regulatory Oversight: Los Angeles Department of Water and Power, California Department of Public Health (CDPH), U.S. Environmental Protection Agency (USEPA)		
Summary of Asset: LADWP's water infrastructure distributes water supply to 676,000 active service connections through a distribution network of over 7,200 miles of pipelines. About 500 miles of pipe in the distribution system is 24 inches or larger in diameter (trunkline). The remaining pipes have a diameter of less than 24 inches (mainline). There are approximately 199,512 feet of pipe in the exposure zone. Pipes carry water through the distribution system to customers.		
Current Observed Vulnerabilities		
The potable water system is vulnerable to storm-related flooding, daily tidal flooding, and interaction with groundwater, which makes accessing underground assets, such as pipes, extremely challenging and raise public health concerns. Erosion could also damage many of the assets.		
Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis		
Sensitivity (HIGH)	Adaptive Capacity (MEDIUM)	Consequences (MEDIUM)
Pipes are sensitive to storm-related flooding, tidal flooding, and interaction with groundwater because the water makes it difficult for crews to access the buried pipes, thus impairing construction and maintenance. The pipes are also sensitive to erosion, because the loss of ground stability could damage or break the pipes, thus impairing operation.	By pumping water out from flooded areas, the pipes could continue to function even if partially disabled. Crews can also limit construction and maintenance to low tide periods. Lastly, because the pipes are part of a networked system, LADWP could potentially bypass an impaired section of the network. The functionality of the pipes, however, might not be quickly or easily restored, because major excavation and construction is required to restore operations. There are no current efforts in place to make the pipes more resilient to these impacts.	Impairment of pipes from sea level rise impacts would have high economic consequences because it affects construction and reduces the life span of the pipes. In addition, there are public health concerns regarding salt water, groundwater, or other substances potentially infiltrating the potable water system. Lastly, pipe failure could potentially exacerbate flooding in flat areas with poor drainage.
Replacement value (e.g., cost of inaction)	None provided	

* Please refer to subregional maps on pages 17-19.

Water Services

Asset Overview		
Location and Number of Assets*		
Pacific Palisades Sub-Region: 9	Venice/LAX Sub-Region: 4,208	San Pedro/Harbor Sub-Region: 11
Owner: City of Los Angeles		
City Department and Point of Contact: Department of Water and Power		
Regulatory Oversight: Los Angeles Department of Water and Power, California Department of Public Health (CDPH), U.S. Environmental Protection Agency (USEPA)		
Summary of Asset: Approximately 4,228 water services in the exposure area connect water mains to customers. This asset includes connections between the water main and the meter, the meters, and meter boxes.		
Current Observed Vulnerabilities		
The potable water system is vulnerable to storm-related flooding, daily tidal flooding, and interaction with groundwater, which makes accessing underground assets, such as pipes, extremely challenging and raise public health concerns. Erosion could also damage many of the assets.		
Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis		
Sensitivity (HIGH)	Adaptive Capacity (MEDIUM)	Consequences (MEDIUM)
Many water services are located below ground. Thus, if they were submerged in water, such as from storm-related flooding, daily tidal flooding, or interaction with groundwater, the water would need to be pumped out before the asset could be placed back into operation. These impacts could impair construction, maintenance, and operation of water services.	By removing the water to a minimum level needed for operations, the water services could continue to function even if they were partially disabled. In addition, there is some redundancy and flexibility in the system, which provides some resilience, but this is highly dependent on the location. If impaired, however, the functionality of water services might not easily or quickly restore. The DWP has undertaken some efforts to make water services more resilient by installing some of the larger services above ground.	These impacts have high economic consequences because they affect construction and reduce the life span of these assets. In addition, there are public health concerns resulting from salt water, groundwater, and/or other substances potentially infiltrating the potable water system. Lastly, failure could exacerbate flooding in flat areas with poor drainage.
Replacement value (i.e., cost of inaction)	None provided	

* Please refer to subregional maps on pages 17-19.

Fire Hydrants

Asset Overview		
Location and Number of Assets*		
Pacific Palisades Sub-Region: 0	Venice/LAX Sub-Region: 248	San Pedro/Harbor Sub-Region: 1
Owner: City of Los Angeles		
City Department and Point of Contact: Department of Water and Power		
Regulatory Oversight: Los Angeles Department of Water and Power, California Department of Public Health (CDPH), U.S. Environmental Protection Agency (USEPA)		
Description of Assets: There are approximately 249 fire hydrants in the exposure area that provide high pressure water for fire fighting efforts and temporary water services.		
Current Observed Vulnerabilities		
None identified.		
Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis		
Sensitivity (HIGH)	Adaptive Capacity (LOW)	Consequences (MEDIUM)
Fire hydrants are sensitive to storm related and tidal flooding, because if the hydrants are submerged in water, firefighting personnel will not be able to access or operate them. Fire hydrants are also sensitive to erosion, because the loss of ground stability could damage the fire hydrant and render it inoperable.	Fire hydrants can function if partially disabled, because they will continue to work in semi-submerged conditions. The function, however, cannot be restored quickly or easily if impaired and there are no current efforts in place to make hydrants more resilient to these impacts.	Flooding, inundation, and groundwater have high economic consequences because they impact the construction and lifespan of the asset. In addition, there are public health concerns regarding salt water, groundwater, or other substances potentially infiltrating the potable water system, since fire hydrants are connected to the potable water system. Lastly, failure of fire hydrants could exacerbate flooding in flat areas with poor drainage because water at high pressure could spill from a broken hydrant.
Replacement value (i.e., cost of inaction)	None provided	

* Please refer to subregional maps on pages 17-19.

Cultural Facilities

Asset Overview		
Location and Number of Assets*		
Pacific Palisades Sub-Region: None in coastal zone	Venice/LAX Sub-Region: None in coastal zone	San Pedro/Harbor Sub-Region: LA Maritime Museum
Owner: City of Los Angeles		
City Department and Point of Contact: Department of Recreation and Parks		
Regulatory Oversight: No Regulatory Oversight		
Description of Assets: The L.A. Maritime Museum is located in the coastal zone, in the 1941 Municipal Ferry Terminal, and is on the National Register of Historic Places.		
Current Observed Vulnerabilities		
Structures like recreation centers and museums are highly vulnerable to flooding and inundation, because the structures would be damaged, inoperable, and/or inaccessible.		
Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis		
Sensitivity (HIGH)	Adaptive Capacity (LOW)	Consequences (MEDIUM)
The museum is sensitive to storm-related flooding, tidal flooding, and erosion. These impacts would cause damage to the structure and/or content of the building and would cause the facility to close to the public.	This facility cannot function if it is partially impaired and cannot be quickly or easily restored if impaired. There are no current efforts in place to make the museum more resilient to the impacts of sea level rise.	The greatest consequence would be the economic impact of a storm-related flood, because this could cause damage to the valuable artifacts within the museum. In addition, closure of the Maritime Museum would be a cultural loss for the local community and greater City of Los Angeles, as this site attracts visitors from around the region.
Replacement value (e.g., cost of inaction)	None provided	

* Please refer to subregional maps on pages 17-19.

Cabrillo Beach
3720 Stephen M. White Dr.
San Pedro, CA 90731

Asset Overview

Owner:
City of Los Angeles

City Department and Point of Contact:
Department of Recreation and Parks

Regulatory Oversight:
No Regulatory Oversight

Summary of Asset:
Cabrillo Beach includes a public beach, a marine aquarium, a recreation center, and a fishing pier.

Current Observed Vulnerabilities

Currently has poor water quality; sand has been replaced twice already.

Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis

Sensitivity (HIGH)	Adaptive Capacity (MEDIUM)	Consequences (HIGH)
The public beach is sensitive to storm-related flooding, daily tidal flooding, erosion, and interaction with groundwater. The public beach could potentially be lost to erosion. In fact, in 2007, a large storm washed away the sand and the outer beach was exposed down to rocks. The sand was replaced naturally over time, but with higher sea level, it is uncertain if the sand would return naturally following a storm event. Storm-related flooding, tidal flooding, and groundwater could damage the recreation center and aquarium.	The public beach could potentially continue to function if partially impaired. For example, if the beach is flooded only during high tides, visitors could potentially use the beach during low tides. Also, it could potentially continue to function if impaired by storm-related flooding. After previous storm events, some of the beach sand still remained, but with a two- to three-foot berm that visitors had to navigate to access the water. On the other hand, partial impairment of the aquarium and recreation center would render them non-functional. Also, these facilities could not be quickly or easily restored if impaired. Flooding in the parking lot or road would result in a loss of access for visitors. There are no current efforts in place to make the facilities at Cabrillo Beach more resilient to the impacts of sea level rise.	Impairment of this asset would have high economic consequences, because the beach and aquarium attract visitors from all over Southern California. The local communities of Wilmington, San Pedro, and Harbor City also use the beach and the recreation center, and the impairment of these assets would be a loss of open space and recreation opportunities for these park-poor communities.

Replacement value (e.g., cost of inaction):	None provided

Parks and Open Space

Asset Overview		
Location and Number of Assets*		
Pacific Palisades Sub-Region: None in coastal zone	Venice/LAX Sub-Region: Playa del Rey: Del Rey Lagoon Park (Playa del Rey)** Venice: Canal Park/Linnie Canal (Venice)** Westminster Park (Venice) Triangle Park (Marr Park) Culver City: Titmouse Park (Culver City)**	San Pedro/Harbor Sub-Region: San Pedro: John S. Gibson Jr. Park
Owner: City of Los Angeles		
City Department and Point of Contact: Department of Recreation and Parks		
Regulatory Oversight: No Regulatory Oversight		
Description of Assets: Neighborhood Parks located in the sea level rise exposure zone include Del Rey Lagoon Park, Canal Park, and Titmouse Park. Del Rey Lagoon features a tidal basin, children's play area, a ball field, and restroom facility. Canal Park is a pocket park located along the Venice canals and it includes grass and a children's play area. Titmouse Park is a small park located near Ballona Creek consisting of native plants that provide habitat for birds.		

Current Observed Vulnerabilities

Parks and other open spaces are generally fairly resilient assets. They can be restored relatively quickly or they can change to cope with new environmental conditions. For example, different landscaping can be introduced to deal with periodic flooding without significantly changing the function of the park. Built structures, such as recreational buildings and museums are much less resilient, because damage takes longer to repair and they cannot function if partially impaired.

The consequences of impairment of these facilities are highly dependent on the location. Some facilities, like the Venice Beach Boardwalk, are iconic destinations and their impairment could have significant economic consequences. Some parks are unique because they provide habitat for rare plants and animals. Other parks and recreation centers are highly valued and used by the local communities, especially in the San Pedro/Harbor area, because few other parks exists in the area.

Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis

Sensitivity (HIGH)	Adaptive Capacity (MEDIUM)	Consequences (LOW)
These parks are sensitive to storm-related flooding, daily tidal flooding, and erosion which could damage the park facilities and make the park unusable an inaccessible.	The parks could function if partially impaired. For example, if only a small part of the park experiences tidal flooding, other parts of the park could be used. The park could be quickly restored depending on how fast storm water recedes. The landscape and vegetation of the parks could change given these impacts and still be useful as habitat for plants and animals.	The consequences of impairment of these parks would be relatively minor given their small size. There would be a loss of recreational opportunities for residents and habitat for plants and animals.

Replacement value (e.g., cost of inaction)	None provided

* Please refer to subregional maps on pages 17-19.
**The physical vulnerability assessment only considers the impacts to these parks.

Recreation Centers

Asset Overview		
Location and Number of Assets*		
Pacific Palisades Sub-Region: None in exposure zone	Venice/LAX Sub-Region: Venice Beach Recreation Center** San Juan Garage	San Pedro/Harbor Sub-Region: None in exposure zone
Owner: City of Los Angeles		
City Department and Point of Contact: Department of Recreation and Parks		
Regulatory Oversight: No Regulatory Oversight		
Description of Assets: Recreation Centers located in the exposure zone include the Venice Beach Recreation Center and San Juan Garage. The Venice Beach Recreation Center consists of a boardwalk, fishing pier, picnic areas, skateboard arena and athletic courts.		
Current Observed Vulnerabilities		
Structures like recreation centers and museums are highly vulnerable to flooding and inundation, because the structures would be damaged, inoperable, and/or inaccessible.		
Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis		
Sensitivity (HIGH)	Adaptive Capacity (LOW)	Consequences (HIGH)
This asset is sensitive to storm-related and daily tidal flooding, which could damage the various elements of the recreation center and render them unusable by the public. The pier already has some structural weakness and it could be further damaged by these impacts. Erosion could also weaken the structural stability of the pier and the boardwalk.	This asset cannot function if partially impaired. The boardwalk and athletic courts could be quickly restored if impaired, but the pier would take considerably longer to restore if damaged. Recreation and Parks is currently working on a plan to reinforce the pier to better withstand current impacts, but the plan does not explicitly take the impacts of sea level rise into consideration.	Impairment of these iconic facilities, particularly the boardwalk, would have high economic consequences, because of their cultural, recreational, and tourist value. They draw visitors from around the region and even from around the world. The boardwalk also includes spaces for about 200 vendors, who would have to seek other locations to sell their goods.
Replacement value (e.g., cost of inaction)	None provided	

* Please refer to subregional maps on pages 17-19.
**The physical vulnerability assessment only considers the impacts to the Venice Beach Recreation Center.

Building Stock and Roads - Venice Area

Asset Overview

Owner:
City of Los Angeles

City Department and Point of Contact:
Department of Planning

Regulatory Oversight:
US Army Corps of Engineers (USACE)*
Los Angeles County Department of Water and Power (LACDWP)*
City of Los Angeles Bureau of Engineering (BOE)*
California Coastal Commission*
City of Los Angeles Ordinance (No. 172,081)**

Description of Assets:
None provided.

Current Observed Vulnerabilities

Roads are vulnerable to flooding, inundation, erosion, and groundwater, which could result in reduced access for residents and impaired regional transport. The building stock is most vulnerable to flooding and inundation in Venice, where it is located very near sea level and there are many older structures.

Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis

Sensitivity (HIGH)	Adaptive Capacity (MEDIUM)	Consequences (HIGH)
The building stock and roads in the Venice area are sensitive to storm-related flooding, tidal flooding, and erosion. The impacts of sea level rise could lead to damaged and/or uninhabitable homes, businesses, schools, and public buildings. Many structures are built at, or very near, sea level. In addition, many of the structures were built before the 1970s, which means they are more sensitive to flooding. In fact, some residents already experience flooded basements during storm events. Damage to roads from the impacts of sea level rise could also result in a lack of access for residents and emergency services.	The ability of the roads and building stock in Venice to continue to function if partially disabled depends on the extent of damage. The functionality of these assets could not be restored very quickly or easily. The City Planning department, in collaboration with the Departments of Building and Safety, Public Works, and Transportation can identify an adaptation strategy for these assets during the next update of the Venice Community Plan.	The economic and social consequences of the impairment of these assets would be high due to the displacement of residents and businesses. In particular, the displacement of low-income residents in the Venice Beach area would have significant social consequences. In addition, flooding in this area could cause damage to the Ballona wetlands, which provides habitat for plants and animals and helps filter groundwater.

Replacement value (e.g., cost of inaction)	None provided

*Flood Protection in the region is managed by 3 agencies: 1) United States Army Corps of Engineers (USACE); 2) Los Angeles County Department of Public Works (LACDPW); and 3) City of Los Angeles Bureau of Engineering (BOE). The USACE oversees projects associated with navigable bodies of water, including ocean harbors. The LACDPW oversees county flood control drainage facilities to reduce the impacts of 100- and 500- year storms. The BOE oversees the City's storm drainage system, which is designed to reduce the impacts of 50-year magnitude storms. Various city agencies implement development permit and slope stability permits. The California Coastal Commission also has permit responsibility in the coastal zone located in San Pedro and the Port of Los Angeles.

**The City of Los Angeles has an ordinance governing permit review and mitigation procedures for issuance of development permits in areas prone to flooding, mudflow, or coastal inundation. The Ordinance (No. 172,081) specifies mitigation measures, which include relocation of structures within a property, increased base elevation, additional structural reinforcement, anchoring, and installation of protective barriers.

Building Stock and Roads - San Pedro/Harbor Area

Asset Overview

Owner:
City of Los Angeles

City Department and Point of Contact:
Department of Planning

Regulatory Oversight:
U.S. Army Corps of Engineers (USACE)*
Los Angeles County Department of Water and Power (LACDWP)*
City of Los Angeles Bureau of Engineering (BOE)*
California Coastal Commission*
City of Los Angeles Ordinance (No. 172,081)**

Description of Assets:
The San Pedro and Harbor area are served by a circulation system of highways (freeways or high capacity roadways), arterials (moderate capacity roadways), collector streets and local streets. Paseo Del Mar, in the southern portion of San Pedro runs in an east-west direction along the coastline. Harbor Boulevard runs in a north-south direction along the harbor shoreline. Being located on a peninsula, San Pedro and the harbor area are limited in the number of through routes.

Current Observed Vulnerabilities

Roads are vulnerable to flooding, inundation, erosion, and groundwater, which could result in reduced access for residents and impaired regional transport.

Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis

Sensitivity (HIGH)	Adaptive Capacity (MEDIUM)	Consequences (HIGH)
The building stock and roads in the San Pedro/Harbor Area are sensitive to storm-related flooding, tidal flooding, and erosion. Not many residential buildings will be exposed to sea level rise because they are terraced up on the hillside, but there are some people that live on boats in the marina. Roads could be damaged by these impacts.	The City Planning department is uncertain if this asset could continue to function if partially disabled, because it depends upon the extent of the damage. The City Planning department, in collaboration with the Departments of Building and Safety, Public Works, and Transportation can identify an adaptation strategy for these assets during the next update of the San Pedro Community Plan.	Impairment of roads would have significant economic consequences because they are important for regional goods movement due to their proximity to the Port of Los Angeles. Damage to roads could also limit access to neighborhoods. Damage to building stock could displace businesses and low-income residents.

Replacement value (e.g., cost of inaction)	None provided

*Flood Protection in the region is managed by 3 agencies: 1) United States Army Corps of Engineers (USACE); 2) Los Angeles County Department of Public Works (LACDPW); and 3) City of Los Angeles Bureau of Engineering (BOE). The USACE oversees projects associated with navigable bodies of water, including ocean harbors. The LACDPW oversees county flood control drainage facilities to reduce the impacts of 100- and 500- year storms. The BOE oversees the City's storm drainage system, which is designed to reduce the impacts of 50-year magnitude storms. Various city agencies implement development permit and slope stability permits. The California Coastal Commission also has permit responsibility in the coastal zone located in San Pedro and the Port of Los Angeles.

**The City of Los Angeles has an ordinance governing permit review and mitigation procedures for issuance of development permits in areas prone to flooding, mudflow, or coastal inundation. The Ordinance (No. 172,081) specifies mitigation measures, which include relocation of structures within a property, increased base elevation, additional structural reinforcement, anchoring, and installation of protective barriers.

Pacific Coast Highway (PCH) - Pacific Palisades Area

Asset Overview
Owner: City of Los Angeles
City Department and Point of Contact: Department of Planning
Regulatory Oversight: U.S. Army Corps of Engineers (USACE)* Los Angeles County Department of Water and Power (LACDWP)* City of Los Angeles Bureau of Engineering (BOE)* California Coastal Commission* City of Los Angeles Ordinance (No. 172,081)**
Summary of Asset: This asset consists of approximately 2.5 miles of PCH from Sunset Boulevard to Entrada Drive. The highway in this stretch generally has six lanes and runs near the ocean, separated from the sea by sandy beaches and some coastal armoring. California Department of Transportation has jurisdiction over PCH, but it provides a critical connection to coastal communities.

Current Observed Vulnerabilities
Roads are vulnerable to flooding, inundation, erosion, and groundwater, which could result in reduced access for residents and impaired regional transport

Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis		
Sensitivity (HIGH)	**Adaptive Capacity (MEDIUM)**	**Consequences (HIGH)**
This asset is sensitive to storm-related flooding, tidal flooding, and erosion. All of these impacts could result in damage to the highway, potentially causing frequent closures and even structural failure.	It is uncertain if PCH could continue to function if partially disabled, because it would depend on decision-making by Caltrans regarding keeping the highway open with a reduced number of lanes.	Impairment of PCH would have significant economic consequences, because it is an important transportation connection in the region. In addition, it would have adverse consequences for communities living in Pacific Palisades who could have difficulty accessing their homes or be less accessible to emergency services.

Replacement value (e.g., cost of inaction)	None provided

*Flood Protection in the region is managed by 3 agencies: 1) United States Army Corps of Engineers (USACE); 2) Los Angeles County Department of Public Works (LACDPW); and 3) City of Los Angeles Bureau of Engineering (BOE). The USACE oversees projects associated with navigable bodies of water, including ocean harbors. The LACDPW oversees county flood control drainage facilities to reduce the impacts of 100- and 500- year storms. The BOE oversees the City's storm drainage system, which is designed to reduce the impacts of 50-year magnitude storms. Various city agencies implement development permit and slope stability permits. The California Coastal Commission also has permit responsibility in the coastal zone located in San Pedro and the Port of Los Angeles.

**The City of Los Angeles has an ordinance governing permit review and mitigation procedures for issuance of development permits in areas prone to flooding, mudflow, or coastal inundation. The Ordinance (No. 172,081) specifies mitigation measures, which include relocation of structures within a property, increased base elevation, additional structural reinforcement, anchoring, and installation of protective barriers.

Port of Los Angeles
Container Terminals
425 South Palos Verdes Street
San Pedro California 90731

Asset Overview

Owner:
Port of Los Angeles

City Department and Point of Contact:
Harbor

Regulatory Oversight:
No description provided.

Description of Assets:
Container terminals are the facilities where cranes load cargo containers to and from ships and onto trucks or trains for onward transportation. These facilities also provide storage for containers in stacks while awaiting transport.

Current Observed Vulnerabilities

Although the Port's assets are highly sensitive to flooding and inundation, the port has low vulnerability because of its high capacity to adapt by building future infrastructure at a higher elevation.

Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis

Sensitivity (MEDIUM)	Adaptive Capacity (HIGH)	Consequences (HIGH)
Container terminals will be sensitive to storm-related flooding during high tide events in the later years of this study. This flooding could render the terminals inaccessible and non-operational with unsecured containers and no power supply for equipment.	In the short-term, container terminals have low adaptive capacity, because they cannot continue to function if partially disabled and their functionality cannot be restored quickly after suffering damage. However, in the long-term the terminals could be redesigned and re-built at higher elevations.	The economic consequences of impaired container terminals are very significant. They are the port's highest revenue generating resource and they have a $2.85 billion replacement value. Furthermore, the economic impacts would ripple through the economy as shipments would be delayed or re-routed. Quantifying the economic consequences of impaired container terminals is extremely difficult because it depends on a variety of factors. According to the National Oceanic and Atmospheric Administration 2008-2017 Strategic Plan, the cost of a shutdown of the POLA/POLB would cost $1 billion per day in regional economic losses.

Replacement value (i.e., cost of inaction)	$2.85 billion replacement value, $1 billion per day cost of shut down of POLA/POLB

Port of Los Angeles
Electrical Infrastructure
425 South Palos Verdes Street
San Pedro California 90731

Asset Overview

Owner:
Port of Los Angeles

City Department and Point of Contact:
Harbor

Regulatory Oversight:
Los Angeles Department of Building and Safety (LADBS)

Description of Assets:
Electrical infrastructure for container handling and lighting.

Current Observed Vulnerabilities

Although the Port's assets are highly sensitive to flooding and inundation, the port has low vulnerability because of its high capacity to adapt by building future infrastructure at a higher elevation.

Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis

Sensitivity (MEDIUM)	Adaptive Capacity (HIGH)	Consequences (HIGH)
The Port's electrical infrastructure could be severely damaged by regular storm-related flooding in the later years of the study, as it is not designed to be flooded or inundated.	In the short term, this asset has low adaptive capacity, because it cannot function if partially disabled and the functionality is not quickly or easily restored if impaired. However, in the long-term, the electrical infrastructure could be redesigned at higher elevations.	This infrastructure is vital to port operations and impairment would cause equipment, such as cranes, to be non-operational. This could cause delays and disruptions in cargo loading and offloading. This asset has a $350 million replacement value.

Replacement value (e.g., cost of inaction)	$350 million

Port of Los Angeles
Breakwater
425 South Palos Verdes Street
San Pedro California 90731

Asset Overview

Owner:
Port of Los Angeles

City Department and Point of Contact:
Harbor

Regulatory Oversight:
Army Corps of Engineers

Description of Assets:
The breakwater is an 8.5-mile rock structure that prevents waves from entering the harbor. It has two openings to allow ships to enter the port areas behind it.

Current Observed Vulnerabilities

Although the Port's assets are highly sensitive to flooding and inundation, the port has low vulnerability because of its high capacity to adapt by building future infrastructure at a higher elevation.

Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis

Sensitivity (MEDIUM)	Adaptive Capacity (HIGH)	Consequences (HIGH)
The breakwater would be sensitive to overtopping and storm surge damage during the later years of the study. This would impact its ability to shelter harbor facilities.	The breakwater could potentially function if partially impaired. For example, if a portion of the breakwater is eroded, the rest of the structure would continue to block waves. Also, if the breakwater is flooded only during high tide, it would continue to function during low tide.	An impaired breakwater would have high economic consequences because it could cause damage to the port, rendering shipping terminals unusable and interrupting flow of cargo. There could also be environmental damage to the shallow water habitat adjacent to breakwater, which is a built ecosystem that supports eelgrass, fish, and bird life. The breakwater has a $500 million replacement value and is managed by the Army Corps of Engineers.

Replacement value (e.g., cost of inaction)	$500 million

Port of Los Angeles
Transportation
425 South Palos Verdes Street
San Pedro California 90731

Asset Overview

Owner:
Port of Los Angeles

City Department and Point of Contact:
Harbor

Regulatory Oversight:
Los Angeles Department of Transportation (LADOT), Metropolitan Transportation Authority (MTA), California Department of Transportation (Caltrans), Public Utilities Commission (PUC)

Description of Assets:
Transportation assets include roads, rails, and grade separations that help move cargo to and from the Port.

Current Observed Vulnerabilities

Although the Port's assets are highly sensitive to flooding and inundation, the port has low vulnerability because of its high capacity to adapt by building future infrastructure at a higher elevation.

Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis

Sensitivity (MEDIUM)	Adaptive Capacity (HIGH)	Consequences (HIGH)
Transportation assets will be sensitive to storm-related flooding and daily tidal flooding, erosion, and groundwater interaction in later years of the study. These impacts could cause the assets to be damaged and thus unusable.	Compared to other port assets, roads can be re-built relatively quickly. In addition, if only one lane is affected by flooding or erosion, the road can potentially still continue to function.	Impaired transportation facilities would have a high economic consequence, because they are vital for transporting cargo from terminals to their final destinations. It could also have a high impact on communities living in San Pedro, Wilmington, and permanent residents in the marinas due to reduced access. The transportation assets are estimated to have a $1 billion replacement value.

Replacement value (e.g., cost of inaction)	$1 billion

Port of Los Angeles
Marinas
425 South Palos Verdes Street
San Pedro California 90731

Asset Overview		
Owner: Port of Los Angeles		
City Department and Point of Contact: Harbor		
Regulatory Oversight: California Coastal Commission, California Department of Boating and Waterways		
Description of Assets: Marinas are docks with moorings for relatively small boats.		
Current Observed Vulnerabilities		
Although the Port's assets are highly sensitive to flooding and inundation, the port has low vulnerability because of its high capacity to adapt by building future infrastructure at a higher elevation.		
Physical Vulnerability to Sea Level Rise Based on USGS Exposure Analysis		
Sensitivity (MEDIUM)	Adaptive Capacity (HIGH)	Consequences (MEDIUM)
Marinas are sensitive to storm-related flooding, daily tidal flooding, and erosion, because they would be damaged by such impacts.	Marinas are relatively resilient to storm-related flooding, because they float on the water, but their groundings would become deteriorated from daily tidal flooding and erosion. In addition, these impacts could reduce access to the marinas.	The consequences of impaired marinas primary relates to their recreational value. They also have an estimated $180 million replacement value. Lastly, permanent residents of the marinas could potentially be displaced.
Replacement value (e.g., cost of inaction)	$180 million	

Social Vulnerability Assessment

A social vulnerability study was conducted by Dr. Julia Ekstrom and Dr. Susanne Moser (see Appendix 3 for full report), which examined the socioeconomic implications of sea level rise to residents and communities in the City of L.A. The authors provide demographic overviews of the three coastal areas within the City of L.A. (Pacific Palisades, Venice/Playa del Rey/LAX, San Pedro/Harbor area) that are likely to experience impacts from sea level rise and other associated flooding (i.e., such as that from stormwater system overflows) (see report in Appendix 3 for more details on demographics). The social vulnerability study focused on census data-derived demographics of the coastal communities rather than directly on the flood models. The demographic overviews are followed by a description of population characteristics that demonstrate which segments of coastal communities may be more socially vulnerable to flooding than others.

The assessment utilizes a variety of sources to discuss characteristics that are commonly associated with higher sensitivity and/or lower adaptive capacity to flooding and sea level rise. Information was compiled from Census 2010 data when available, American Communities Survey Census 2006-2010 data, Census 2000 data (when it provided information at a higher resolution), and pre-existing information from secondary data sources, such as City and County planning documents, other assessments related to vulnerable segments of the City (and some cases County's) population, and newspaper articles about past floods. The characteristics discussed include: income, poverty, education, females as head of household, race, linguistic isolation, age, housing type and age, and physical and mental illnesses and disabilities.

Income and poverty level are considered the primary indicators of adaptive capacity. While per capita income in Los Angeles overall tends to be higher along the coast than in the interior, there are communities along the coast that average some of the lowest income levels in L.A. County (Figure 7), (e.g., portions of San Pedro and Wilmington have an average income of $13,000 per year compared to

Per Capita Income ($) - City of L.A.

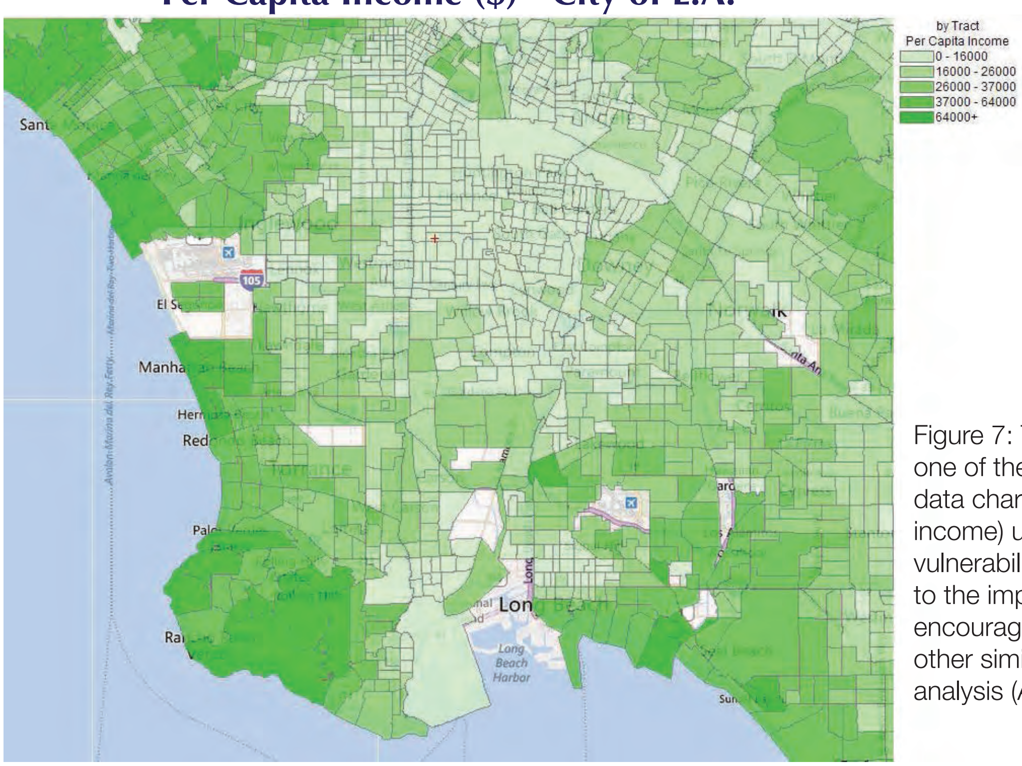


Figure 7: This figure provides an example of one of the many figures representing census data characteristics (in this case per capita income) utilized to determine the social vulnerability of City of Los Angeles residents to the impacts of sea level rise. Readers are encouraged to view the full report to review other similar figures for other census data analysis (Appendix 3).

the more affluent communities on the Palos Verdes Peninsula which average $128,000 per year). Similarly, over 76% of the census tract population on the west side of Wilmington lives below the federal poverty level. While these are not the only areas in the City of L.A. that have this combination of low income and high poverty levels, these are the most vulnerable communities within the sea level rise exposure zone.

Studies of public health and vulnerability to disasters also indicate that minority populations tend to have lower capacity for responding to disasters and adapting to climate change than non-Hispanic whites. Other studies have shown that the likely reason for the correlation between race and lower adaptive capacity is the disproportionate amount of poverty and lower incomes among African Americans and Latinos compared to White/non-Hispanic segments of the population. In coastal communities within the City of L.A., there are very high concentrations of Latino populations residing in the eastern, low lying portion of San Pedro (closest to the inner Harbor/Port) and throughout Wilmington, as well as some small areas of Latino populations in Venice and El Segundo. African Americans are mainly concentrated in the interior of Los Angeles, but some higher concentrations reside in San Pedro, Wilmington and Long Beach (the latter is outside of the City of L.A.'s boundaries) (Figure 8).

Geography of Race in L.A. by Percent of Total Population

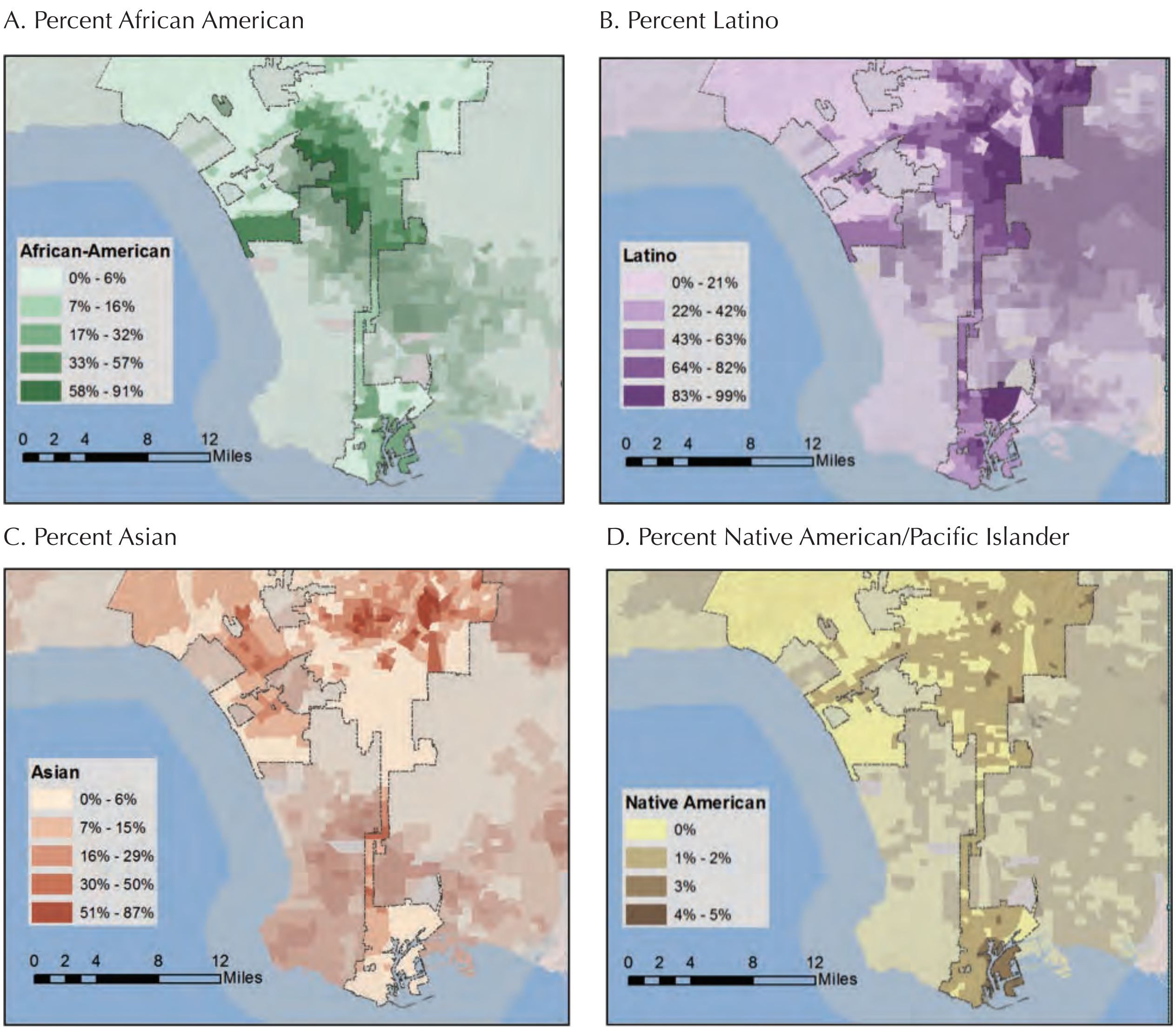


Figure 8: Figures showing the geography of race in Los Angeles by percentage of the total population. The boundaries of the City of Los Angeles are indicated by the black dashed line (Source: Census 2010).

Similarly, low education levels and linguistic isolation (defined by the U.S. Census Bureau, as a household in which no one over the age of 14 speaks English or speaks English less than "very well") leads to lower adaptive capacity by limiting the household's ability to obtain and understand emergency preparedness and response information. Census data in San Pedro and Wilmington show high proportions of Latino populations that are linguistically isolated. Identifying populations that are more vulnerable because of these factors (low education level, race and linguistic isolation) can inform emergency response planning for flooding and help to develop communication strategies to engage community members in the climate adaptation planning process.

Other vulnerable communities include segments of the population that may need special assistance in emergencies because of lack of mobility or other disadvantages. These include the elderly, homeless, those with physical or mental illness or disabilities, and those living in group quarters. An important first step in preparing special assistance for these populations during emergency situations is to document where they reside so first responders understand the extent of the need and can direct assistance appropriately when the time comes.

Beyond examining census data in isolation, in recent years, a number of tools and indices have been developed that identify communities' social vulnerability to various hazards. The social vulnerability index (SOVI), a method developed by Susan Cutter and colleagues at the University of South Carolina, integrates 32 census variables to create a picture of relative social vulnerability within a given region

Social Vulnerability Index (SOVI) Results for the City of L.A.

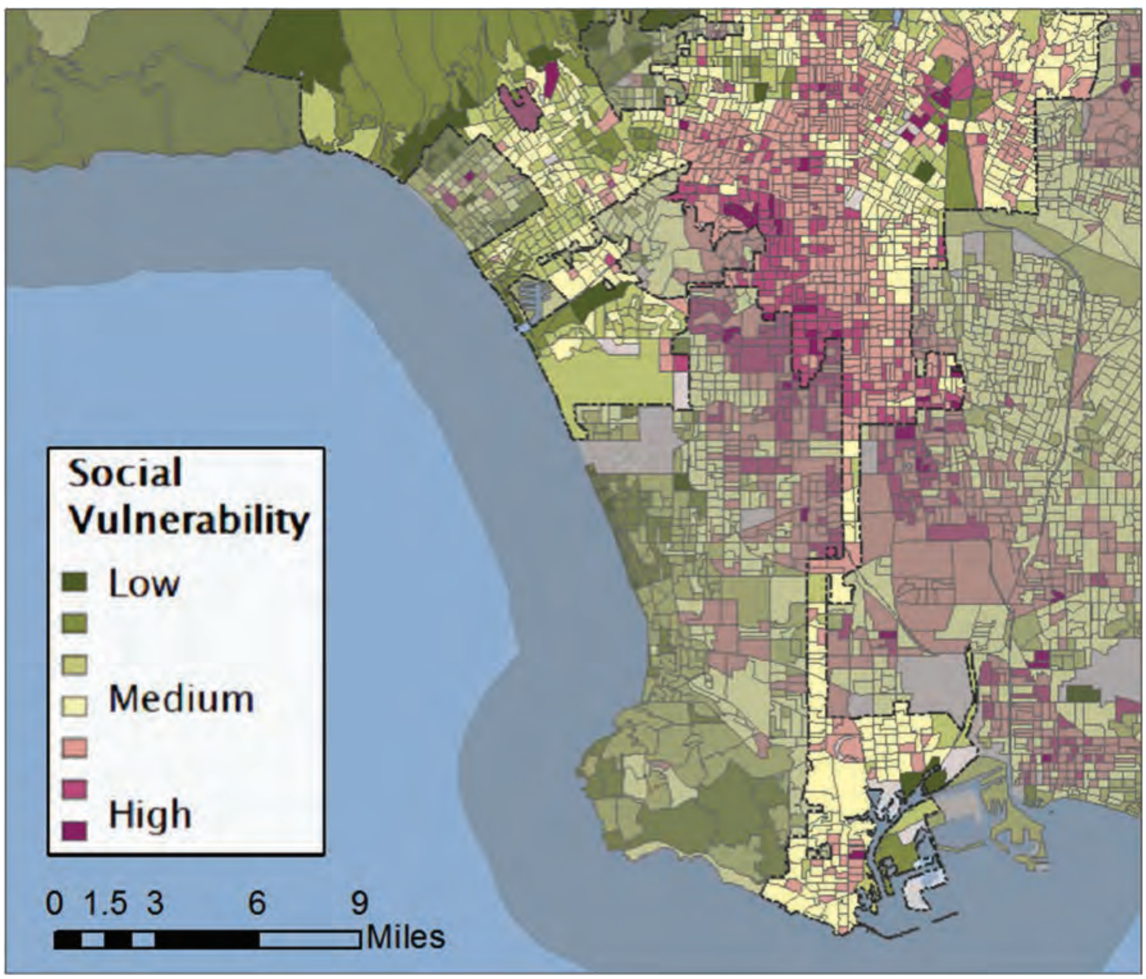


Figure 9: The social vulnerability index (SOVI) provides an integrated view of a population's social vulnerability. The index integrates 32 socioeconomic and demographic variables. (Source: Census 2000 data, Integrated summary provided by NOAA Coastal Services Center).

(Cutter et al. 2003). It does not integrate physical climate change factors, thus providing an objective snapshot of where the populations reside that are associated with low adaptive capacity and high sensitivity to hazardous events. Based on these data, portions of San Pedro, Wilmington and a portion of Venice show relatively high social vulnerability compared to the rest of the City (Figure 9).

The results of the integrated SOVI analysis provide the same snapshot of vulnerability as the analysis of specific census data sets. That is, the communities of Wilmington, Venice, and low-lying portions of San Pedro, seem to have the highest social vulnerability with respect to sea level rise impacts.

Other social characteristics presented by Ekstrom and Moser that indicate high vulnerability include housing type and control over living situation. Census data show a high proportion of older housing units, which may be more sensitive to flooding (e.g., less restrictive building codes, less flood-proofing), in Venice and in neighborhoods around the Port of Los Angeles. These same communities have a high proportion of renters (over 80% in Wilmington and eastern portions of San Pedro and 45 - 80% in Venice), who tend not to have the means or incentive to flood-proof their homes.

The social vulnerability assessment also reveals that a number of community services and supporting infrastructure are potentially at risk of impairment from short-term or long-term damage from flood events as sea level rises. These include impairment of drainage and treatment of wastewater and sewage, rapid emergency response, access to food and prescription medicines, risk of salinization to coastal groundwater reservoirs, access to and functionality of energy-related facilities, transmission and transformers, and important ecosystem services. Interruption of these services can have disproportionate impacts on residents who are more sensitive and have lower adaptive capacity for dealing with flooding as sea level rises.

This assessment thus allows the City to begin to identify adaptation and communication strategies that target these populations. Strategies can include: documenting where these vulnerable populations reside, so first responders understand the extent of the need and can direct assistance appropriately when the time comes; conducting workshops and preparing other public outreach materials in multiple languages; and, given low education and high poverty levels, using alternative educational/informational methods that do not require literacy or internet access.

Economic Vulnerability Assessment

USC Sea Grant commissioned Dr. Dan Wei and Dr. Sam Chatterjee from the USC Price School of Public Policy to conduct a preliminary analysis of the potential economic impact of sea level rise on the City of L.A. (see Appendix 4 for full report).

In this study, the researchers analyzed temporary flooding in the coastal zone caused by extreme coastal storms (10-year and 100-year flood event scenarios) and sea level rise increase of 0.5 m from 2000 - 2050 and 1.4 m from 2000 - 2100. The study focused on the coastal regions within the City that are directly affected by coastal flooding events (Pacific Palisades, Venice/Playa del Rey, and San Pedro/Wilmington).

Economic impacts evaluated in this study included property losses (building and content losses), as well as direct and indirect business interruption losses due to extreme coastal flooding events. Indirect business interruption losses included not only the multiplier (ripple) effects of the direct business interruption losses taking place within the City, but also the indirect effects to the City stemming from the losses to the coastal regions that are outside of the City but within the boundaries of L.A. County. Potential impacts to the transportation and utility systems were evaluated. Impacts caused by long-term and permanent beach area losses from sea level rise were not covered in this study.

The analysis in the study was performed based on the application of two modeling tools. HAZUS MH 2.1, the Federal Emergency Management Agency's (FEMA) standardized modeling tool for estimating potential losses from hazards, was used to evaluate the property damage to building stocks (including both buildings and their contents) and the direct business interruption losses in the flooding affected region. The Input-Output (I-O) model, one of the most widely used tools for analyzing regional impacts, was then applied to calculate the total business interruption losses based on the direct loss estimates from the HAZUS model.[6]

Based on the researchers' analysis, the potential direct building-related losses could be substantial. Direct property losses with respect to buildings include: 1) building repair and replacement costs (including both structural and non-structural damage); 2) building contents losses; and 3) building inventory losses. The results indicate that the expected general building losses increase with sea level rise and the severity of the flooding. For a 10-year flood event, the total building losses are $242.7 million under baseline conditions. The losses increase to $410.3 million in the 0.5 m sea level rise scenario, and to $714.9 million in the 1.4 m sea level rise scenario. For a 100-yr flood event, the building losses increase from $588.6 million under current conditions to $820.2 million and $1,441.3 million in the 0.5 m and 1.4 m sea level rise scenarios, respectively. Losses to residential buildings account for about 50% of the total losses. The other 50% losses are split evenly between the commercial buildings and the industrial buildings in all the scenarios except for the scenario of a 100-yr flood with 1.4 m sea level rise (Table 1).

Notably, and consistent with findings from the physical vulnerability assessment, the researchers found that flood events with the two sea level rise scenarios simulated in this study would only cause very limited impacts to the utility systems. According to their simulation, in the worst case scenario (the 100-year flood event in the 1.4 m sea level rise scenario), there are only moderate damages to two

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[7.] Please refer to the full study for more specific information on the modeling analysis tools utilized (see Appendix 4).

Category	Baseline Conditions		0.5 m Sea Level Rise		1.4 m Sea Level Rise	
	10-yr Flood	100-yr Flood	10-yr Flood	100-yr Flood	10-yr Flood	100-yr Flood
Building Losses	$103.3	$260.9	$179.4	$364.4	$315.0	$649.9
Content Losses	$132.6	$312.1	$219.6	$435.5	$380.2	$759.9
Inventory Losses	$6.8	$15.5	$11.3	$20.3	$19.7	$31.5
Total Building Losses	$242.7	$588.6	$410.3	$820.2	$714.9	$1,441.3

Table 1. This table presents the summary results of general building losses in millions of 2010 $US. (Table from Wei & Chatterjee Economic Vulnerability Assessment, Appendix 4).

Category	Baseline Conditions		0.5 m Sea Level Rise		1.4 m Sea Level Rise	
	10-yr Flood	100-yr Flood	10-yr Flood	100-yr Flood	10-yr Flood	100-yr Flood
Output Losses	$3.4	$7.4	$5.8	$10.5	$9.1	$21.9
Income Losses	$2.3	$4.9	$3.8	$6.6	$5.9	$13.6
Employment Losses	24	52	41	74	64	158

Table 2. This table presents the summary of business interruption losses in millions of 2010 $US (output/income losses) and number of jobs (employment losses). (Table from Wei & Chatterjee Economic Vulnerability Assessment, Appendix 4).

wastewater treatment facilities and three oil refineries. The simulations indicate no damages in all the scenarios for other critical lifeline facilities, including water, natural gas, and electricity. In examining business interruption losses, the simulation suggested that for a 10-year flood event, the total output losses (i.e., total business interruption losses) increase from $3.4 million under current conditions to $5.8 million in the 0.5 m sea level rise scenario, and to $9.1 million in the 1.4 m sea level rise scenario. For a 100-year flood event, the output losses increase from $7.4 million under current conditions to $10.5 million in the 0.5 m and $21.9 million in the 1.4 m sea level rise scenarios (Table 2). The impacts to income and employment have similar patterns across the scenarios. The major reason for the relatively low business interruption losses caused by the coastal flood events is that over 95% of the damaged buildings are residential buildings, rather than buildings of producing sectors. Another reason for the relatively low business interruption losses is the HAZUS model has taken into consideration likely production recapture. This refers to the ability of businesses to recapture lost production through overtime and extra shifts until operational capability is restored.

The researchers emphasize that the potential economic impacts of sea level rise to the City in their analysis should be considered to be on the conservative side. The analysis only focuses on the potential impacts from the temporary flooding in the coastal area due to extreme coastal storms, and how those impacts can be amplified by sea level rise. Any impacts caused by long-term and permanent coastal erosion and beach area losses were not covered in this study. Also, the researchers did not perform further economic impact analysis on the potential damages to the transportation system. While the preliminary simulation results indicated there are minimal impacts to the transportation system in the City, analysis under the Physical Vulnerability Assessment found that city roads are vulnerable to flooding, inundation, and groundwater inflow. Further economic studies to assess potential impacts on tourism, transportation systems, goods movement, and the regional economy would help to elucidate a more robust picture of potential impacts. At the same time, addressing the impacts of which we are aware could be viewed as strengthening resilience and therefore maintaining a strong economic climate in Southern California.

Ecological Vulnerability Assessment

Most of the coastal zone in the City of L.A. is highly urbanized. The vulnerability of the least urbanized areas such as open space areas, parks or recreation centers, was assessed in the physical vulnerability assessment conducted by ICLEI (Appendix 2). While most of the beaches along the coast, with the exception of Cabrillo Beach, fall within city lines, these are primarily managed by L.A. County's Department of Beaches and Harbors. Therefore, these resources were not analyzed directly in this vulnerability assessment. We anticipate that these resources will be studied more thoroughly when the planning process is expanded to include other coastal cities and L.A. County, through collaboration with LARC and coastal cities.

However, it is necessary to highlight one very important ecological asset located within City boundaries: the Ballona Wetlands Ecological Reserve. Ballona Wetlands Ecological Reserve is located between Marina del Rey and Playa Del Rey (the del Rey bluff) at the estuary of Ballona Creek (Figure 10). It is a 600-acre ecological reserve mostly owned by the State of California with a portion of the site in unincorporated L.A. County and the rest in the City of L.A. Elevation varies and ranges from 0 to 25 feet above sea level. Remnant areas of the wetland complex also include Del Rey Lagoon, Ballona Lagoon, Marina del Rey, Oxford Basin, and the Venice Canals.

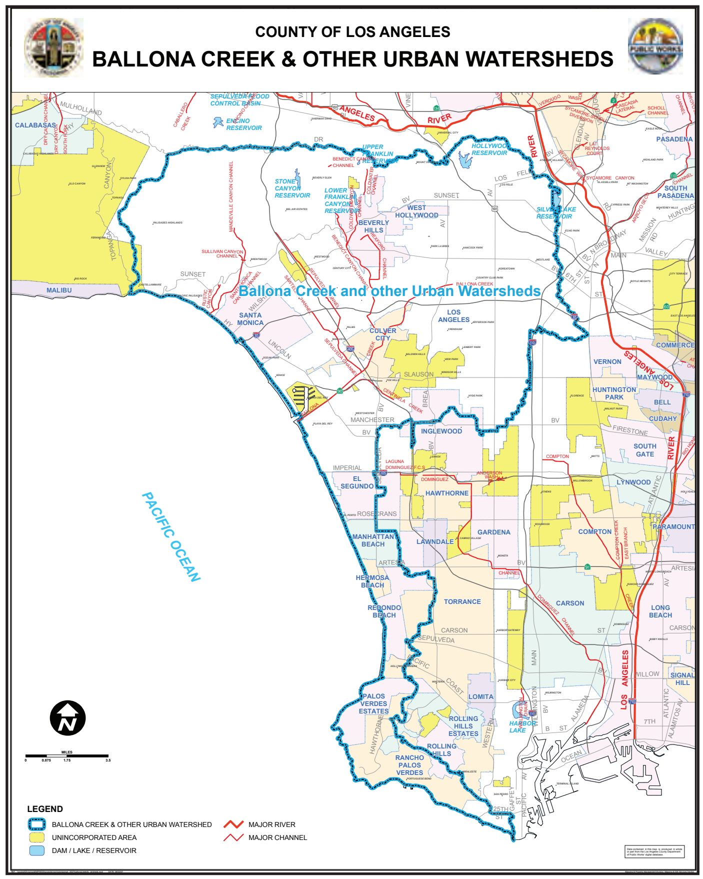

Figure 10: Map of the Ballona Creek Watershed. (Map courtesy of L.A. County Department of Public Works: http://ladpw.org/wmd/watershed/bc/).

The Ballona Wetlands is the largest remaining coastal wetland within urban L.A. County and is an ecological treasure. It supports a range of habitats and functions, including estuarine-dependent plants and animals and creates opportunities for aesthetic, cultural, recreational, research and educational uses by people throughout the region.

Researchers from Loyola Marymount University and the Santa Monica Bay Restoration Foundation (SMBRC), with funding from the Environmental Protection Agency's Climate Ready Estuaries Program, recently conducted a study to understand the climate change implications for Ballona Wetlands Restoration (Bergquist et al. 2012). This included an analysis of the impacts of 0.5 m and 1.4 m sea level rise with a 100-year storm scenario.[7]

It was determined that an increase in frequency, duration, and intensity of storm events would cause flooding over the current flood control levee structures that divide Ballona Creek from the

[8] *Climate Change Implications for Ballona Wetlands Restoration* study was not funded by the City of L.A. or USC Sea Grant; thus, it was not included in the appendix of this report. If readers are interested in this research, the study report can be accessed at http://www.santamonicabay.org/ballonarestoration.html. For further information, contact USC Sea Grant (seagrant@usc.edu) or SMBRC (http://www.santamonicabay.org/).

Reserve. The levees are not currently sufficient to support a 100-year storm event. This flooding could cause significant impacts to the habitats currently within the Reserve. Furthermore, extreme wet weather will cause additional flooding in developed areas and roadways adjacent to the site boundary that are below sea level and currently experience flooding in wet weather conditions (e.g. Culver Boulevard and Playa Del Rey).

Ballona Wetlands Ecological Reserve. (Photo credit: Lisa Fimiani, http://www.cooperecological.com/BallonaBirds.htm).

Additionally, the current western wetland habitats of the Reserve receive muted tidal flooding via self-regulated tide gates. Sea level rise would reduce the functionality of these gates, resulting in altered hydrology and tidal influence. Significant sea level rise would prevent the tide gates from functioning at all and would allow no tidal influence to remain to the wetland habitats. This altered hydrology and freshwater influence would have significant effects on the habitat types, salinity, and current ecosystem of the area. To alleviate the predicted impacts of sea level rise on the restored wetlands, planners and land managers may want to consider a restoration alternative that can accommodate the transgression of habitats upslope.

Although the City of Los Angeles does not manage Ballona Wetlands, this wetland is an important ecological resource for the City, which provides a plethora of ecosystem services including, but not limited to, biological productivity energy flow, nutrient cycling, foraging, nursery, and sheltering and resting places for wildlife, sediment accretion, and wave attenuation. Another important and well-known function of the wetlands is water purification such as infiltrating and thereby treating runoff and stormwater from the watershed upstream. As such, it is in the interest of the City to ensure that the wetland is protected and that it is involved in identifying any adaptation strategies and plans.

Moving Forward - Guidance for Developing Adaptation Measures

The main purpose of this report is to provide information on the vulnerabilities the City of L.A. currently faces and may face in the future due to sea level rise. Understanding these vulnerabilities is an important first step toward preparing to meet the challenges of climate change. The next milestone is to begin to identify appropriate adaptation strategies. To help the City of L.A. move forward on this next step, in this section, we review several important considerations for the development of adaptation strategies and provide a matrix of possible coastal adaptation strategies.

Considerations for Development of Adaptation Strategies

Invest in a Strong Foundation for Climate Adaptation

Climate adaptation is a complex process, involving decision-makers at all levels of government (even if the focus of adaptation is a local community), as well as in civil society and the private sector. As we have noted throughout this study, we advocate a model of "adaptive adaptation planning." This means that adaptation planning is not a one-time effort; it requires periodic updates of information to correspond with the latest scientific understanding and needs to include this new information in the decision-making process. Ideally, the process goes far beyond technical and structural actions, and involves policy changes, creative financing, capacity-building among key staff and decision-makers, and effective public engagement.

At this early stage in sea level rise adaptation, it is important to lay a strong foundation for such an ongoing planning process. Elements of such a foundation could include:

- Acquiring the best available science and developing a formal strategy for regular updates of scientific information in planning and decision-making procedures;

- Investing in engineering and geotechnical studies for vulnerable assets that require technical approaches (e.g. as noted in the physical vulnerability assessment for Bureau of Sanitation, engineering studies that include assumptions about flood depth and duration would help to refine an evaluation of adaptive capacity);

- Conducting robust and thorough risk analyses;

- Assessing and ascertaining the information needs of local government departments, agencies, commissions, and boards as well as their capacity and willingness to integrate sea level rise vulnerability and social vulnerability into their planning, budgetary, and policy decisions;

- Initiating 'soft' adaptation strategies, such as staff training, developing trusting relationships with community organizations, identifying and supporting local champions in government, business, and civic organizations, and building governance structures across sectors and jurisdictions to increase adaptive capacity, foster buy-in, and generate the necessary institutional and political support (Cicin-Sain et al. 1998);

- Creating opportunities to foster periodic, meaningful public engagement that gathers information about affected neighborhoods and communities' concerns, vulnerabilities, and constraints; to educate communities about risks related to climate change; and to jointly develop strategies that are designed to meet current and future needs. Such engagement should also offer opportunities for communities to express any concerns and needs around procedural justice and equitable burden sharing and outcomes of adaptation.

Define Clear Adaptation Goals

Most adaptation planning processes to date in the U.S. have been undertaken without clearly defining goals and "success." Goals could focus on both procedural and outcome intentions. Failing to define success has several important implications directly relevant to local decision-making: it is difficult to prioritize and justify expenditures when a goal or purpose is not identified, and it is politically difficult to justify when people cannot visualize the intended outcome (even if just a temporary outcome). It is also difficult to show that a strategy made a positive difference or to measure progress toward the desired goal. The City would therefore be well advised in not just stating a "pie in the sky" goal, but to spend concerted effort both internally and with community involvement to define desirable and feasible outcomes of adaptation. Effective strategies flow more easily from clearly identified goals.

Develop Clear Prioritization and Selection Criteria for Choosing Among Possible Adaptation Strategies

A corollary to the need for a clearly defined goal is the establishment of criteria that help select options from the universe of potential adaptation strategies. Such criteria would help with prioritization when budgets, timelines, technical considerations, and social concerns and political feasibility inevitably place constraints on preferred solutions. Again, such criteria are best selected in consultation and agreement with affected stakeholder communities, as exclusion from defining how decisions will be made can lead to political resistance and lack of buy-in. That, of course, could endanger the ultimate success of the entire effort.

Continue "Adaptive Adaptation Planning" Approach

As stated in this report, the use of a 10-year flood scenario with sea level rise was a pragmatic choice in light of the best available, most defensible physical science at this time. Ten-year floods, however, are not the common planning standards (100- and 500-year floods are benchmarks for FEMA, for example). In addition, sea level rise scenarios may change over time; as the science advances, so will decisions about land use, the level of coastal protection, and the demographic and socioeconomic situation of coastal populations. Thus, the City would be well advised to closely track scientific developments and update the current vulnerability assessment as needed to ensure its adaptation plans and preparedness measures are up-to-date.

Expand Partnerships in Developing Adaptation Options

Much adaptation that addresses social vulnerability and public concerns requires close collaboration with the affected groups. Thus, to the extent collaborative ties are not yet established, it is important to establish working relationships with marginalized groups or organizations that represent them, and to expand the network of adaptation stakeholders to include those already working on increasing community resilience in the face of disasters. Doing this early in the process helps to build the trust and long-lasting bonds that will be needed to make difficult choices.

LARC
Los Angeles Regional Collaborative for Climate Action and Sustainability

The Los Angeles Regional Collaborative on Climate Action and Sustainability (LARC) is an important partner of the City's effort and will serve to help expand partnerships within the region by applying the techniques and strategies to the hazards posed in the other coastal communities and municipalities through greater Los Angeles.

Matrix of Potential Coastal Adaptation Strategies

The matrix provided on pages 60-76, developed by Lesley Ewing (California Coastal Commission) and Dr. Reinhard Flick, outlines some of the most common coastal adaptation techniques available to coastal communities. This matrix is divided into adaptation techniques that help communities:

- Avoid hazards;
- Move development away from hazards;
- Move hazards away from development;
- Provide barriers between hazards and development; and
- Flood-proof.

For each of these sub-categories, information is provided on the details of the technique, the spatial and temporal scales associated with the technique, the ability to adjust the technique depending on changing conditions (referred to in the matrix as “adaptive capacity”), the party or agency that would be responsible for managing the adaptation technique, a relative approximation of costs (e.g. high, medium or low), and general comments.

This matrix is intended to provide insight into the available options for communities and help the community better understand the described technique. In considering any of these options for application in the adaptation planning effort, each should be analyzed for the site-specific conditions, environmental concerns, technical feasibility and compatibility with existing constraints. Clearly, not all techniques are available for all situations; rather, this matrix is meant to provide a range of adaptation response options.

A Google Earth image of heavy rock armoring along PCH in Malibu. Rock armoring is one of the many adaptation strategies described in the matrix on pages 67-83.

Avoid Hazards

General Techniques	Technique Details	Spatial Scale	Temporal Scale (Implement/ Effective)	Adaptive Capacity	Responsible Party	Costs	Comments
Land Acquisition	Fee Simple Acquisition	One or more lots	Short/ Long-term	Yes	Government, Non-Governmental Organization, Homeowner Association, Geologic Hazard Abatement District	High	Provides greatest control over land use and hazard response. Land can be purchased from willing sellers or by governments using eminent domain.
	Conservation Easements	One or more lots	Short/ Long-term – lessen with time	Yes	Government, Non-Governmental Organization, Homeowner Association, Geologic Hazard Abatement District	Low to Moderate	Provides less control than fee simple acquisition. Can be part of a permit action. Land can be purchased from willing sellers.
	Transfer Development Credit	Jurisdiction, Region	Moderate/ Long-term	Yes	Government, Geologic Hazard Abatement District	Low to Moderate	Provides fee simple acquisition of high hazard lots. Takes time to set up TDC Program and develop criteria for hazardous lot acquisitions. Costs to administer are low. Acquisition costs paid by developers. Cost of coastal land may make program infeasible.

Move Development Away from Hazards

General Techniques	Technique Details	Spatial Scale	Temporal Scale (Implement/ Effective)	Adaptive Capacity	Responsible Party	Costs	Comments
Land Acquisition	(see above)						
Managed Retreat		One or more lots	Moderate/ Long-term – Increase with time	Yes	Government, Homeowner Association, Geologic Hazard Abatement District	Moderate	Best if included in initial design to allow phased removal of development. Costs paid by owners with or without government or non-profit contributions.
Rolling Easements		One or more lots	Moderate/ Long-term – Increase with time	Yes	Government, Non-Governmental Organization, Homeowner Association, Geologic Hazard Abatement District	Moderate to high	Easements acquired by government or NGO. Costs to acquire will be likely to vary indirectly with risk.
Setbacks		One or more lots	Moderate/ Long-term – Lessen with time	Not normally	Government, Homeowner Association, Geologic Hazard Abatement District	Low	Setback provides protection from hazard until setback is gone. Variable cost to developer and/or homeowner - foregoing use of some portions of the property.
Elevation		One or more lots	Moderate/ Long-term – Lessen with time	Not normally	Government, Homeowner Association, Geologic Hazard Abatement District	Low to moderate	Elevation provides protection from ocean hazards. May introduce other risks from slope instability, etc. Need to include access and utilities for long-term effectiveness.

Move Hazards Away from Development

General Techniques	Technique Details	Spatial Scale	Temporal Scale (Implement/ Effective)	Adaptive Capacity	Responsible Party	Costs	Comments
Maintain or Restore Natural Sand Supply	Remove dams	Region/ watershed	Long time/ Long-term	No	Government, Water Board, Non-Governmental Organization	High to Very High	Only effective if stream flows are sufficient to move sediment to the coast. Raises difficult engineering issues if sand must be moved to the coast. Involves multiple jurisdictions. But, dam removal is occurring with as yet unknown benefits.
	By-pass sand around dams	Region/ Littoral cell	Moderate/ As long as continued	Yes	Government, Water Board	High to Very High	Only effective if stream flows are sufficient to move sediment to the coast. Raises difficult engineering issues if sand must be moved to the coast. Feasibility for large volumes is unlikely, since sand transportation cost to the coast is high, and may have unacceptable traffic and air quality impacts as well as barriers to truck access at the beach.

Move Hazards Away from Development (continued)

General Techniques	Technique Details	Spatial Scale	Temporal Scale (Implement/ Effective)	Adaptive Capacity	Responsible Party	Costs	Comments
Maintain or Restore Natural Sand Supply	Harbor dredging or By-passing	Region/ Littoral Cell	On-going/ As long as continued	Yes	Government, Harbor district	Moderate to High	Dredging is often necessary for harbor maintenance. Historically, this has been a major source of nourishment sand in certain locations. Testing and placing sand on beaches often adds only a marginal cost.
Improve or Augment Sand Supplies/ Beneficial Reuse of Sand	Interrupt rip currents	Local	Long time/ As long as continued	Yes	Government	High	Complex engineering issue. Unlikely to be feasible even for fixed rip currents located at structures or geomorphic features. This is an unproven idea likely not suitable to high tide-range environments with public opposition to surf-zone structures and likely high cost. Effects would be similar to offshore breakwaters with less guarantee of success.
	Nourish with coarser sand than native	Multiple lot/ Region	Moderate/ As long as continued	Yes	Government, Non-Governmental Organization, Homeowner Association, Geologic Hazard Abatement District	High	This approach is widely used by engineers to increase the lifetime of beach replenishment projects. Feasibility depends on availability of suitable sand sources.

Move Hazards Away from Development (continued)

General Techniques	Technique Details	Spatial Scale	Temporal Scale (Implement/ Effective)	Adaptive Capacity	Responsible Party	Costs	Comments
Improve or Augment Sand Supplies/ Beneficial Reuse of Sand	Canyon Interceptors	Region/ Littoral Cell	Long time/ As long as continued	Yes	Government	Very High	Complex and unproven engineering concept that would need detailed studies to determine feasibility. Likelihood of success is not knowable since the amount of offshore sand loss in canyons versus offshore losses along the beach is unknown.
Sources of Beach Material	Offshore Sand	Multiple lot/ Region	Short to moderate/ As long as continued	Yes		Moderate to High	Costs very dependent on scale --- mobilizing the dredge is a fixed cost regardless of volume delivered.
	Reservoir and Debris Basins	A few lots to multiple lots	Moderate/ As long as continued	Yes		High to extreme	Sand testing important. Sorting and handling costs can be large. No unit savings on transport costs with larger volumes moved. Feasibility is unlikely for large volumes, since sand transportation cost to the coast is high, and may have unacceptable traffic and air quality impacts as well as barriers to truck access at the beach. Involves multiple jurisdictions.

Move Hazards Away from Development (continued)

General Techniques	Technique Details	Spatial Scale	Temporal Scale (Implement/ Effective)	Adaptive Capacity	Responsible Party	Costs	Comments
Sources of Beach Material	Back-passing	Region/ Littoral Cell	Moderate/ As long as continued	Yes		Moderate to high	Sand quality normally compatible with existing beach material. This method holds promise since fixed plants can be used and engineering basis is relatively simple.
	Cobbles	A few lots to multiple lots	Moderate to long/ As long as continued	Yes		High to Very high	Cobble sources are limited. Poses environmental concerns for beaches without existing cobble.
	Crushed glass	A few lots to multiple lots	Moderate to long/ As long as continued	Yes		Very high	Crushed glass would need to be tumbled to round off sharp edges. Handling costs would be high.
Retention of Sand/Beach Material	Beach Berms	A few lots to multiple lots	Short/ As long as continued	Yes	Government, Non-Governmental Organization, Homeowners Association, Geologic Hazard Abatement District	Low	May need to be repeated multiple times a season. Source of sand should be identified. State sovereign land issues arise.

Move Hazards Away from Development (continued)

General Techniques	Technique Details	Spatial Scale	Temporal Scale (Implement/ Effective)	Adaptive Capacity	Responsible Party	Costs	Comments
Retention of Sand/Beach Material	Groins	Region/ Littoral Cell	Long/ Moderate to long	Yes	Government, Homeowners Association, Geologic Hazard Abatement District	Very high	Engineering issue. Pre-fill likely to be required to minimize downcoast impacts. Sensitive to orientation of waves and sediment supplies and transport direction and magnitude. Public opposition to structures is an issue that needs to be solved.
	Jetties	Region/ Littoral Cell	Long/ Long	No	Government, Harbor District	Very High	Engineering issue. Normally only used at river mouths and harbor entrances. Public opposition to structures is an issue that needs to be solved.
	Dune Nourishment	A few lots to multiple lots	Moderate/ As long as continued	Yes	Government, Non-Governmental Organization, Homeowners Association, Geologic Hazard Abatement District, individual		Limited application in CA, since few beaches depend on dune storage of sand, especially in southern California.

Move Hazards Away from Development (continued)

General Techniques	Technique Details	Spatial Scale	Temporal Scale (Implement/ Effective)	Adaptive Capacity	Responsible Party	Costs	Comments
Retention of Sand/Beach Material	Breakwaters	Region/ Littoral Cell	Long/ Long	No	Government, Harbor District	High	Proven effective and feasible. Public opposition to structures, especially ones that directly impact surfing, is an issue that needs to be solved. Presents potential swimming and boating safety hazards. Construction cost is high, but benefits are long-term. Santa Monica Breakwater is about 80 years old and functions well with little maintenance.

Move Hazards Away from Development (continued)

General Techniques	Technique Details	Spatial Scale	Temporal Scale (Implement/ Effective)	Adaptive Capacity	Responsible Party	Costs	Comments
Innovative Options for Retention of Sand/Beach Material	Perched beach	A few lots to multiple lots	Long/ Long	No	Government, Non-Governmental Organization, Homeowners Association, Geologic Hazard Abatement District, individual		May require frequent re-nourishment. Also can produce negative consequences if large storm waves remove sand shoreward of perching structure that then cannot migrate back upslope onto the beach. Can modify offshore slope and pose a danger to swimmers. Also reduces circulation in the perched beach area, leading to water quality and sand contamination issues.
	Artificial seaweed	Region		Possible	Government, Non-Governmental Organization, Homeowners Association, Geologic Hazard Abatement District, Individual	Low to high	Never shown to be effective in field tests, and almost certainly cannot be effective due to low mass in high wave and tide-range environment. Clean up costs can be high.

Move Hazards Away from Development (continued)

General Techniques	Technique Details	Spatial Scale	Temporal Scale (Implement/ Effective)	Adaptive Capacity	Responsible Party	Costs	Comments
Innovative Options for Retention of Sand/Beach Material	Artificial headland	Region/ Littoral Cell		No	Government	Very high	Complex engineering; experimental effort. Likely to be effective and feasible if designed to function like a groin or jetty. Public opposition to structures, especially ones that impact beach access or surfing, is an issue that needs to be solved.
	Delta augmentation	Region/ Littoral Cell		Possible	Government	Very high to extreme	Complex engineering; experimental effort unproven in practice. Would require large additions of material spread over large area, and may require multiple additions of material.
	Active Beach dewatering	A few lots to multiple lots	Short to moderate/ As long as continued	Yes	Government, Non-Governmental Organization, Homeowners Association, Geologic Hazard Abatement District, Individual	Moderate	Principle is sound. Would be a localized effort. Only financially feasible if co-located with other active dewatering, such as desalination plants. May have consequences on other beach communities downcoast. No long-term results known in the reviewed engineering literature.

Move Hazards Away from Development (continued)

General Techniques	Technique Details	Spatial Scale	Temporal Scale (Implement/ Effective)	Adaptive Capacity	Responsible Party	Costs	Comments
Innovative Options for Retention of Sand/Beach Material	Passive beach dewatering	A few lots to multiple lots	Short/ As long as maintained	Yes	Government, Non-Governmental Organization, Homeowners Association, Geologic Hazard Abatement District, Individual	Low	Passive beach dewatering has never been successfully demonstrated.
	Floating breakwaters	Region/ Littoral Cell	Short to moderate/ Moderate	Slightly	Government	High	Complex engineering, but proven principle. Most uses have been for temporary protection or ship deployment.
	Multi-purpose reefs	Region/ Littoral Cell	Long/ Moderate to long	No	Government	High to very high	Complex engineering; experimental efforts. Costs to remove have proven to be very high (i.e., Pratte's Reef). Engineering criteria conflict for dual-use surfing-shore protection reefs because of high tide range in CA. Reef must be low to enable surfing at most tide elevations, but high to protect property during high wave and tide events.

Barriers between Hazards and Development

General Techniques	Technique Details	Spatial Scale	Temporal Scale (Implement/ Effective)	Adaptive Capacity	Responsible Party	Costs	Comments
Revetments	Rock	One or more lots	Moderate/ Moderate	Possible if part of initial design	Government, Non-Governmental Organization, Homeowners Association, Geologic Hazard Abatement District, Individual	High	High impact on beach areas short and long-term, including passive erosion. Changes habitat along a sandy shoreline. Public opposition to structures, especially ones that impact beach access is an issue that needs to be solved.
	Concrete units	One or more lots	Moderate/ Moderate	Possible if part of initial design	Government, Non-Governmental Organization, Homeowners Association, Geologic Hazard Abatement District, Individual	High	High impact on beach areas short and long-term, including passive erosion. Changes habitat along a sandy shoreline. Also, public opposition (see above).
	Gabions	One or more lots	Moderate/ Short	Possible, but not likely	Government, Non-Governmental Organization, Homeowners Association, Geologic Hazard Abatement District, Individual	Moderate to high	High impact on beach areas short and long-term, including passive erosion. Changes habitat along a sandy shoreline. Poor long-term performance due to weaknesses in netting. Also, public opposition (see above).

Barriers between Hazards and Development (continued)

General Techniques	Technique Details	Spatial Scale	Temporal Scale (Implement/ Effective)	Adaptive Capacity	Responsible Party	Costs	Comments
Seawalls	Vertical tie-back walls	One or more lots	Moderate/ Moderate	Possible if part of initial design	Government, Non-Governmental Organization, Homeowners Association, Geologic Hazard Abatement District, Individual	High	Low initial impact on beach, high long-term passive-erosion impact. Also, public opposition (see above).
	Gravity walls	One or more lots	Moderate/ Moderate	Possible if part of initial design	Government, Non-Governmental Organization, Homeowners Association, Geologic Hazard Abatement District, Individual	High	High impact on beach areas short and long-term, including passive erosion. Also, public opposition (see above).
	Cantilever walls	One or more lots	Moderate/ Moderate	Possible if part of initial design	Government, Non-Governmental Organization, Homeowners Association, Geologic Hazard Abatement District, Individual	High	Low initial impact on beach, high long-term passive-erosion impact. Also, public opposition (see above).

Barriers between Hazards and Development (continued)

General Techniques	Technique Details	Spatial Scale	Temporal Scale (Implement/ Effective)	Adaptive Capacity	Responsible Party	Costs	Comments
Miscellaneous	Native vegetation	One or more lots	Short/ As long as continued	Yes	Government, Non-Governmental Organization, Homeowners Association, Geologic Hazard Abatement District, Individual	Low	Not useful by itself on the CA moderate-wave energy and high tide-range coast. Normally used as part of a larger sand nourishment project to stabilize back shore.
	Sea cave fills	One or more lots	Moderate/ Moderate	No	Government, Non-Governmental Organization, Homeowners Association, Geologic Hazard Abatement District, Individual	Low to moderate	Can slow erosion in areas with bluff undercutting or cave formation. Proven feasible and cost effective. Low initial impact on beach, high long-term passive-erosion impact. Also, public opposition (see above).
	Surface & ground water controls	One or more lots	Short/ As long as continued	Yes	Government, Non-Governmental Organization, Homeowners Association, Geologic Hazard Abatement District, Individual	Low	Normally used as part of a larger project. Proven feasible and effective (even necessary) to reduce or prevent sudden cliff collapse. Not usually considered a form of beach sand erosion control.

Flood Protection

General Techniques	Technique Details	Spatial Scale	Temporal Scale (Implement/ Effective)	Adaptive Capacity	Responsible Party	Costs	Comments
Building Protection	Elevate structure	Individual structures	Moderate/ Long-term – Lessen with rising sea level	Not unless part of initial design	Building Owner	Low to Moderate	Elevation can provide protection from flood water if building is high enough. Often includes lower stories with break-away walls that can become floating debris.
	Sand Bags	Individual structures	Short term/ Long-term – lessen with rising sea level	Height will depend on bag stability	Building Owner	Low	Sand bagging can provide short-term protection. Requires warning of impending flood and ability for rapid response prior to the flood event. Interrupts building access while in use.
	Storm shutters	Individual structures	Moderate/ Long-term	Moderate	Building Owner	Low	Storm shutters can be available to cover all openings (normally doors and windows). Requires warning of impending flood to secure all entrances. Interrupts building access while in use.

Flood Protection (continued)

General Techniques	Technique Details	Spatial Scale	Temporal Scale (Implement/ Effective)	Adaptive Capacity	Responsible Party	Costs	Comments
Electrical Equipment	Elevation	Individual structures	Short term/ Long-term	Depends on building height	Building Owner Building Code	Low	Elevation of electrical equipment can insure continuity of power during and after a flood provided equipment can be located higher than flood levels
	Vaults	Individual structures	Short-term/ Long-term	None	Building Owner	Low to Moderate	Vaults would protect electrical equipment from flooding; would need routine maintenance to insure effectiveness when needed.
	Pumps	Individual structures	Short-term/ Moderate	None	Building Owner	Moderate	Useful to remove flood waters from sensitive areas. Require a reliable power source and location to which water can be pumped.

Flood Protection (continued)

General Techniques	Technique Details	Spatial Scale	Temporal Scale (Implement/ Effective)	Adaptive Capacity	Responsible Party	Costs	Comments
Tunnels	Permanent Storm Barriers	Individual systems	Moderate/ Long-term – Lessen with rising sea level	Low	Community/ Project Manager	Moderate	Storm barriers would need to cover all openings – tunnel openings, ventilation, etc. Requires warning of impending flood to secure all entrances. Interrupts access and tunnel use while barriers are in place. Depending upon storage method, they can be an annoyance to travelers when not in use.
	Temporary Entrance covers	Individual structures	Short term/ Long-term – lessen with rising sea level	Low	Building Owner	Low	Entrance covers (sand bags, inflatable plugs, etc,) can provide short-term protection. Requires warning of impending flood and ability for rapid response prior to the flood event. Interrupts tunnel access while in use.

Conclusion

By commissioning these studies and implementing the planning process, the City of L.A. has shown leadership by confronting climate change, and sea level rise specifically, proactively rather than reactively.

We have summarized the findings from a coastal issues report, and three commissioned vulnerability assessments that examined the potential social, physical and economic challenges the City of L.A. may face in the future due to accelerated sea level rise. We also discuss the importance of the Ballona Wetlands Ecological Reserve to the City and the region. We close by providing guidance for moving ahead with identifying the range of appropriate adaptation strategies that will build the City's resilience. The findings in this report, while preliminary, are meant to provide the City with a starting point for planning.

Although the results of this study highlight some of the City's physical, social and economic vulnerabilities, the City is now well poised to begin planning now and not in 20 years when many of the impacts of sea level rise will already be felt. We encourage the City to continue its efforts and to embrace the "adaptive adaptation planning" process in which new science and information is continuously assessed and incorporated. This will allow the City to plan in the efficient manner necessary to tackle the challenges. We also encourage the City to continue its strategy to include stakeholder and public input to the greatest extent possible. With broad public support and a coherent and continuous strategy for confronting change, Los Angeles will continue to serve as a model for other large metropolises facing a changing future.

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Appendices

Appendix 1: City of L.A. Coastal Issues Related to Future Mean Sea Level Rise

CITY OF LOS ANGELES
COASTAL ISSUES RELATED TO FUTURE MEAN SEA LEVEL RISE

Prepared for the
CITY OF LOS ANGELES
Los Angeles, California

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CITY OF LOS ANGELES
COASTAL ISSUES RELATED TO
FUTURE MEAN SEA LEVEL RISE

1 INTRODUCTION

The City of Los Angeles (LA) expects to face numerous planning challenges due to climate change, including from impacts related to increasing sea levels. The City manages critical and valuable infrastructure along the coast, including two sewage treatment plants, two power plants, the Port of Los Angeles, Marina Del Rey small craft harbor, and sandy beaches in Venice and the Marina Peninsula. In addition, critical transportation and utility corridor infrastructure is vulnerable to erosion and flooding damage at Pacific Palisades, and cliff erosion threatens parts of San Pedro. Moreover, there is the threat of saltwater intrusion into the City's groundwater supplies, potentially diminishing already low levels of potable water.

2 CITY OF LOS ANGELES COAST OVERVIEW

Inspection of a map of the Los Angeles city boundaries (Figure 1) shows four distinct coastal regions of the city that are partly separated by other jurisdictions. These are: 1) Pacific Palisades; 2) Venice-Marina Peninsula-Playa Del Rey-LAX; 3) San Pedro (exposed coast); and 4) San Pedro (sheltered)-Wilmington-Terminal Island-LA Harbor. Each region has a unique coastal setting and ocean exposure, and a different history of development and human intervention. For these reasons, each area has a different suite of current coastal problems. Similarly, each area is expected to have dissimilar sensitivity to the effects of future mean sea level rise (MSLR) and so will require different adaptation strategies to remain viable.

Pacific Palisades is a relatively high-relief shoreline with a critical coastal transportation and utility corridor. The viability of Pacific Coast Highway (PCH) is certainly the main concern. The expansive beach area from Venice to the foot of Los Angeles International Airport (LAX) is a low-relief and important recreational and storm-wave protection resource that has been highly modified by human activities since the early 20th century. The ocean-front exposed shore of San Pedro has urban development, and is once again high-relief with unprotected sea cliffs subject to geotechnical instabilities. The sheltered harbor-side of San Pedro with Wilmington and Terminal Island form the Port of LA. It is one of the largest and

most important ports in the world that serves critical local, regional, and national ocean shipping needs and provides large economic benefits. The area is protected by the LA-Long Beach outer breakwater, which has its root at Cabrillo Point. Detailed descriptions of LA shoreline segments are given by Orme (2005) and Sherman and Pipkin (2005).

3 MEAN AND EXTREME SEA LEVEL

Mean sea level (MSL) has risen globally and along the California coast by about 18 cm (0.6 ft, or 7 inches) during the 20th Century. This 1.8 mm/year rise was caused by a combination of ocean volume expansion and addition of fresh water from continental ice melt in response to gradual global warming. The rate of MSL rise (MSLR) has apparently increased to about 3 mm/year since about 1990 owing to greater rates of ice melt. MSL is expected to rise from 0.5-2 m (1.6-6.6 ft) by 2100, which presents a large range of uncertainty (Nicholls *et al.*, 2011; NRC 2012). Interestingly, while global MSLR has accelerated, it has been suppressed along the California coast due to changes in wind patterns over the Pacific Ocean (Bromirski *et al*., 2011). No net increase in sea level has occurred off California since about 1980. However, these wind patterns are expected to reverse over the coming decades and bring a resumption of MSLR in California to at least the global rate (Bromirski *et al.*, 2012). This means that any coastal flooding or erosion over the past 30 years has occurred with a backdrop of essentially no sea level rise, and that these problems can be expected to worsen once MSLR resumes.

On the open coast, beach erosion, structure damages, and facilities flooding are mainly caused by waves and wave-driven runup and overtopping, especially when these coincide with high tides. Storm surges, seasonal sea level cycles, and prolonged, several-year long elevated sea levels related to El Niño conditions are relatively less important, but can nevertheless add up to 0.5 m (1.6 ft) to total water level. On this coast, the extreme tide range is almost 3 m (10 ft) or nearly 1.5 m (4.9 ft) above and below MSL. Large storm waves reaching 8-10 m (26-33 ft) offshore can produce shoreline runup reaching about 1-2 m (3-6 ft) in vertical elevation on the beach. Large runup together with an extreme tide, storm surge, and El Niño conditions can potentially produce maximum total water levels at the shoreline of up to 4 m (13 ft) above ambient MSL under rare conditions.

It is the recurrence of extreme total water levels that dictates the vulnerability of the coast to erosion and flooding, and their consequent damages. The main effect of future MSLR on the

California coast will be to shorten the average interval between given extreme total water levels over time. For example, a total high water level of 3 m (10 ft) that may occur only once every 50-100 years at current MSL will occur more and more frequently as MSL goes up. Eventually, this same total high water level could occur on average every 20 years, then 10 years, then every year, *etc*. depending on ultimate MSL elevation. Sometimes this is called "return-period creep." While waves and wave runup are what actually cause flooding, damage, and erosion, especially during high tides, inundation from MSLR gradually brings those same conditions higher and farther landward over time.[1]

4 SHORELINE EROSION

One of the most noticeable long-term effects of MSLR is to shift the shoreline on sandy beaches upward and landward. Essentially, this occurs as nature's way of keeping constant the relative geometry of the beach profile and MSL for any given set of wave conditions. In other words, 18,000 years ago when sea level was 120 m (390 ft) lower than it is today, the beaches presumably looked the same except for being lower and some distance offshore (assuming the wave climate was the same, and there was sufficient sand to form beaches in the first place). The beaches gradually prograded landward and upward as MSLR proceeded over the last 18 millennia and erosion removed the land. This process can be described by the "Bruun Rule" (Bruun, 1962), which provides compelling quantitative, albeit as yet poorly documented guidance for estimating long-term shoreline retreat as a function of MSLR rates.

The ability of beaches to remain intact as they retreat in response to MSLR depends on the erodibility of the backshore. On sandy coasts, or ones with relatively weak cliffs, and for sufficiently slow rates of MSLR, erosion proceeds and the beach reforms from the eroded material pushed onshore and upward during periods of mild waves. The shoreline rises, and both the shoreline and backshore essentially retreat landward more or less together in response to MSLR.

However, when the rate of MSLR is too large, or the backshore is structurally hardened or naturally resistant for erosion to occur rapidly enough to provide sufficient sand, beaches narrow and eventually drown. This process is called "passive erosion." This occurred under natural conditions at hard, rocky headlands such as Palos Verdes, where sand supply and accumulation are minimal and sizable beaches do not generally form.

[1] See Flick *et al.* (2012) for a discussion of the useful distinction between "flooding" and "inundation."

Currently, passive erosion is increasingly related to the hardening protection of many beaches that have revetments and seawalls at their back. Shore armoring is especially and increasingly prevalent in southern California, including many areas in the City of LA. In this case, the backshore essentially cannot erode, which eventually leads to a sand shortage on the beach as the shoreline retreats. As the shoreline gradually moves upward and landward in response to MSLR, the hardened backshore can only remain fixed. Therefore, the beach width decreases and eventually disappears when the shoreline intersects the backshore. This sand shortage can be expressed as a certain volume per unit time (cubic meters or yards per year) over a given length of shoreline. In turn, this can be used to estimate the cost of stabilizing the shoreline position or the price of inaction.

Sand from an outside source placed on the beach at the proper rate can remedy this shortage and mitigate the shoreline retreat and beach width loss. This illustrates the basis for future beach nourishment activity that will undoubtedly be necessary if there is desire and support to maintain beach widths at anything like their current dimensions. Flick and Ewing (2009) used the Bruun Rule to make rough estimates of the range of sand volumes that would be needed in southern California to "keep up" with shoreline retreat from a range of MSLR scenarios. They concluded that the (current dollar) average cost of \$19-\$48 million per year for the lower-range (0.5 m or 1.6 ft by 2100) of future MSLR scenarios was surprisingly small compared with the dollar value of coastal-dependent economic activity, estimated at about \$14 billion per year.

Beach sand nourishment can and has been done as projects for their own sake, or as a consequence of other coastal construction activities where "opportunistic" sand is produced as a byproduct. In southern California, most beach sand nourishment has occurred as a byproduct of coastal construction, as summarized below. Where dedicated sand replenishment projects have been carried out, these have been sponsored by some combination of federal, state, and local funding. The U.S. Army Corps of Engineers and the California Department of Boating and Waterways (DBW)[2] are (respectively) the federal and state agencies responsible for beach sand nourishment projects, while the cities are generally the local sponsors. In all cases, funds must be appropriated in federal, state, and local budgets. A unique privately-funded sand replenishment project is being planned at Broad Beach in Malibu, California (The Malibu Times, 2012).

[2] Division of Boating and Waterways in the California Department of Parks and Recreation as of July 1, 2013.

5 SHORELINE CHANGE MODELING

Shoreline change modeling may be useful in the LA beach areas to provide the ranges of expected long-term projected shoreline retreat as a function of future MSLR. While many coastal change computer numerical models exist, there are as yet no proven models that can be used to reliably accomplish this task. Nonetheless, experimental data-based models of shoreline retreat in two southern California military installations (Naval Base Coronado and Marine Corps Base Camp Pendleton) have been developed (Chadwick *et al.*, 2011).

These models seek to mimic two processes that affect beach width at different time scales. First, the day-to-day and seasonal erosion and accretion cycles are modeled using the equilibrium method of Yates *et al.* (2009). This is a crude, but proven model for these wave-driven changes. Historical beach width information and hindcast six-hourly wave height and period were used to calibrate the model (Figure 2A). Projected ocean wave conditions for 2000-2100 derived for the IPCC (2007) A2 climate change scenario were then used to estimate coastal wave conditions (O'Reilly and Guza, 1991) at the military bases and the resulting future beach fluctuations. Finally, the long-term and much slower erosion of beach width was estimated using the Bruun Rule for four MSLR scenarios of 0.5 m, 1.0 m, 1.5 m, and 2.0 m (1.6-6.6 ft) and combined with the wave-driven fluctuations.

Figure 2B shows the results of these calculations for 2050-2100 at a relatively wide beach in Coronado, California. Regular, seasonal fluctuations in beach width range up to about 50 m (160 ft). However, sharp decreases up to 150 m (490 ft) occur during periods of very high wave energy, but rapid recovery is also projected. The slow trends of beach width downward are evident for the four MSLR scenarios used as shown by the green, black, aqua, and red curves, respectively. Beach width loss between 2000 and 2050 (not shown) is only about 5-25 m (15-80 ft), depending on the MSLR scenario, but accelerates later in the century as projected MSLR rates increase. By 2100, 20-80 m (65-260 ft) of net decrease in beach width can be expected from MSLR alone.

It is important to recognize the limitations of this experimental composite model. These include the fact that no tide or explicit runup information is used in the Yates *et al*. (2009) formulation; that the interconnection of rapid and slow beach width change are not explicitly modeled; that the Bruun Rule approach has not been proven on decadal time scales; and that there is no account of sand budget deficits or surpluses, although these could be included if they were known; among others.

Nonetheless, results are useful for illustrating beach width scenarios from which various trajectories, summaries, and statistics about possible future average and minimum beach width can be estimated. For example, it is clear that the number of days that the beach width falls below a given minimum value increases over time. The reliability of these kinds of models can only be improved with measurements. This underscores the critical need to monitor regional beach width going forward. Without continuing measurements, future assessments and projections will be no more reliable than today's.

6 CITY OF LOS ANGELES COAST

6.1 Pacific Palisades (LA City-County Line to Santa Monica)

This coastal area is southwest-facing extending approximately from the LA City-County line at Topanga Canyon Blvd (Hwy 27) east of Topanga Beach to Montana Avenue at Santa Monica (Figure 3). PCH sits on a bench cut between the retreating low sea cliff and another cliff on the north (landward) side.

6.1.1 *County Line to Gladstones*

East of the LA county line, there are three segmented beaches backed by PCH (Hwy 1), which is protected by several segments of rock revetment (Figure 4). These beaches are therefore already hindered in their ability to migrate landward by the existing revetments, or will be when erosion threatens to undermine PCH and new revetments must be built. A number of storm drains are also evident, but only two major developments exist seaward of PCH. These are the Chart House restaurant on the point just east of Hwy 27 (Figure 5A), and Gladstones Restaurant at the promontory by the foot of Sunset Blvd (Figure 5B). These beach fragments remain important recreational assets, even though parking is extremely challenging and limited to the shoulder of PCH where it is still wide enough.

The extent of existing revetments shows that this reach has and continues to experience episodic erosion that threatens to undermine PCH and shore-side developments with high economic value. Flooding under current MSL conditions seems to be mainly related to heavy rainfall. However, future MSLR will almost certainly cause decreases in the width of the existing segmented beaches, as well as eventually and occasionally threaten to overtop the revetments and flood PCH and the restaurants. This reach is particularly sensitive to waves from the south, including southern swell and potential future tropical storm waves.

As MSLR proceeds, it would be wise to initiate a storm watch and notification program that uses standard available weather and wave forecast products to provide warnings several days in advance of when dangerous wave and tide combination conditions may occur. This would facilitate traffic management, increase safety, and provide engineering data that will be useful once adaptation measures become necessary.

This reach presents mainly a major geotechnical and coastal engineering challenge, and also thorny societal and legal issues, but less of a technical or scientific problem. The inland stretch along PCH is heavily developed with few or no good options for retreat of the highway. Since PCH is not likely to be moved, continued and improved armoring seems the only realistic choice for avoiding wave-driven erosion undermining. This seems to be the most vulnerable part of the entire LA city shoreline, at least in the short to medium term of years to decades.

Heavily-used PCH has occasionally been undermined in some spots. It has required attention since it was first constructed, and will continue to do so in the future. LA City, County, and Caltrans highway engineers are undoubtedly aware of these problems, and are in the best position to suggest solutions once the future vulnerabilities are better defined. Careful quantification of the times, locations, and extent of any future overtopping and ocean flooding and erosion undermining of PCH and other infrastructure can eventually form the basis for a phased and ongoing plan to address these geotechnical and revetment needs.

The area's segmented beaches show "pocket beach" characteristics with wave-driven sand transport predominantly to the east. That is, they are narrow or non-existent upcoast (west) where headlands block the flow of sand or divert it offshore, and wider down-coast, reaching maximum width just west of the next headland. At least annual monitoring[3] of the beach widths will eventually provide the history that will be necessary to address the issues of stabilization with groins or other measures, and periodic nourishment that will almost certainly be needed in the future to maintain sandy beach.

[3] Beach width monitoring surveys limited to once per year should be conducted in the autumn, just before the first winter-season storm, to ensure a consistent time history of maximum beach width. While minimum, spring-time beach width data are highly desirable, attempts to actually record these are almost always unsuccessful.

6.1.2 *Will Rogers State Beach*

Will Rogers State Beach extends about 3 km (nearly 2 miles) from just east of Sunset Blvd where the beach is narrow to non-existent, toward Santa Monica where it widens and blends into Santa Monica Beach (Figure 6). The area was part of Will Roger's estate that was donated to the state of California in 1944 and is currently operated by LA County. The western half is stabilized by a series of groins built prior to the 1960s. The groins are dilapidated and were slated for removal, but this would de-stabilize the beach and undoubtedly would cause it to narrow further.

This segment is highly instructive in that it illustrates successful and relatively unobtrusive groin beach width stabilization structures that will almost certainly become increasingly and widely necessary if area beaches are to be preserved in the future. Everts Coastal (2002) provides quantitative assessments of major shoreline sand retention structures and guidelines that will be helpful for engineers planning future structures. The use of sand retention structures to maintain beach stability should be considered. As with the segmented beaches to the west, at least annual systematic monitoring of beach width should be conducted.

Toward the southeast, beach width increases due to the up-coast influence of the Santa Monica breakwater located just offshore of Santa Monica pier (Figure 7). The breakwater was built in the 1930s as an unsuccessful attempt to create a small craft harbor. It did lead to an astonishing increase in beach width and equally importantly, to beach width stability. For this reason, the southern end of Will Rogers State Beach is less vulnerable to long-term erosion than most other beaches in southern California that are not stabilized. This beach configuration is also instructive, since the Santa Monica breakwater is also a relatively unobtrusive structure at the head of Santa Monica pier that provides sound property protection and recreation opportunities, and the related economic benefits.

Of course, the breakwater functions, as they all do, to trap sand by decreasing wave action. This obviously impacts surfing and swimming in the adjacent beach areas by eliminating waves or significantly changing their patterns, and by creating a water hazard. As beaches begin to narrow in response to future MSLR, the tradeoffs between beach width and stability and other recreational needs like surfing will have to be considered and evaluated. Issues like this represent some of the most difficult associated with future MSLR.

6.2 Venice-Marina Peninsula-Playa Del Rey-LAX

This reach is a central part of Santa Monica Bay's iconic "Bay Watch" beach system (although the TV program was filmed mostly at Will Rogers State Beach) that extends from Malibu to Redondo Beach (Figure 8). It provides major economic benefits from coastal recreation and tourism, boating, and utility and facility siting. The beaches are mostly wide to very wide and were largely created by sand supplied as a by-product of coastal construction activity, including LAX, Marina Del Rey, and the Hyperion sewage treatment plant (Flick, 1993; Leidersdorf and Woodell, 1993, 1994). Between the late 1930s and 1963, over 24 million cubic meters (m^3) (32 million cubic yards [yd^3]) of sand were placed on these beaches, giving an average rate of about 800,000 cubic meters per year (m^3/year) (1 million yd^3/year). The increases in beach width are easily visible by comparing the view in Figure 8 with the one in Figure 9, which is a view north from Venice Beach circa 1930. The heavy construction of the piers appearing in Figure 9, most of which are now gone, inhibited wave-driven sand transport and trapped cusp-like features that locally increased beach width. Only Santa Monica pier (background) and a smaller Venice pier (center) remain.

This artificially wide beach configuration has continued to be stabilized by a number of large structures that provide sand-retention as a primary or secondary benefit. These include the Santa Monica and Venice breakwaters, Marina Del Rey jetties, and a number of groins south of Marina Del Rey, including El Segundo and ending at Redondo Beach (Figure 8). With completion of Marina Del Rey in 1963, the rate of sand deposition slowed to about 50,000 m^3/year (65,000 yd^3/year) (Flick, 1993). This vastly reduced amount may not be sufficient to maintain the current artificially wide beaches in the face of normal wave sand transport.

While these beaches have been wide and stable for many decades, gradual retreat is already in progress. A major concern for the future is that sand is not being provided at nearly the rate it was up to the 1960s. As MSLR resumes and likely accelerates in the future, these iconic LA beaches will undoubtedly narrow at an even faster rate. It is unlikely that any storm-wave driven flooding or property damage will occur in the foreseeable future, but if MSLR takes one of the higher trajectories, problems should become evident around mid-century.

In order to maintain the property protection and recreational benefits of these beaches, sand nourishment will undoubtedly be necessary sometime in the future. In the meantime, the City and its regional partners should continue efforts to facilitate delivery to the beach of any

opportunistic sand supplies that become available. To enable sound engineering benefit/cost analysis for these inevitable projects, it will be necessary to monitor the beach width going forward in a manner similar to that discussed in the context of the beaches in the Pacific Palisades reach. The Venice-Marina Peninsula-Playa Del Rey-LAX reach is ripe for wave- and MSLR-driven beach retreat modeling, since a wealth of historical beach profile, shoreline position, and wave data exists. Such work could help to narrow the uncertainty of future rates of beach loss due to MSLR using empirical models now under development. This is of course a regional, and in fact a state-wide need, and not only a City of LA concern. However, the City can play a vital role in highlighting the need for monitoring and coordination of local, regional, state, and federal constituencies.

6.3 San Pedro – Exposed Coast

The San Pedro part of LA has a south-facing exposed open-coast portion, and an east-facing section sheltered behind the LA-Long Beach outer breakwater (Figure 10). Both sections are heavily sub-urbanized atop a flat coastal terrace that has a 35 m (115 ft) high sea cliff at its seaward edge. The geology suggests relatively resistant formations at sea level near Cabrillo Point, but more erodible material to the west toward Point Fermin. As MSLR resumes and accelerates, the weaker cliff sections will be subject to more undermining from wave action and eventual collapse than the more resistant sections. Ongoing and at least annual monitoring of cliff retreat is recommended.

Inspection of aerial photos (Google earth) shows that about 25% of the cliff edge in San Pedro is occupied by park or other open space, which minimizes the vulnerability of property loss from cliff failure (Figure 11). Cliff-top development on the other 75% of the exposed western end of San Pedro has substantial setback from the edge of the cliff. Therefore, few if any developments will be immediately threatened. However, several areas of geotechnical instability are evident, especially related to landsliding (Figure 12). Some residential development on the cliff top at the eastern end of the exposed section of San Pedro has little setback and may be threatened if cliff retreat resumes or accelerates in response to MSLR (Figure 13).

6.4 San Pedro (Sheltered)-Wilmington-Terminal Island-LA Harbor

The LA-Long Beach outer breakwater emanates from Cabrillo Beach and largely protects everything landward from wave attack (Figure 15). Of course, the harbor infrastructure and

operations are vulnerable to MSLR. But, this presents mostly a series of harbor engineering challenges that will have to be addressed in stages as problems become apparent and as rebuilding opportunities arise. Anecdotal evidence suggests that the port infrastructure can accommodate even mid-to high-range MSLR scenarios by periodically being raised during major refitting projects. However, the enormous uncertainty presented by the large range of possible future MSLR (Nicholls *et al.*, 2011; NRC, 2012) presents the largest climate change-related obstacle to planning port infrastructure adaptation needs and methods.

At least one study (by the Rand Corporation) is underway to determine port vulnerabilities and possible adaptation strategies. Adaptation measures necessitated by subsidence at the Wilmington Oil Field beginning in the late 1930's should be reviewed (Mayuga and Allen, 1970), since subsidence is in many ways functionally equivalent to MSLR. Future difficulties associated with extreme high water levels should be documented to facilitate planning.

While the outer breakwater is highly effective at sheltering the harbor and adjacent coast from wave action, it is frequently overtopped during high wave events coinciding with high tides. Increased wave transmission over the breakwater and associated habitat losses nearby can be expected with MSLR. But, more frequent damage to the breakwater itself is likely only if the wave climate becomes more severe. The breakwater elevation could be increased if it does not provide sufficient protection with future higher water levels. However, this would be expensive since raising the crest would require that the entire structure be widened to maintain stability.[4]

7 RECOMMENDATIONS

1. Monitor all LA City beaches at least annually in the fall, or more frequently if possible, to provide data to establish the reliability of beach change models needed for projections of future conditions.

2. Continue to lead and promote local, regional, state, and federal efforts to monitor and model beach conditions.

3. Facilitate continued delivery of any opportunistic sand supplies that become available for area beaches.

[4] Paragraph based on comments kindly provided by Mr. Russ Boudreau of Moffatt & Nichol Engineers.

4. Consider and plan for sand-retention structures such as the groins at Will Rogers State Beach to enhance future beach stability.

5. Initiate a storm watch for Pacific Palisades to provide weather and wave warnings to facilitate traffic management, increase safety, and provide engineering data for future adaptation measures.

6. Document times, locations, and extent of overtopping, flooding, and erosion undermining of PCH and other infrastructure at Pacific Palisades to plan geotechnical adaptations.

7. Document times, locations, and extent of cliff failures and other erosion events at San Pedro to aid in developing and planning geotechnical adaptations.

8. Review adaptation measures for past Wilmington Oil Field and port subsidence.

9. Document times, locations, and degree of difficulties from extreme high water levels to better determine port facility vulnerabilities and aid adaptation planning.

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Figure 1. Coastal segments of Los Angeles city (white) include Pacific Palisades, Venice-Marina Peninsula-Playa Del Rey-LAX, San Pedro (exposed), and San Pedro (sheltered)-Wilmington-Terminal Island-LA Harbor. Note that the LA-Long Beach Harbor outer breakwater is not shown. (Los Angeles Almanac wall map).

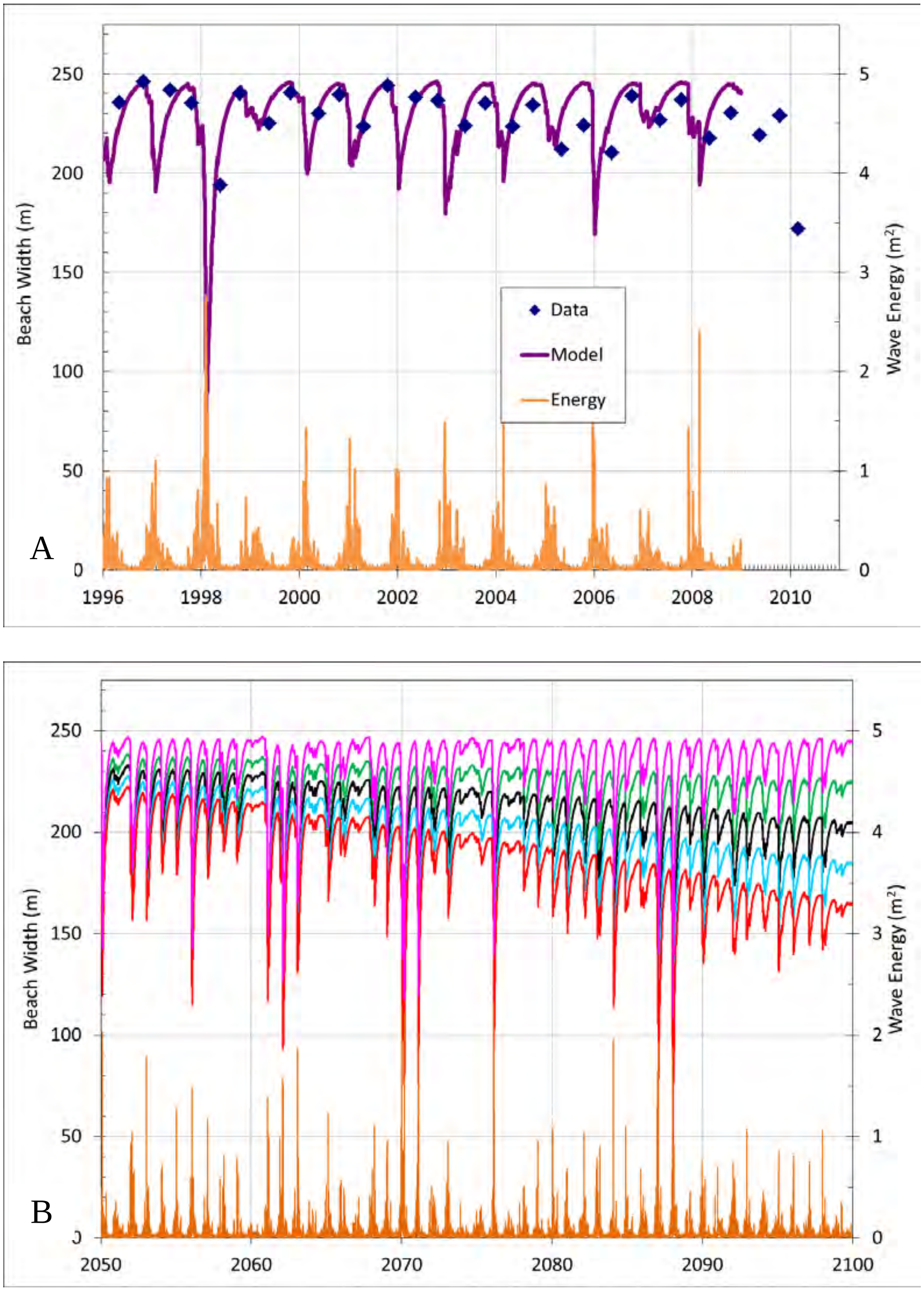

Figure 2. (A) Experimental beach width change model (violet curve) calibration at Coronado, CA, using measured beach width (blue symbols) and hindcast wave energy (orange) 1996-2009. (B) Projected beach width for projected future wave energy (orange) for waves only (pink), and waves plus four MSLR scenarios (0.5 m-green, 1 m-black, 1.5 m-aqua, 2 m-red, by 2100).

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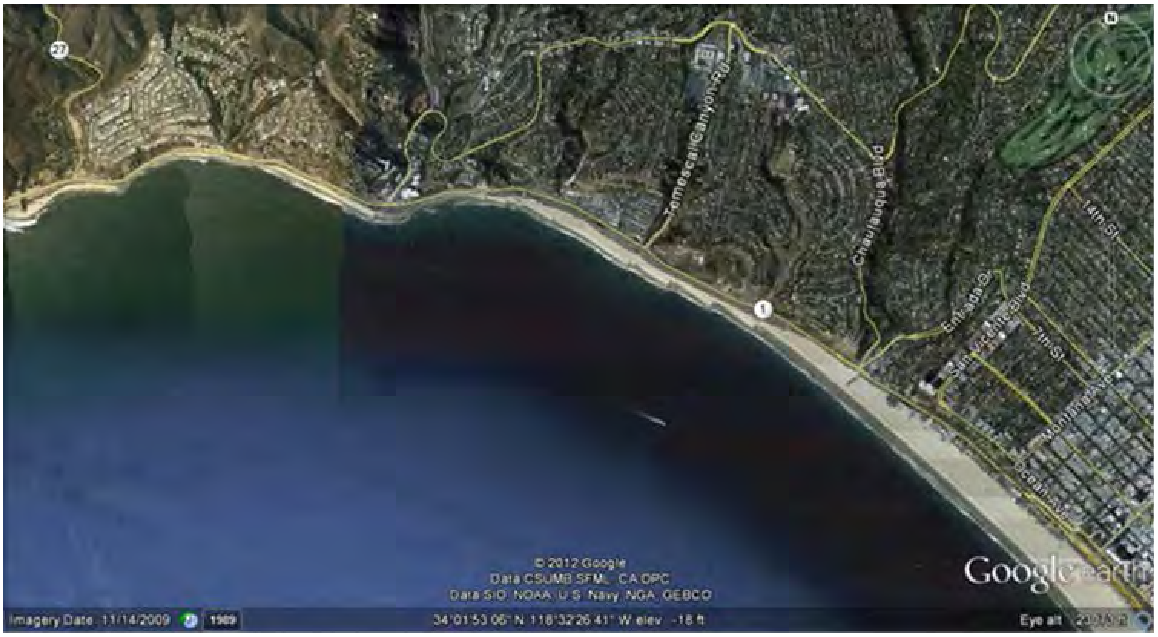

Figure 3. South-facing shore of Pacific Palisades including heavily protected Pacific Coast Highway east of Sunset Boulevard, and groins at Will Rogers State Beach (Google earth).

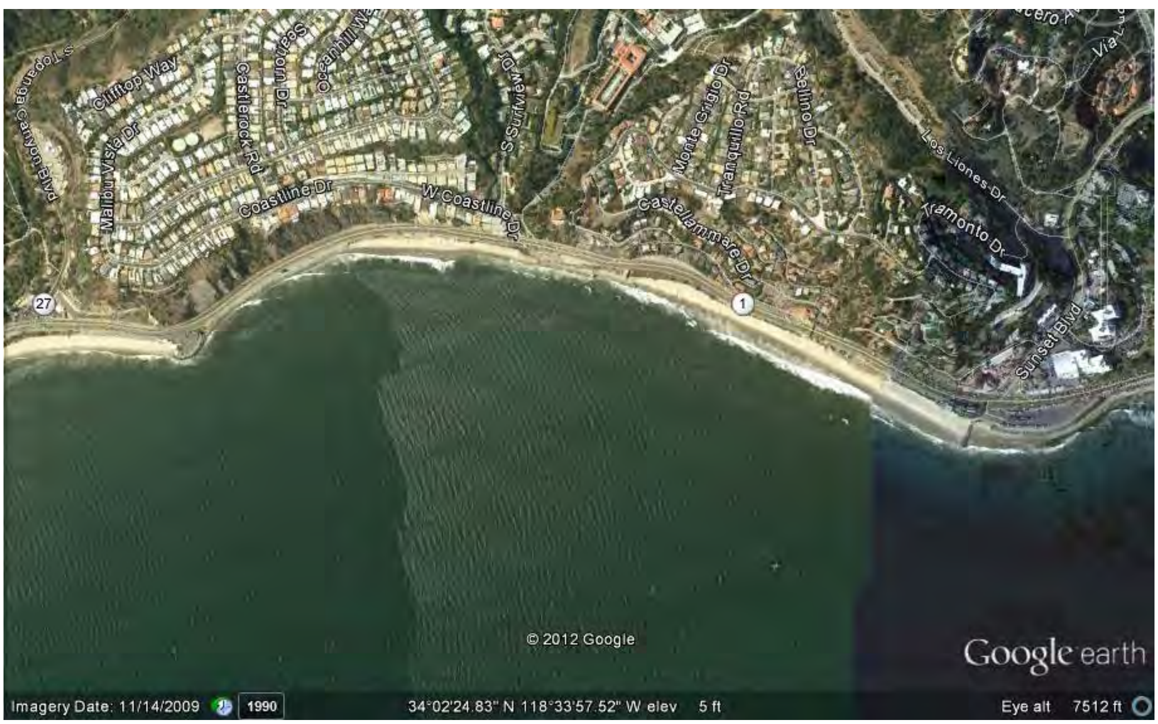

Figure 4. Reach south of Topanga Canyon Blvd (Hwy 27) to Sunset Blvd shows several segmented beaches and PCH (Hwy 1) heavily armored in places. Evidence of coastal erosion, cliff landslides, and other geotechnical instability are evident (Google earth photo).

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Figure 5. (A) Point with Chart House Restaurant on PCH (Hwy 1) east of Hwy 27 showing heavy rock armoring. (B) Foot of Sunset Blvd at PCH with heavily armored Gladstones Restaurant and a terminal groin stabilizing a small beach segment (left) (Google earth photos).

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Figure 6. Will Rogers State Beach with effective groin beach sand stabilization (center left). Beach widens and blends into Santa Monica Beach to the southeast (Google earth photo).

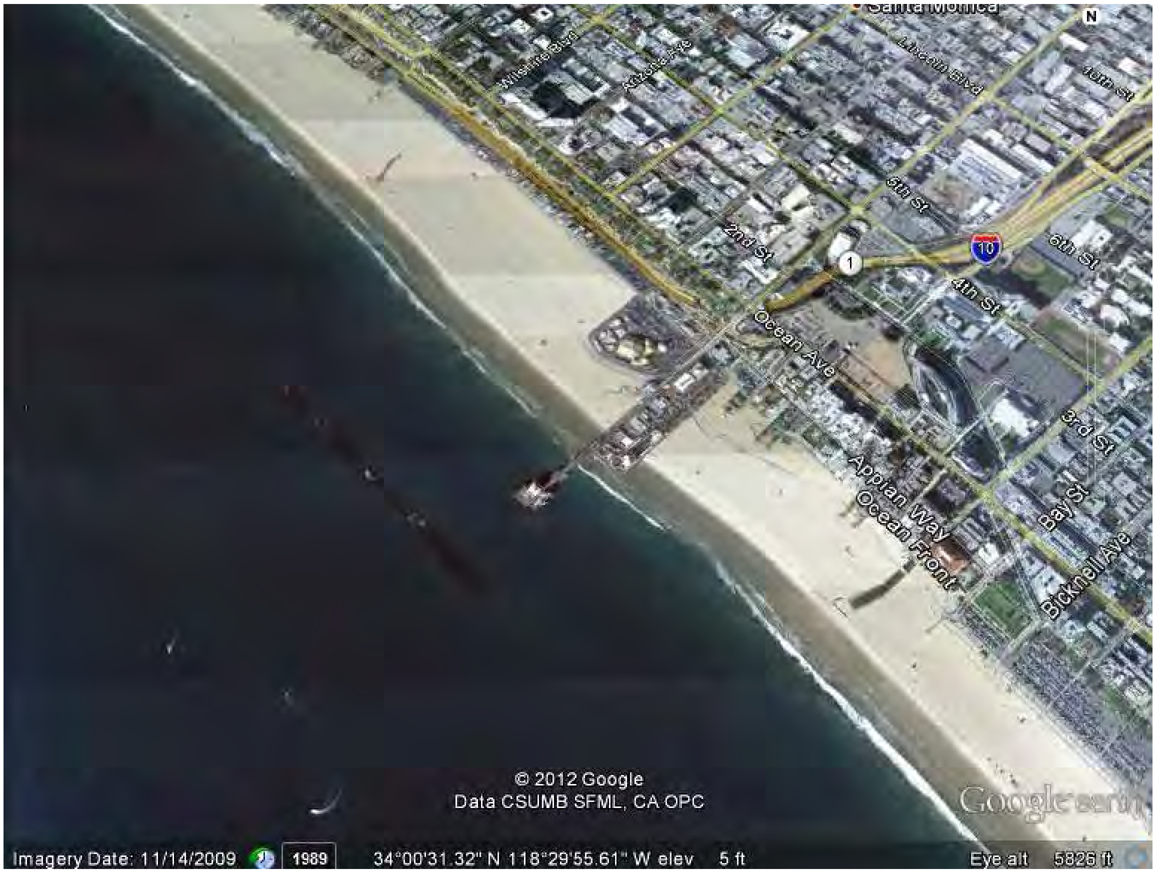

Figure 7. Santa Monica pier and offshore breakwater, which stabilizes beach width for several miles up and down-coast (Google earth photo).

Figure 8. View toward south of iconic beaches of central Santa Monica Bay: From Venice (pier, lower right) past Marina Del Rey jetties and west end of LAX runways, toward Redondo Beach (Wikimedia photo, 2007).

Figure 9. View north *circa* 1930 from Venice Beach with Sunset pier (removed *circa* 1940, foreground), old Venice pier (destroyed 1946), Ocean Park pier (removed late 1960s), Crystal pier (removed mid-1940s), and Santa Monica pier, the only one still standing. Note beach width stabilizing effects of the piers (Spence Air Photos, accessed from http://venicebeachbustours.com).

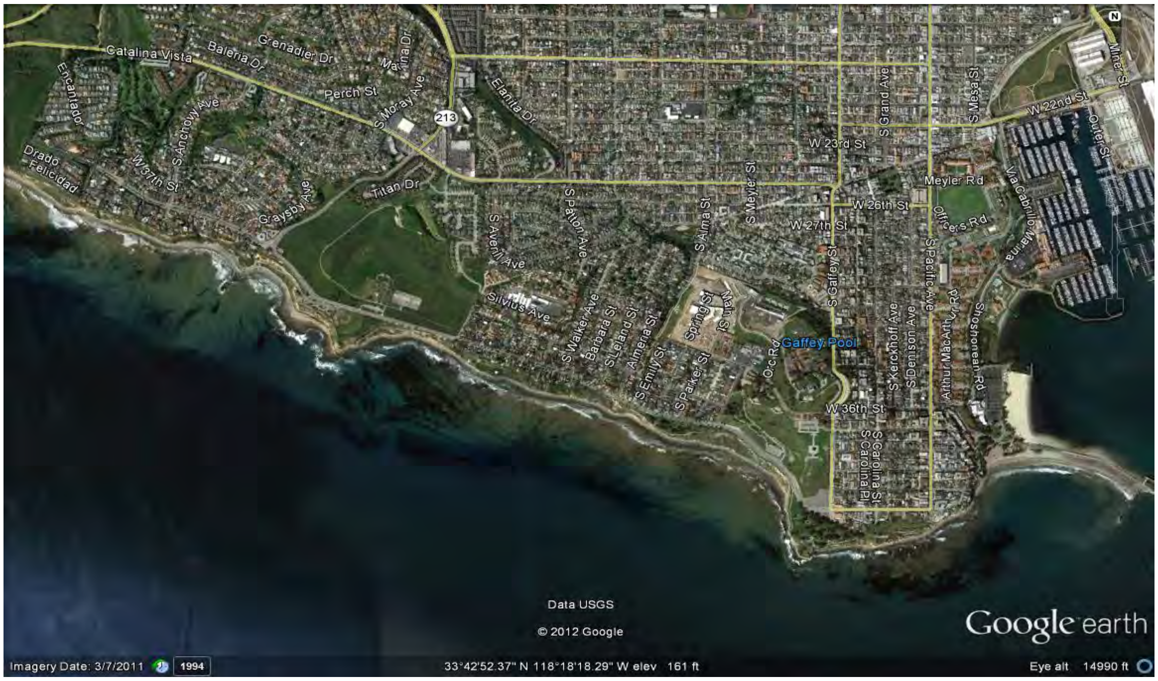

Figure 10. San Pedro reach of LA with south-facing open coast segment on the west, and east-facing portion behind LA-Long Beach outer breakwater, which starts at Cabrillo Point (lower right, Google earth photo).

Figure 11. Exposed segment of San Pedro has sizable park and other open space near the cliff edge and most suburban development has considerable setback (Google earth photo).

Figure 12. Landslides east of Point Fermin present geotechnical challenges in this segment (California Coastal Records Project Photo 201002554).

Figure 13. Eastern end of San Pedro with landslide (lower left and Figure 12) and suburban development with little setback (center right, Google earth photo).

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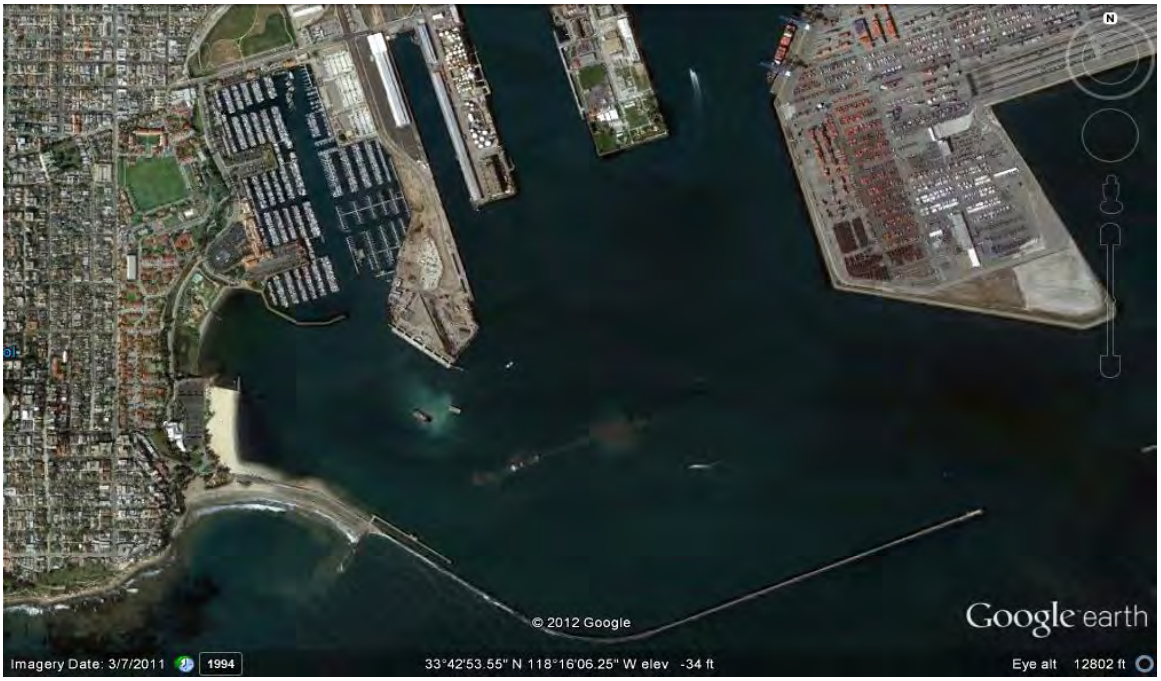

Figure 14. Eastern portion of San Pedro sheltered behind LA-Long Beach outer breakwater (lower center), with portion of Terminal Island (upper right, Google earth photo).

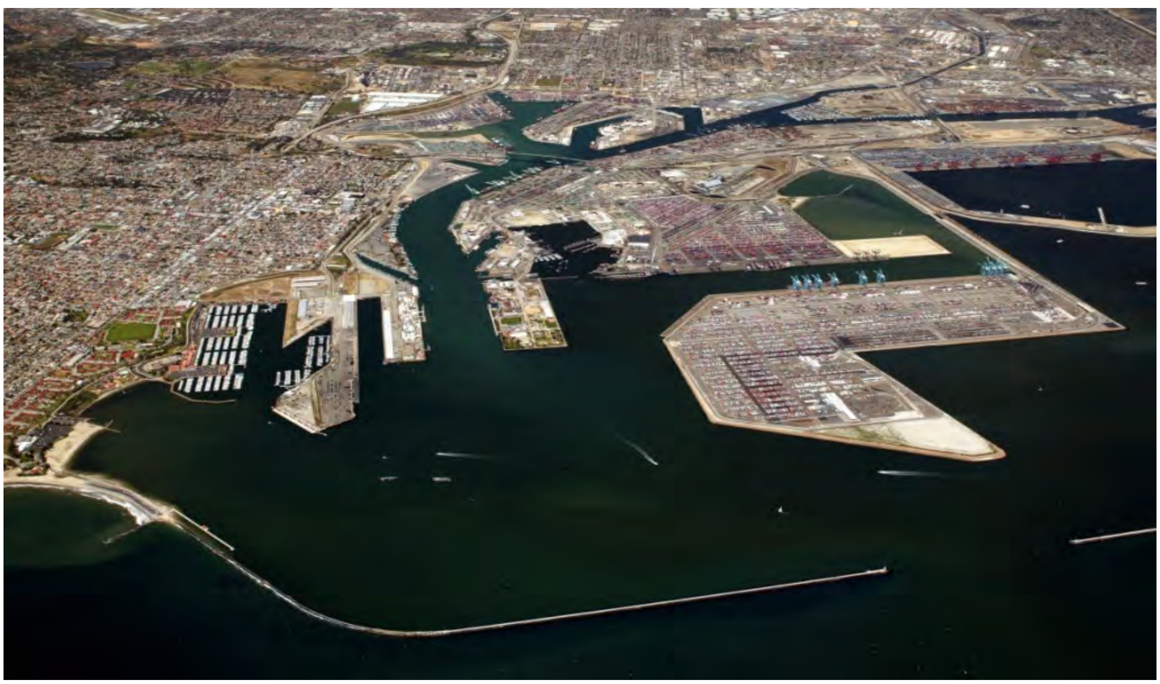

Figure 15. View north over LA-Long Beach outer breakwater and Angel's Gate (lower right) toward Port of Los Angeles and Terminal Island (right). Wilmington is in the distance (Port of Los Angeles photo).

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Appendix 2: Physical Vulnerability Assessment

Physical Vulnerability Assessment Findings

For the City of Los Angeles

Final Report
January 2013

ICLEI
Local Governments for Sustainability
USA

Introduction

A climate change physical vulnerability assessment evaluates the degree to which important community assets are susceptible to, and unable to accommodate, the adverse effects of climate change. This document identifies potential impacts of sea level rise and the sea level rise vulnerabilities of critical assets that the City of Los Angeles owns, maintains, or manages.

This document seeks to inform policymaking by not only identifying the sectors and systems that are likely to be affected by the impacts of sea level rise, but also by enhancing understanding of the sources and components of each sector's vulnerabilities. Understanding asset vulnerabilities will help the City develop strategies to increase resilience. This document also assesses the consequences of impaired assets to help understand connections between systems and prioritize future strategies to build resilience.

This report discusses the impacts of sea level rise, the methodology that ICLEI used to assess vulnerability, and then provides both the key findings and detailed descriptions of the vulnerabilities of each sector.

Sea Level Rise Planning Scenario

This assessment evaluates long-range vulnerabilities using a sea level rise scenario based on USGS data collected from a storm that occurred in January 2010 and a projection of sea level in 100 years. More specifically, this scenario is a 10-year storm event (a storm with a 10 percent chance of occurring in any given year) coupled to 1.4 meters of sea level rise.

Sea Level Rise Impacts

Sea level rise is generally associated with a number of different impacts, including storm-related coastal flooding, daily tidal flooding, permanent inundation, interaction with groundwater, and erosion. This section briefly describes these impacts.

Flooding and Inundation

Flooding refers to the circumstance of normally dry land being covered by water for a limited period of time due to a high water event. The scenarios considered in this report used a 10-year storm, or a storm with a 10 percent chance of occurring each year, which includes local sea level factors such as El Niño effects and storm surge, but does not account for precipitation and river flooding. In addition to storm-related flooding, sea level rise could result in certain dry locations around coastal Los Angeles being flooded by daily high tides. Inundation, on the other hand, occurs when land that was once dry becomes permanently wet.

Erosion

Erosion, which is defined as the wearing away of earth's surface by any natural process, often occurs at the intersection of land and water. In coastal areas, there are two major

erosion processes: episodic erosion and chronic erosion. Episodic erosion occurs during major storm events and results in extreme shifts in shorelines. Natural environments typically recover from these episodic shifts, returning to their pre-storm state over time. However, if the frequency or intensity of these events were to increase, a natural system might not be able to recover. Chronic erosion is the slow migration of sand away from the shore or to a different location. Sea level rise, which will alter daily high tide conditions, could also exacerbate chronic erosion of non-hardened surfaces.

Interaction with groundwater

It is generally understood that if sea levels were to rise, the water table could also rise, impacting subsurface infrastructure. A rising water table would pose risks to underground infrastructure, such as storm water and wastewater facilities, potable water distribution, and transportation facilities as well as other utility and communications infrastructure

Assessment Methodology

This physical vulnerability assessment provides a snapshot of the vulnerabilities of various systems and assets managed by the City of Los Angeles by analyzing three components of vulnerability relative to sea level rise: exposure, sensitivity, adaptive capacity, and consequences.

A critical component of vulnerability is **exposure**, or a determination of whether community assets will experience a specific changing climate condition. City staff members were provided with exposure maps developed by Patrick Barnard of USGS, which they used to determine if their assets would be exposed to sea level rise impacts under the scenario described above. The assets included in this assessment fall within the mapped exposure zone.

Sensitivity is the degree to which assets would be impaired by a climate impact, if they were exposed to that impact. Assets that are greatly impaired by sea level rise have a high sensitivity, whereas assets that are minimally impaired by the same change in sea level have a low sensitivity.

Adaptive Capacity is the ability of an asset to make adjustments in response to a climate impact in order to maintain its primary functions. This does not mean that the asset must look the same as before the impact, but it must provide the same services and functions as it did before the impact occurred.

Consequences are the adverse effects that occur as the result of an asset being impaired by a climate impact. Survey respondents were also asked to describe consequences for the economy, environment, and communities and populations. Respondents were asked to consider the magnitude of the consequence, such as a size of the population, land area, or resources that would be affected.

ICLEI employed a qualitative and participatory methodology to gauge the sensitivity and adaptive capacity of the sectors and assets addressed in this report. This participatory method ensures that the information comes directly from the experts

who work with these assets and systems on a daily basis. In addition, City staff members become more aware of the risks of sea level rise through participating in this process. Specifically, ICLEI used a survey method, whose steps are outlined in greater detail below:

1. Several technical experts from key City departments were identified and invited to serve on the City Adaptation Leadership (CAL) team.

2. ICLEI provided the CAL team with a training and information packet explaining the tenets of sensitivity and adaptive capacity.

3. A detailed survey on sensitivity, adaptive capacity, and consequences was developed in Qualtrics, an online survey tool. The survey required that respondents take some time to think about and answer guiding questions related to a system's sensitivity, adaptive capacity, and consequences. The survey questionnaire can be found in Appendix I. The following City of Los Angeles Departments participated in the survey:

- Los Angeles Department of Water and Power
- Port of Los Angeles
- Bureau of Sanitation
- Recreation and Parks
- City Planning

4. Based upon answers to the survey and subsequent follow-up conversations with City staff, ICLEI determined the primary asset vulnerabilities for each sector. Complete assessments of asset vulnerabilities for each sector are presented below.

Summary of Findings

The table below describes the primary vulnerabilities for the sectors evaluated based on the sea level rise scenario and exposure definitions described above. Vulnerabilities and mitigating activities are described in more detail in later sections.

.

Primary Vulnerabilities by Sector

Wastewater Management
• Collection systems (sewers) in low lying areas are vulnerable to flooding and groundwater inflow, which could exceed their designed capacity, causing temporary wastewater discharges into the ocean. • Treatment and pumping plants would be vulnerable to flooding, which could damage electrical equipment, generators and/or process operations, resulting in partially treated wastewater discharged into the ocean.
Storm Water Management
• The storm water management system is vulnerable to coastal flooding and inundation, which could impair storm water management facilities and exacerbate flooding from storm water runoff in low-lying areas.

Potable Water
• The potable water system is vulnerable to flooding, inundation, and groundwater, which make accessing underground assets, such as pipes, extremely challenging and raise public health concerns.
Port of Los Angeles
• Although the Port's assets are sensitive to flooding and inundation, the port has low vulnerability because of its limited exposure in the near term, and high capacity to adapt by building future infrastructure at a higher elevation.
Energy Facilities
• Energy facilities have low vulnerability to the impacts of sea level rise, because all coastal energy assets were designed to withstand exposure to water. In addition, replacement schedules and system redundancies reduce vulnerability.
Recreation and Parks
• Parks and open space have low to moderate vulnerability to flooding, because they can be restored relatively quickly or can change to cope with new environmental conditions. • Coastal structures, including bathrooms, recreation centers and museums have higher vulnerability to flooding and inundation, because the structures could be damaged and become inoperable, and/or inaccessible.
Land Use and Transportation
• Roads near the shoreline are highly vulnerable to flooding, inundation, and undermining from erosion and rising groundwater, which could result in reduced access for residents and impaired regional transport. • The building stock is most vulnerable to flooding and inundation in Venice, where it is located very near sea level and there are many older structures.

Sector Vulnerabilities

This section presents the vulnerability assessment findings in greater detail. Assets included in the section were identified as exposed to flooding under the sea level rise planning scenario described above.

Wastewater & Storm Water Management

Overview

In the City of Los Angeles, the Bureau of Sanitation (BOS) manages both storm water and wastewater. Wastewater and storm-water management facilities are highly-vulnerable to the impacts of sea level rise. Wastewater and storm water collection systems are impacted by inflows from high tides, storm-related floods, and groundwater, which reduce their conveyance capacity. In addition, wastewater treatment plants and pumping plants are vulnerable to flooding because their electrical equipment and process operations can be damaged.

The BOS has recognized that climate change effects may impact assets and operations and has identified Strategic Planning Goals and outcomes to lessen these impacts. Additionally, the BOS includes capabilities for upgrades and replacement of equipment, facilities and infrastructure in its planning and capital improvement programs. BOS operations personnel are capable of taking actions necessary for spill response, emergency response and in repairing and restoring operations. The BOS has undertaken prior studies related to climate change impacts and is continuing this work to better understand what can be expected and how to prepare.

The BOS has undertaken some efforts to make their assets more resilient to sea level rise, and especially storm-related flooding. Two years ago, a microburst storm event caused sewage stormwater to back-up into homes in a handful of locations. This storm event became the impetus to initiate a study to examine how the impacts of sea level rise could impact the Venice Pumping Plant and sewer storm drains in San Pedro. In the case of San Pedro, the Department of Public Works has taken action to reroute the storm drains and reduce the number of turns that the water flows through until it reaches an outlet. This area now has greater capacity to safely move storm runoff. The BOS continuously assesses and addresses storm event effects to improve performance and builds into its operations program improvements in conveyance and water treatment infrastructure.

BOS also has emergency plans that include relocating portable generators, vacuum trucks and staffing to respond quickly in the event of storm related flooding. As to long range capital improvements, the recently approved Sewer Service Charge (SSC) rate increase will allow additional projects to be developed for asset protection, plans performance improvements and redundancy will be implemented.

This sector has relatively high level of social resources for adapting to sea level rise. The BOS staff is involved with different groups, such as the Los Angeles Collaborative for Climate Action and Sustainability (LARC), which provides opportunities to collaborate and learn from efforts in other cities in the region. The BOS has economic, technological, and environmental resources for adapting to sea level rise, but BOS has substantial fixed coastal assets that would be difficult to fully protect or relocated, and is not prepared for a catastrophic system wide failure. The BOS made a case for a rate charge to consumers to finance capital improvement projects, which was approved and has provided some additional economic resources for adaptation, but this is a very new source of funding for the department. Like many City departments, the BOS budget is highly constrained and has a large scope, servicing four million residents and businesses and 29 contract cities using 6,500 miles of pipeline and four wastewater treatment plants

Wastewater Management Asset Vulnerabilities

Hyperion Wastewater Treatment Plant (HTP)

HTP is located across from Dockweiler State Beach at approximately 32 feet above sea level. The facility treats approximately 290 million gallons per day of wastewater. The major treatment processes at this plant include screening, grit removal, primary sedimentation, and secondary treatment. The treated secondary effluent is discharged

via a five-mile outfall into Santa Monica Bay.

Sensitivities: HTP would be sensitive to flooding under the sea level rise scenario, which could impact equipment and operations due to damage of electrical pumps and panels if exposed to water. In addition, a dramatic increase in sea level could reduce the plant's ability to gravity-discharge effluent and may increase the pumping hours of the effluent pumping station. As part of the Plant's redundancy, HTP also has a one-mile outfall that can be used during emergencies to discharge wastewater offshore.

While erosion could result in some loss of the beach in front of the plant, the plant itself is not very sensitive to undermining from erosion or interaction with the groundwater because it is built on top of a large cement catacomb.

Adaptive Capacity: The plant's ability to continue to function if it is partially disabled depends on the severity of the impacts. Any release of partially treated wastewater would be of short duration. Built-in redundancy and emergency preparedness provide the facility with the capacity to continue wastewater treatment and discharge offshore. Emergency diesel generators have been placed at all critical facilities and the Bureau of Sanitation is building its own on-site power source using a renewable energy source. In addition, at current plant flow rate, HTP has some additional capacity that can be used to handle the quantity of wastewater entering the plant.

Consequences: The primary economic consequence would be repairing the plant which, depending on the severity of the impact, may be quite significant. Impacts to individual pieces of equipment would cost significantly less than the loss of the entire facility. The facility has an estimated total replacement value of $3 billion. In addition, the primary environmental consequence would be the discharge of partially treated wastewater into the Santa Monica Bay. In addition to impacting habitat and wildlife, this could also have negative economic impacts due to the recreational value of the beaches. Any release of partially treated wastewater would be of short duration. The BOS continues to ensure this asset is protected and is of highest priority for improvements since this is the key to protecting public health and the environment.

Terminal Island Water Reclamation Plant (TIWRP)

TIWRP is a tertiary/advanced water reclamation plant that treats municipal and industrial wastewater. It is located on Terminal Island, and is situated on a 19.8-acre site. Wastewater reaches the plant through a series of pumping plants and force mains. The plant provides preliminary, primary, secondary, tertiary and advanced water treatment. TIWRP also has a solids handling facility. TIWRP currently discharges tertiary treated effluent through an outfall within Los Angeles Harbor.

Sensitivities: TIWRP is sensitive to coastal flooding, which could cause equipment damage and operations failures. In fact, the plant is already impacted by extreme high tides during which pumps are employed to mitigate these impacts. A storm-related event combined with higher mean sea levels could exceed the design capacity of the plant, flooding galleries and potentially damaging equipment. As a result, partially or untreated wastewater could be discharged into the Los Angeles Harbor. At current flow

of 15 MGD, the plant has some spare capacity to deal with increased flow during storm events.

Adaptive Capacity: Depending on the equipment damaged caused by high water levels, the plant may be temporarily or partially disabled and would require emergency generators or pumps to be used to ensure that wastewater continues to be discharged to the outfall. Engineering studies that include assumptions about flood depth and duration would help to refine an evaluation of adaptive capacity and allow for enhanced planning.

Consequences: As with any fixed asset, the economic consequences of impairment of TIWRP could be high depending on the extent of the damage. If the pumps are inundated with seawater, it could be costly to repair or install new equipment so that the plant is fully functional and wastewater is treated to full capacity. In addition, some partially or untreated wastewater could spill into the San Pedro Harbor, temporarily affecting fishing communities as well as recreational opportunities.

Wastewater Pumping Plants

Pumping plants are located underground and move wastewater from a lower elevation to a higher one, so that it can be transported through municipal sewers for eventual processing at a treatment plant. There are approximately 21 plants located in the exposure zone. During a storm event, some urban runoff or rain may enter the system through infiltration.

Sensitivities: The wastewater pumping plants are currently designed to handle wastewater and stormwater flow during storm events and during high tides. However, they may be impacted by sea level rise over time. Higher water levels could contribute to localized overflows. If electrical equipment is inundated, it might fail resulting in a temporary wastewater overflow.

Adaptive Capacity: The system is continuously evaluated for deficiencies. These plants are of high priority and are redesigned and upgraded due to changes in local conditions over time. For long term planning and asset protection, the BOS has the ability to modify and improve the individual pumping plants as wastewater volumes change and sea level rise projections and observations become more certain. In the event that an electrical system fails or a pump is disabled, there are back up generators on site and additional resources would be provided to reduce the impacts to the coastal system and ensure public health is protected. The BOS is undertaking efforts to make these plants more resilient to flooding.

Consequences: Impairment of these plants would have moderate to high economic consequences. If the entire facility were destroyed, each of these 21 plants has an approximate $2 million replacement value. However impacts to individual pieces of equipment would cost significantly less than the loss of the entire facility. In addition, damage to these plants could result in sewage spills, with economic and environmental consequences.

Venice Collection System

The Venice Wastewater Collection System is anchored by the Coastal Interceptor Sewer, which runs along the coast from West Los Angeles to the Hyperion Treatment Plant.

Sensitivities: The Venice collection system is sensitive to coastal flooding and to interaction with groundwater, because water can infiltrate the collection system at the pipe joints during high water events. Ultimately, this effect could reduce the capacity for transporting wastewater to HTP. Although most of the pipes lie under the roads, heavy erosion could damage the pipes.

Adaptive Capacity: Although it may be at reduced capacity, the collection system can continue to function even if partially disabled, and continue to convey wastewater into the Venice Pumping Station and Hyperion Treatment plant. Depending on the damage caused by any single event, the repairs and replacement may extend the time that portable emergency equipment is required. If the flow rate or damage exceeds certain thresholds, the system cannot restore itself easily. The BOS is currently conducting a study to learn about challenges in capacity and the potential volume of groundwater and flood water that could enter the Venice Collection System. This area is a high priority and BOS is planning and preparing capital improvement projects to include further protection of the area's infrastructure.

Consequences: The economic consequences of impairment to this asset include the costs of repairing the system and the local impacts. Damage to the system may cause spills into storm drains that empty into Santa Monica Bay, which would have environmental impacts and raise public health concerns.

Storm Water Management Asset Vulnerabilities

Venice Storm Water Pumping Plant (VSPP)

The Venice Storm Water Pumping plant is designed to move storm water/urban runoff from a lower elevation up to a higher one, so that it can be transported through pipelines by gravity for eventual processing at a treatment plant during low flows and discharge into the ocean during storm flows.

Sensitivities: The VSPP is sensitive to coastal flooding and undermining from erosion. In fact, the plant is currently affected by both impacts. The plant is located between the beach and a channel, so the plant could potentially be flooding from both sides of the facility.

Adaptive Capacity: The plant has been identified as an asset that is functioning at capacity. The BOS is working to make the plant more resilient to storm-related flooding through proactive maintenance and functional improvements. In addition, BOS has

emergency plans, so that power and pump function can be restored quickly with onsite back up generators during a power loss.

Consequences: The greatest economic consequence of impairment of the VSPP would be the potential for storm-related flooding of streets and other infrastructure in the Venice area. Flooding would have high social consequences including possible displacement of residents and public health concerns. The replacement value of the plant in its entirety would be $10 million. However impacts to individual pieces of equipment would cost significantly less than loss of the entire facility.

Low Flow Diversion Pumping Plants

There are four low flow diversion pumping plants located in the exposure zone, and they are designed to move urban runoff during low flow periods from lower to higher elevation, so it can be transported through pipes by gravity for eventual processing and cleaning at a treatment plant, eliminating or reducing discharges directly on the beach or the adjacent ocean. They do not usually operate during storm events.

Sensitivities: These plants could be sensitive to coastal flooding, which could impact electrical components and thus make them unable to pump urban runoff during the dry season.

Adaptive Capacity: The plants would not normally operate during a storm event. Long term, sea level rise may impact the plants but the BOS indicates that they will be evaluated for inclusion in the capital improvement program as impacts are indicated. Additionally, the facilities would continue to function even if partially disabled; the plants can be quickly restored if they are impaired by storm coastal flooding. The BOS has efforts underway to make them more resilient to flooding.

Consequences: The primary economic consequence would be repair or replacement of the plants if destroyed; the replacement value is $1.5 million each. However, impacts to individual pieces of equipment would cost significantly less than loss of the entire facility.

San Pedro Storm Water Collection System

The San Pedro storm water collection system includes the storm drain network in the San Pedro area, with many trunk lines located below sea level.

Sensitivities: This system is sensitive to coastal flooding, because if large amounts of water enter the system, capacity could be exceeded, causing neighborhoods to flood.

Adaptive Capacity: The system is able to function if partially disabled, because it can continue to convey storm water at a reduced capacity. The ability of the system to be quickly restored depends on the severity of the storm and the functionality of other connected facilities in the system. In fact, this system has been impacted by storm-related flooding and the Department of Public Works was able to reroute, relocate and resize the pipes, as well as removing some turns which had constrained the flow.

Consequences: The consequences of an impaired system are high due to the economic consequences of flooded homes and streets. Impairment of the system could also result in the transport of additional urban pollutants from localized flooding into the ocean. The BOS estimates a replacement cost of $1.37 million.. However impacts to individual pieces of equipment would cost significantly less then loss of the entire facility.

Potable Water

Overview

The Los Angeles Department of Water and Power (LADWP) manages the potable water system. LADWP is the largest municipally owned utility in the U.S., serving a 464 square-mile area with a population of 3.8 million people. LADWP's water infrastructure distributes water supply to 676,000 active service connections through a distribution network of over 7,200 miles of pipelines. About 500 miles of pipe in the distribution system is 24 inches or larger in diameter (trunkline). The remaining pipes have a diameter of less than 24 inches (mainline). LADWP also manages water regulatory valve stations, but there are none located in the exposure area.

This sector's assets are vulnerable to coastal flooding, and interaction with groundwater, because these conditions would make accessing these primarily underground assets extremely challenging. Erosion could also damage many of the assets.

The system has some short-term adaptive capacity that includes pumping out water to improve access or re-routing water to other parts of the network. However, once the assets are impaired, it might be difficult to bring them back into a full functioning state quickly.

LADWP's objectives with respect to emergency preparedness, response and recovery are to maintain an organization that is capable of taking decisive action to restore and maintain water service to the City of Los Angeles in a safe and timely manner. The Emergency Response Plan covers the administration, mitigation, preparedness, and response and recovery efforts to respond to emergencies.

Asset Vulnerabilities

Pipes

There are approximately 186,961 feet of pipe in the exposure zone. Pipes carry water through the distribution system to customers.

Sensitivity: Pipes are sensitive to coastal flooding and interaction with groundwater because the presence of water makes it difficult for crews to access the buried pipes, thus impairing construction and maintenance. The pipes are also sensitive to undermining from erosion, because the loss of ground stability could damage or break

the pipes, thus impairing operation.

Adaptive Capacity: By pumping water out from flooded areas, the pipes could continue to function even if partially disabled. Crews can also limit construction and maintenance to low tide periods. Lastly, because the pipes are part of a networked system, LADWP could potentially bypass an impaired section of the network.

The functionality of the pipes, however, might not be quickly or easily restored, because major excavation and construction is required to restore operations. There are no current efforts in place to make the pipes more resilient to these impacts.

Consequences: Impairment of pipes from sea level rise impacts would have high economic consequences because it affects construction and reduces the life span of the pipes. In addition, there are public health concerns regarding salt water, groundwater, or other substances potentially infiltrating the potable water system. Lastly, pipe failure could potentially exacerbate flooding in flat areas with poor drainage.

Water Services

The approximately 4,228 water services in the exposure area connect water mains to customers. This asset includes connections between the water mains, meters, and meter boxes.

Sensitivities: Many water services are located below ground. Thus, if they were submerged in water, such as from flooding or interaction with groundwater, the water would need to be pumped out before the asset could be placed back into operation. These impacts could impair construction, maintenance, and operation of water services.

Adaptive Capacity: By removing the water to a minimum level needed for operations, the water services could continue to function even if they were partially disabled. In addition, there is some redundancy and flexibility in the system, which provides some resilience, but this is highly dependent on the location. If impaired, however, the functionality of water services might not easily or quickly restored. The DWP has undertaken some efforts to make water services more resilient by installing some of the larger services above ground.

Consequences: These impacts have high economic consequences because they affect construction and reduce the life span of these assets. In addition, there are public health concerns resulting from salt water, groundwater, and/or other substances potentially infiltrating the potable water system. Lastly, failure could exacerbate flooding in flat areas with poor drainage.

Fire Hydrants

There are approximately 249 fire hydrants in the exposure area that provide high pressure water for fire fighting efforts and temporary water services.

Sensitivities: Fire hydrants are sensitive to flooding, because if the hydrants are

submerged in water, firefighting personnel will not be able to access or operate them. Fire hydrants are also sensitive to undermining from erosion, because the loss of ground stability could damage the fire hydrant and render it inoperable.

Adaptive Capacity: Fire hydrants can function if partially disabled, because they will continue to work in semi-submerged conditions. The function, however, cannot be restored quickly or easily if impaired and there are no current efforts in place to make hydrants more resilient to these impacts.

Consequences: Flooding would have moderate economic consequences because it impacts the life span of the asset. In addition, there are public health concerns regarding salt water, groundwater, or other substances potentially infiltrating the potable water system, since fire hydrants are connected to the potable water system. Lastly, failure of fire hydrants could exacerbate flooding in flat areas with poor drainage because water at high pressure could spill from a broken hydrant.

Port of Los Angeles

Overview

Assets at the Port of Los Angeles would be significantly vulnerable to flooding and inundation if they were exposed, and impairment of the assets could potentially have significant economic impacts if cargo shipments are delayed or re-routed. The Port has recognized this source of vulnerability and is currently identifying the risks of sea level rise and strategies for responding to those risks through a report commissioned with the Rand Corporation.

The Port's vulnerability is mitigated by its relatively strong capacity to adapt, which comes primarily from the Port's economic resources. The Port is an important driver of economic activity in the region, providing $6 billion in tax revenue and $63 billion in trade. The Port has a (AA) Bond Rating, which is the highest credit rating for any stand-alone U.S. port and reflects confidence of the rating agency in the financial strength of the Port. In the future, the Port could incorporate sea level rise into their engineering and planning process, building future infrastructure at higher elevations, thus becoming more resilient.

Asset Vulnerabilities

Container Terminals

Container terminals are the facility where cranes load cargo containers to and from ships and load them onto trucks or trains for onward transportation. This facility also provides storage for containers in stacks while awaiting transport.

Sensitivities: Container terminals are sensitive to flooding, which could render the

terminals inaccessible and non-operational with unsecured containers and no power supply for equipment.

Adaptive Capacity: In the short-term, container terminals have low adaptive capacity, because they cannot continue to function if partially disabled and their functionality cannot be restored quickly after suffering damage. However, in the long-term the terminals could be redesigned and re-built at higher elevations.

Consequences: The economic consequences of impaired container terminals are very significant. They are the port's highest revenue generating resource and they have a $2.85 billion replacement value. Furthermore, the economic impacts would ripple through the economy as shipments would be delayed or re-routed. Quantifying the economic consequences of impaired container terminals is extremely difficult because it depends on a variety of factors. According to the National Oceanic and Atmospheric Administration 2008-2017 Strategic Plan, the cost of a shutdown of the POLA/POLB would cost $1 billion per day in regional economic losses[1].

Electrical Infrastructure

Sensitivities: The Port's electrical infrastructure could be severely damaged by coastal flooding, because is not designed to be exposed to water.

Adaptive Capacity: In the short term, this asset has low adaptive capacity, because it cannot function if partially disabled and the functionality is not quickly or easily restored if impaired. However, in the long-term, the electrical infrastructure could potentially re-designed and relocated to higher elevations.

Consequences: This infrastructure is vital to port operations and impairment would cause equipment, such as cranes, to be non-operational. This could cause delays and disruptions in cargo loading and offloading. This asset has a $343,750,000 replacement value.

Breakwater

The breakwater is an 8.5-mile rock structure that prevents waves from entering the harbor. It has two openings to allow ships to enter the port areas behind it.

Sensitivities: The breakwater is sensitive to higher water levels and erosion. With sea level rise, the breakwater could be overtopped by high tides or scoured out by wave action, and then cease to hold back waves from the harbor area.

Adaptive Capacity: The breakwater could potentially function if partially impaired. For example, if a portion of the breakwater is eroded, the rest of the structure would continue to block waves. Also, if the breakwater is inundated only during high tide, it would continue to function during low tide.

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[1] http://www.pmel.noaa.gov/pubs/PDF/bern3168/bern3168.pdf

Consequences: An impaired breakwater would have high economic consequences, because it could cause damage to the port. There could also be environmental damage to the shallow water habitat adjacent to breakwater, which is a built ecosystem that supports eelgrass, fish, and bird life. The breakwater has a $500 million replacement value and is managed by the Army Corps of Engineers.

Transportation

Transportation assets include roads, rails, and grade separations that help move cargo to and from the Port.

Sensitivities: Transportation assets are sensitive to coastal flooding, undermining from erosion and rising groundwater. These impacts could cause the assets to be damaged and thus unusable.

Adaptive Capacity: Compared to other port assets, roads can be re-built relatively quickly. In addition, if only one lane is affected by flooding or undermining from erosion, the road can potentially still continue to function.

Consequences: Impaired transportation facilities would have a high economic consequence, because they are vital for transporting cargo from terminals to their final destinations. It could also have a high impact on communities living in San Pedro, Wilmington, and permanent residents in the marina due to reduced access. The transportation assets are estimated to have a $1 billion replacement value.

Marinas

Sensitivities: Marinas are sensitive to coastal flooding and undermining from erosion, because they would be damaged by such impacts.

Adaptive Capacity: Marinas are relatively resilient to storm-related flooding, because they float on the water, but their groundings would become deteriorated from daily tidal flooding and chronic erosion. In addition, these impacts could reduce access to the marina.

Consequences: The consequences of impaired marinas primary relates to their recreational value. They also have an estimated $180 million replacement value. Lastly, permanent residents of the marinas could potentially be displaced.

Energy Facilities

Overview

The Department of Water and Power (DWP), the largest municipally owned utility in the country, manages energy facilities in the City of Los Angeles. Most energy assets located in the exposure zone are not sensitive to the impacts of sea level rise, because as coastal assets, they were designed to withstand exposure to coastal flooding and erosion. All outdoor equipment is water resistant, indoor equipment has pumps, and spare equipment is kept on hand.

This sector also has high levels of resources for adaptive capacity, which reduces vulnerability. In terms of economic resources, the DWP has a strong mechanism for raising funds. In terms of governance resources, DWP works closely with other agencies and is involved with communities regarding environmental protection procedures. LADWP has a vast workforce that provides service to the City of L.A. Work crews are also located in areas outside of the City. Should emergency situations necessitate the use of additional staff, crews can be called in to assist. LADWP is also member to several Mutual Assistance Agreements that can be activated for additional support of resources.

Energy facilities also have a high long-term adaptive capacity, because DWP maintains a robust asset replacement schedule of 30-35 years. As such, new infrastructure will likely be designed with sea level rise and other environmental risks in mind. Furthermore, redundancies in the electric power system mean that the consequences of impaired coastal assets would likely not be widely felt.

Asset Vulnerabilities

Harbor Generation Station

The Harbor Generation Station is a natural gas fired steam electric generating facility located in the Wilmington area. The facility's total capacity is 472 megawatts and it occupies approximately 20 acres.

Sensitivities: DWP analysis concludes that the Harbor Generation Station is not sensitive to the impacts of sea level rise, because, as a coastal asset, it was designed to be able to cope with these impacts.

Adaptive Capacity: This asset can continue to function if partially disabled and its functionality can be restored quickly if impaired. Outdoor components are designed for water resistance and exposure. Indoor components are designed for water to drain into sumps and are also equipped with pumps to quickly remove the water from the sumps.
Consequences: Impacts would be equally distributed to the immediate area.

Haynes Generation Station

Haynes Generation Station is a natural gas fired power plant located in the Long Beach area with a capacity of 1556 megawatts.

Sensitivities: DWP analysis concludes that this asset is not sensitive to the impacts of sea level rise, because, as a coastal asset, it was designed to be able to cope with these impacts.

Adaptive Capacity: This asset can continue to function if partially disabled and its functionality can be restored quickly, because outdoor assets are designed for water resistance and exposure. Indoor assets are designed for water to drain into sumps and are also equipped with pumps to quickly remove the water from the sumps.

Consequences: Impairment of Haynes would have moderate economic consequences, because clean up could take time, potentially affecting the power supply to other parts of Los Angeles. The disruption in power supply could also have environmental consequences, because it could impact power supply to waste water treatment plants, potentially resulting in sewage spills.

Receiving Station Q

Receiving Station (RS) Q is located in the Wilmington area and is comprised of equipment that receives power from generation, transforms the voltage, and distributes the power out again into the distribution network. Specifically, it has underground transmission connections to RS-C and Harbor Generation stations and connection to distribution stations that serve the San Pedro and Wilmington areas.

Sensitivities: DWP analysis concludes that this asset is not sensitive to the impacts of sea level rise, because as a costal asset, it was designed to be able to cope with these impacts.

Adaptive Capacity: This asset can continue to function if partially disabled and its functionality can be restored quickly, because outdoor assets are designed for water resistance and exposure. Indoor assets are designed for water to drain into sumps and are also equipped with pumps to quickly evacuate the water from the sumps.

Consequences: The DWP reports minor economic consequences from the potential impairment of RS-Q, because impacts would be distributed equally in the immediate area. A vulnerability assessment conducted by USC reported that the loss of RS-Q would disrupt power supply in the Los Angeles harbor area, but not the rest of the city.[2] Impairment of RS-Q could have moderate environmental consequences, however, because it could impact power supply to wastewater treatment plants, potentially resulting in a sewage spill.

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[2] http://create.usc.edu/2005/05/vulnerability_assessment_and_s.html

Local Electricity Distribution Assets

Local electricity distribution assets include three distribution stations, poles, transformers, wires, vaults, and cables. These assets help deliver electricity at relatively low voltages to customers.

Sensitivities: DWP analysis concludes that these assets are not sensitive to the impacts of sea level rise, because, as coastal assets, they were designed to be able to cope with these impacts.

Adaptive Capacity: These assets can continue to function if partially disabled. Outdoor assets are designed for water resistance and exterior exposure. Indoor assets are designed for water to drain into sumps and are also equipped with pump to quickly evacuate the water from the sumps. In addition, assets are laid out in a manner that is easily reparable and their function can also be restored quickly. Lastly, if needed, power can be re-routed to other parts of the network.

Consequences: The DWP reports minor consequences from the potential impairment of these assets, because impacts would be distributed equally in the immediate area.

230KV Scattergood-Olympic Cable

This is an underground cable in the Dockweiler Beach/ Venice area that connects to a high voltage interstate line.

Sensitivities: This asset is potentially sensitive to coastal flooding that would make maintenance and repair difficult.

Adaptive Capacity: This asset can continue to function if partially disabled. Outdoor assets are designed for water resistance and exterior exposure. Their function can also be restored quickly.

Consequences: The DWP reports minor consequences from the potential impairment of this asset, because impacts would be distributed equally in the immediate area.

Electrode Vault

This is an underground vault. It is currently being redesigned and moved for reasons unrelated to sea level rise.

Sensitivities: DWP analysis concludes that this asset is not sensitive to the impacts of sea level rise, because, as a coastal asset, it was designed to deal with these impacts.

Adaptive Capacity: This asset can continue to function if partially disabled. Outdoor assets are designed for water resistance and exterior exposure. Their function can also be restored quickly.

Consequences: The DWP reports minor consequences from the potential impairment of this asset, because impacts would be distributed equally in the immediate area.

Recreation and Parks

Overview

The Recreation and Parks Department manages parks and recreational facilities in the City of Los Angeles. There are three assets located in the flood exposure zone in the San Pedro/Harbor area and five assets located in the flood exposure zone in the Venice area. This sector has relatively limited adaptive capacity because the department is already operating under budget constraints that make it difficult to meet current demand and cope with current challenges at these locations.

Despite these constraints, parks and other open spaces are generally fairly resilient assets, because they can be restored relatively quickly or they can change to cope with new environmental conditions. For example, different landscaping can be introduced that can deal with periodic flooding without significantly changing the function of the park. However, these parks and greenspaces may be reduced in size or access due to sea level rise. Built structures, such as recreational buildings and museums, are much less resilient, because damage takes longer to repair and they cannot function if partially impaired.

The consequences of impairment of these facilities are highly dependent on the location. Some facilities, like the Venice Beach Boardwalk, are iconic destinations and their impairment could have significant economic consequences. Some parks are unique because provide habitat for rare plants and animals. Other parks and recreation centers are highly valued and used by the local communities, especially in the San Pedro/Harbor area, because few other parks exist in the area.

Asset Vulnerabilities in the San Pedro Harbor Area

Cabrillo Beach

Cabrillo Beach includes a public beach, a marine aquarium, a recreation center, and a fishing pier. The beach area is divided into an outer beach and an inner beach.

Sensitivities: The public beach is sensitive to flooding, erosion, and interaction with groundwater. The public beach could potentially be lost to erosion. In fact, five years ago, a large storm washed away the sand and the outer beach was exposed down to rocks with much of the sand being deposited on the inside of the breakwater. The sand on the outer beach was replaced naturally over time, but with higher sea level, it is uncertain if the sand would return naturally following a storm event. Flooding could also damage the inner beach, recreation center and aquarium.

Adaptive Capacity: The public beach could potentially continue to function if partially impaired. For example, if the beach is inundated only during high tides, visitors could potentially use the beach during low tides. Also, it could potentially continue to function if impaired by storm-related flooded. After previous storm events, some of the beach sand

still remained, but with a two to three foot berm that visitors had to navigate to access the water.

On the other hand, partial impairment of the aquarium and recreation center could render them non-functional. Also, these facilities could not be quickly or easily restored if impaired. Flooding in the parking lot or road would result in a temporary loss of access for visitors. There are no current efforts in place to make the facilities at Cabrillo Beach more resilient to the impacts of sea level rise.

Consequences: Impairment of this asset would have high economic and social consequences, because the beach and aquarium attract visitors from all over Southern California. The local communities of Wilmington, San Pedro, and Harbor City also use the beach and the recreation center, and the impairment of these assets would be a loss of open space and recreation opportunities for these park-poor communities.

The Los Angeles Maritime Museum

One cultural facility affected by sea level rise in the San Pedro Harbor Area is the Los Angeles Maritime Museum. The Maritime Museum is located in the 1941 Municipal Ferry Terminal and is on the National Register of Historic Places.

Sensitivities: The museum site is sensitive to coastal flooding and undermining erosion. These impacts would cause damage to the structure and/or contents of the building and would cause the facility to close to the public.

Adaptive Capacity: This facility cannot function if it is partially impaired and cannot be quickly or easily restored if impaired. There are no current efforts in place to make the museum more resilient to the impacts of sea level rise.

Consequences: The greatest consequence would be the economic impact of a storm-related flood, because this could cause damage to the valuable artifacts within the museum. In addition, closure of the Maritime Museum would be a cultural loss for the local community and greater City of Los Angeles, as this site attracts visitors from around the region.

Asset Vulnerabilities in Venice Area

Venice Beach Recreation Center

The Venice Beach Recreation Center consists of a boardwalk, fishing pier, picnic areas, and athletic courts.

Sensitivities: This asset is sensitive to coastal flooding, which could damage the various elements of the recreation center and render them unusable by the public. The pier already has some structural weakness and it could be further damaged by these impacts. Erosion could also weaken the structural stability of the pier and the boardwalk.

Adaptive Capacity: This asset cannot function if partially impaired. The boardwalk and athletic courts could be quickly restored if impaired, but the pier would take considerably longer to restore if damaged. Recreation and Parks is currently working on a plan to reinforce the pier to better withstand current impacts, but the plan does not explicitly take the impacts of sea level rise into consideration.
Consequences: Impairment of these iconic facilities, particularly the boardwalk, would have high economic consequences, because of their cultural, recreational, and tourist value. They draw visitors from around the region and even from around the world. The boardwalk also includes spaces for about 200 vendors, who would have to seek other locations to sell their goods.

Neighborhood Parks

Neighborhood Parks include Del Rey Lagoon Park, Canal Park, and Titmouse Park. Del Rey Lagoon features a tidal basin, children's play area, a ball field, and restroom facility. Canal Park is pocket park located along the Venice canals and it includes grass and a children's play area. Titmouse Park is a small park located near Ballona Creek consisting of native plants that provide habitat for birds.

Sensitivities: These parks are sensitive to flooding and erosion that could damage the park facilities and make the park unusable an inaccessible.

Adaptive Capacity: The parks could potentially function if they were partially impaired. For example, if only a small part of the park experiences tidal flooding, other parts of the park could in use. The park could also potentially be quickly restored depending on how fast flood water recedes. The landscape and vegetation of the parks could potentially change given these impacts and still be useful as habitat for plants and animals.

Consequences: The consequences of impairment of these parks would be relatively minor given their small size. There would be a loss of recreational opportunities for residents and habitat for plants and animals.

Land Use Planning

Overview

The Planning Department carries out land use planning in the City. While there has not yet been monies identified for the development of climate adaptation plans, the department recognizes the importance of such plans and will be looking to obtain funds for adaptation plans in the forthcoming years. In the meanwhile, several neighborhood groups have become organized and engaged around the topic of risks related to climate change and are helping to raise the profile of this important topic.

Asset Vulnerabilities

Building Stock and Roads in Venice Area

Venice is particularly vulnerable to sea level rise because of its exposure not only via the beach, but also the channels.

Sensitivities: The building stock and roads in the Venice area are sensitive to flooding and undermining from erosion. The impacts of sea level rise could lead to damaged and/or uninhabitable homes, businesses, schools, and public buildings. Many structures are built at, or very-near, sea level. In addition, many of the structures were built before the 1970s, which means they are more sensitive to flooding. In fact, some residents already experience flooded basements during storm events. Damage to roads from the impacts of sea level rise could also result in a lack of access for residents and emergency services.

Adaptive Capacity: The ability of the roads and building stock in Venice to continue to function if partially disabled depends on the extent of damage. The functionality of these assets could not be restored very quickly or easily. The City Planning department does not have any plans in place to make the roads and buildings in Venice more resilient to the impacts of sea level rise.

Consequences: The economic and social consequences of the impairment of these assets would be high due to the displacement of residents and businesses. In particular, the displacement of low-income residents in the Venice Beach area would have significant social consequences. In addition, flooding in this area could cause damage to the Ballona wetlands, which provides habitat for plants and animals and helps filter groundwater.

Building Stock and Roads in the San Pedro/HarborArea

Sensitivities: The building stock and roads in the San Pedro/Harbor Area are sensitive to flooding and undermining from erosion. Not many residential buildings will be exposed to sea level rise because they are terraced up on the hillside, but there are some people that live in boats in the marina. Roads could be damaged by these impacts.

Adaptive Capacity: The City Planning department is uncertain if this asset could continue to function if partially disabled, because it depends upon the extent of the damage. The City Planning Department does not have any efforts in place to make these assets more resilient.

Consequences: Impairment of roads would have significant economic consequences because they are important for regional goods movement due to their proximity to the Port of Los Angeles. Damage to roads could also limit access to the neighborhoods. Damage to the building stock could displace businesses and low-income residents.

Pacific Coast Highway (PCH) in Pacific Palisades Area

This asset consists of approximately 2.5 miles of PCH from Sunset Boulevard to Entrada Drive. The highway in this stretch generally has six lanes and it runs near the ocean, separated from the sea by sandy beaches and some coastal armoring. CalTrans has jurisdiction over PCH, but it provides a critical connection to coastal communities.

Sensitivities: This asset is sensitive to flooding and undermining from erosion. These impacts could result in damage to the highway, potentially causing frequent closures and even structural failure.

Adaptive Capacity: It is uncertain if PCH could continue to function if partially disabled, because it would depend on decision-making by CalTrans regarding keeping the highway open with a reduced number of lanes.

Consequences: Impairment of PCH would have significant economic consequences, because it's an important transportation connection in the region. In addition, it would have adverse consequences for communities living in Pacific Palisades who could have difficulty accessing their homes or be less accessible by emergency services.

Appendix 3: Social Vulnerability Assessment

Sea-level rise Impacts and Flooding Risks in the Context of Social Vulnerability: An Assessment for the City of Los Angeles

Prepared for the Mayor's Office, City of Los Angeles

Prepared by
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CONTENTS

EXECUTIVE SUMMARY

In 2008, California's then-Governor Schwarzenegger signed the Executive Order S-13-2008 that required the California Natural Resources Agency to coordinate the development of a state Climate Adaptation Strategy. Following this executive order, the state completed its first statewide adaptation strategy in December 2009, which is being updated in 2012 (at the time of this assessment). Partially in response to the state's adaptation strategy, several regions and communities across California have initiated studies and planning processes to better understand how climate change will affect their areas and also to determine how to reduce and prepare for these impacts. This social vulnerability assessment for the City of Los Angeles makes up part of the City's overall vulnerability assessment for sea-level rise, which fulfills Milestone 2 of the City's initial adaptation planning process in 2012-2013.

Concepts Defined

For the purposes of this report, we employ the terminology used in the State of California's 2009 Climate Adaptation Strategy. ***Vulnerability*** – in the most general sense – describes a system's susceptibility to harm or change. Vulnerability is the combined result of exposure, sensitivity, and adaptive or response capacity and, as such, a function of the character, magnitude, and rate of the climate change hazard to which a system is exposed, as well as of non-climatic (social and environmental) characteristics of the system, which determine its sensitivity and adaptive capacity. This assessment focuses on the **s*ocial vulnerability***, pointing to the factors that make certain groups of people more susceptible to harm. Thus, we describe the social and economic characteristics of coastal neighborhoods in the City of Los Angeles that are associated with lower adaptive capacity and higher sensitivity to flood events, and when possible, we reference to their potential exposure to flooding from sea-level rise. The term adaptation is often defined as any adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which minimizes harm or takes advantage of beneficial opportunities. In this report, we will refer to ***adaptation*** as including all those adjustments in planning, management and decision-making a government entity, business, or private citizen might make to prepare for and deal with the impacts of climate change.

Sea-Level Rise and Flood Risk from Climate Change

Sea-level rise – largely a result of warming ocean waters and melting ice caps – is among the most certain consequences of climate change, although considerable uncertainty remains over the exact extent of rise both globally and along different stretches of the coastline. Over the past century, sea level has risen by approximately 7 inches along the California coast, which is consistent with the observed global average. A set of maps created and provided by the US Geological Survey were used to inform this assessment with an initial estimate of the areas and communities that could be impacted by sea-level rise inundation or storm-related flooding as the baseline elevation increases. The maps show the estimated extent of flooding from a relatively minor storm after 16 and 55 inches of sea-level rise, representing projections for 2050 and 2100, respectively. The storm scenario is based on the January 2010 storm, which is considered "10 year flood," i.e. a flood with a 10% probability of occurring in any

given year. For the purposes of this assessment, the more commonly used planning scenarios by local communities – such as the 100- (1% chance) or 500-year flood (0.2% chance of occurring in any given year) – were not yet available.

Scientists estimate that by the end of the 21st Century, the extremely high flood levels currently associated with "century" or "100-year" flood events will occur on average once per year along California's coast (Bromirski et al. 2012). This means that a storm such as the January 2010 storm (a decadal or "10-year" storm at present and the design storm for this adaptation planning effort) can be expected to occur at least annually well before the end of the century, and probably much sooner and far more frequently.

Demographic Characteristics Indicating High Social Vulnerability

This assessment describes the elements of social vulnerability as they relate to sea-level rise flooding risks and the City of Los Angeles' residents. We provide brief snapshots of the three coastal areas within the City of L.A. that will experience the direct impacts of sea-level rise, which is followed by a description of population characteristics that indicate how and where some segments of coastal communities are more socially vulnerable to flooding than others. Characteristics presented include:

- Income and poverty
- Education levels
- Females as head of household
- Race
- Language isolation
- Age
- Housing type and age
- Physical and mental illnesses and disabilities

These characteristics are associated with a higher sensitivity and/or lower adaptive capacity to flooding and sea-level rise, and thus can inform adaptation planning.

Key Findings

First, income is one of the most important indicators of adaptive capacity. Per capita income in Los Angeles overall tends to be higher along the coast than in the interior. However, there is a pocket located around the Port of L.A. where a high proportion of the population lives below the poverty level. High proportions of the population with low education levels (e.g. those over 25 years old not graduated from high school) are also associated with lower adaptive capacity. They can be found particularly in San Pedro and Wilmington. In these same neighborhoods Census data shows that high proportions are linguistically isolated (speak English less than "very well") and are largely Hispanic/Latino[1].

Identifying populations that are more vulnerable due to these particular factors can inform emergency response planning for flooding, especially as sea level rises, and for developing strategies to engage community members to participate actively in the climate adaptation planning process. This might include, for example, conducting workshops and preparing other public outreach materials in Spanish

and, given low education and high poverty levels, using alternative methods that do not require literacy or internet access.

Other characteristics that indicate social vulnerability presented in this assessment include housing type and control over living situation. Census data shows a high proportion of older housing, which tends to be more sensitive to flooding (lower building codes, less flood-proofing), in Venice and, again, neighborhoods surrounding the Port of L.A. These same communities have a high proportion of renters, which tend to not have the means or incentive to flood proof their homes. Segments of the population that may need special assistance in emergencies because of a lack of mobility or other disadvantages include the elderly, homeless, those with existing physical or mental illness, and those living in group quarters. An important first step to preparing special assistance for these populations in emergency situations is to document where they reside so that first responders know the extent of the need and can direct it appropriately when the time comes.

Researchers have developed different methods integrating these (and other) social vulnerability characteristics. Here, we calculate a Social Vulnerability Index (SOVI), based on a combination of population characteristics representing adaptive capacity and sensitivity. It shows relatively low overall social vulnerability along the coast in Los Angeles. Instead the highest vulnerability is concentrated in the interior of the city and county. Still, based on this SOVI measure, portions of San Pedro, Wilmington, and one census block in Venice score with relatively high social vulnerability compared to the rest of the county.

The Climate Change Community Screening Tool (CCCST), developed by the California Department of Public Health specifically for climate change impacts, results revealed clear racial disparities in terms of who is at risk of climate change impacts. The screening tool showed that in Los Angeles County, African-Americans and Hispanics/Latinos were at higher risk of climate change stressors than whites. They also found that, in terms of income levels, households with lower income are at higher risk from climate change stressors. The mapped results of overall climate change vulnerability from this screening tool show a much higher measure of overall vulnerability along the coast of L.A. This measure incorporates the exposure dimension of vulnerability in the cumulative vulnerability score by including risk of climate change impacts (including flooding exacerbated by sea-level rise), whereas the SOVI focuses only on sensitivity and adaptive capacity indicators. This methodological divergence partially explains the differences in results. The difference in results between the two tools highlights the importance of understanding the underlying methods and variables used to calculate integrated snapshot vulnerability in Los Angeles. Importantly, however, the underlying drivers of social vulnerability are consistent in the two approaches.

Integrated scores of vulnerability can be useful to help prioritize areas of concern for climate adaptation planning, but the review of individual characteristics can help inform the development of specific adaptation strategies.

Community Services

A number of services and supporting infrastructure are potentially at risk of impairment from short term or long term damage from flood events as sea level rises. These include impairment of drainage and treatment of wastewater and sewage, rapid emergency response, access to food and prescription medicines, risks of salinization to coastal groundwater reservoirs, access to and functionality of energy-related facilities, transmission, and transformers, and important ecosystem services. While assessing these services is beyond the purview of this report, it is important to highlight that the interruption of these services and supporting infrastructure can have disproportionate impacts on those more sensitive to and with lower adaptive capacity for dealing with flooding as sea level rises and other climate change stressors ensue. Impairment of these services can also affect households and communities outside the current or future floodplain. Thus, an integrated approach to adaptation planning (with neighboring jurisdictions) is important to examine these critical linkages.

Recommendations

Based on this assessment we offer the following recommendations for moving forward with the adaptation process:

- *Invest in a strong foundation for climate adaptation*: Effective adaptation to climate change in a region entails building on regional, local and other efforts over time. Investing in a strong foundation in the early stages of the process can help support adaptation efforts in the future. Elements of such a foundation would consist of continually improving the scientific foundation in support of technical and structural solutions, but also exploring the feasibility of policy changes, creative financing, capacity building among key staff and decision-makers, and effective public engagement.
- *Define clear adaptation goals:* Most adaptation planning processes to date in the US have been undertaken without clearly defining what "success" would look like. Goals could focus on both procedural and outcome intentions. Strategies flow more clearly from identified goals.
- *Develop clear prioritization and selection criteria for choosing among possible adaptation strategies:* Such criteria would help with prioritization when budgets, timelines, technical considerations, and social concerns and political feasibility inevitably place constraints on preferred solutions.
- *Update the vulnerability assessment as better flood risk models and maps become available*
- *Expand partnerships in developing adaptation options:* Much adaptation that addresses social vulnerability and public concerns requires close collaboration with the affected groups and extending the network of adaptation stakeholders to include those already working on increasing community resilience in the face of disasters.
- *Incorporate more detailed community-based information as it becomes available*
- *Coordinate adaptation with neighboring communities beyond the city borders*

This social vulnerability assessment serves as first step for incorporating on-the-ground conditions into climate adaptation planning for the City of Los Angeles. Adapting to climate change is a continual process, and just like climate change science, social vulnerability information should also be updated regularly to place adaptation planning and implementation on the most up-to-date informational foundation. This report describes existing vulnerabilities and inequalities that can be addressed now and

in the future regardless of the extent of climate change. In other words, reducing social vulnerabilities has benefits independent of climate change that can support a socially equitable and prosperous city.

1. Introduction: Goal, Purpose and Audience of this Study

1.1 Purpose and Goal

The purpose of this study is to contribute social science-based information and knowledge about population segments at risk to sea-level rise impacts as part of the City of Los Angeles' climate adaptation planning process. The goal of this report is to assess social vulnerability to coastal flooding within the City of Los Angeles, focusing solely on sea-level rise and related flooding during extreme events. Information about social vulnerability, in combination with an assessment of physical risks to infrastructure, helps prioritize support (both for disaster response and long term adaptive responses) on those least able to help themselves. Thus the adaptation process is likely to be smoother, not resulting in extensive losses during disasters or the disorderly abandonment of the coast. Moreover, by including consideration of social vulnerability and the populations who could be disproportionately affected by climate change as adaptation options are developed, it is more likely to prevent socio-political tensions in implementing adaptation options.

The timeline for conducting this assessment was from May through June 2012. Thus, this report constitutes a first, rapid assessment of social vulnerability based on pre-existing information from secondary data sources, such as City and County planning documents, other assessments related to vulnerable segments of the city (and some cases county's) population, newspaper articles about past floods, Census 2010 data when available, American Communities Survey Census 2006-2010 data, and Census 2000 data when it provides information at a higher resolution[2]. These data and information sources were compiled and synthesized to provide a first social vulnerability assessment for the City. It does not constitute technical, primary research due to the timeline of the project. Yet, it aims to show the value of incorporating social vulnerability into climate adaption planning for the City. In addition, this report also points to additional information or processes that may be useful in developing a more sophisticated assessment. Adapting to climate change is a continual process, and – just like physical climate change science – this type of information should be updated regularly as adaptation planning continues in the future and as additional information becomes available.

1.2 Context and Audience

In 2008, California's then-Governor Schwarzenegger signed Executive Order S-13-2008 that required the California Natural Resources Agency to coordinate the development of a statewide Climate Adaptation Strategy. Following this executive order, the state completed its first statewide adaptation strategy in December 2009,[3] which is being updated in 2012 (at the time of this assessment). Partially in response to the state's first adaptation strategy,[4] several regions and communities across California have initiated studies and planning processes to better understand how climate change will affect their areas and determine how to reduce and prepare for these impacts.[5] This social vulnerability assessment for the City of Los Angeles is part of the overall vulnerability assessment, which fulfills Milestone 2 of the City's initial adaptation planning process in 2012-2013.

This social vulnerability assessment is one element of the City's adaptation planning process. Established phases, with an end date of April 2013, include:

Milestone 1: Develop existing conditions & policy review report

Milestone 2: Develop sea-level rise vulnerability and risk assessments

Milestone 3: Develop sea-level rise adaptation measures and a sea-level rise adaptation plan

Milestone 4: Adopt a first sea-level rise Adaptation Plan

The impacts of climate change are disproportionately distributed across populations – harming some segments of the population more than others. Some populations, especially those who experience social inequalities, are less able to prepare for, respond to or recover from a disastrous event than others.[6] To reduce the most severe impacts to these populations, adaptation strategies can be strategically developed addressing the existing conditions and social vulnerabilities within a community and region. Such strategies can only be developed by knowledge of the socially vulnerable, which is how this assessment aims to serve the city.

Disproportionate impacts of climate change are a long-standing concern among researchers, community organizations, and governments as climate adaptation efforts increase. The State of California has supported several studies to help better identify and understand social vulnerabilities to climate change. The California Office of Environmental Health Hazard Assessment (at the request of the California Environmental Protection Agency) has published a report[7] about environmental justice indicators in California, focusing only on heat and air quality impacts associated with climate change. With support from the California Energy Commission, the Pacific Institute published a statewide assessment of how sea-level rise could affect coastal communities in 2009[8] and then more broadly across other climate change impacts in 2012,[9] both of which included a range of environmental justice indicators. The California Department of Public Health recently completed a study developing a climate vulnerability screening tool that indicates social vulnerability (in terms of sensitivity, adaptive capacity and exposure) to impacts of flooding from sea-level rise, increased heat events, and poor air quality conditions (from increasing ozone in hot, polluted air basins). They piloted the tool in counties of L.A. and Fresno, therefore results of this work is also included in the discussion of this assessment. These studies apply slightly different methods, but utilize many of the same indicators to identify populations at risk.

Social vulnerability and the unequal burden of climate impacts are also growing concerns of governments and communities at the local and regional levels as these entities begin adaptation planning. In California this type of social vulnerability analysis has also been conducted as part of the adaptation planning processes in San Luis Obispo,[10] Fresno Counties[11] and the San Francisco Bay Area.[12] Aside from California-based studies, the assessment methodology has also been applied nationally and internationally, most of which has been developed for disaster response planning and assessments (e.g. Emrich and Cutter, 2008; Martinich et al. 2012).[13] These use indicators of social vulnerability based on US Census data about the characteristics of populations within a given area.

2. Adaptation and Vulnerability: Defining Key Concepts and our Research Approach

2.1 Key Concepts and Definitions

The effects of climate change even in just one location, such as Los Angeles will differ widely because of the regional differences in the nature of expected climate change (whether it is sea-level rise, higher temperatures, or patterns of extreme events) and because of the differences in existing conditions of the affected systems within the given regions. Together, the physical changes in climate, the condition of the interacting natural and human systems, and whatever measures are taken to prepare for, and minimize the risks will determine the ultimate impacts.

For the purposes of this report, we employ the terminology used in the California's 2009 Climate Adaptation Strategy.[14] We first distinguish climate change impacts from vulnerabilities. A ***climate change impact*** is an effect of climate change on the structure or function of a system. Potential impacts are those that may occur without considering adaptation. By contrast, ***vulnerability*** – in the most general sense – describes a system's susceptibility to harm or change. Vulnerability is the combined result of exposure, sensitivity, and adaptive or response capacity and as such a function of the character, magnitude, and rate of climate change to which a system is exposed, as well as of non-climatic (social and environmental) characteristics of the system, which determine its sensitivity and adaptive capacity. This assessment focuses on the ***social vulnerability***, pointing to the factors that make certain groups of people more susceptible to harm. Thus, we describe the social and economic characteristics of coastal neighborhoods in the City of Los Angeles that are associated with lower adaptive capacity and higher sensitivity to flood events, and when possible, we reference to their potential exposure to flooding from sea-level rise.

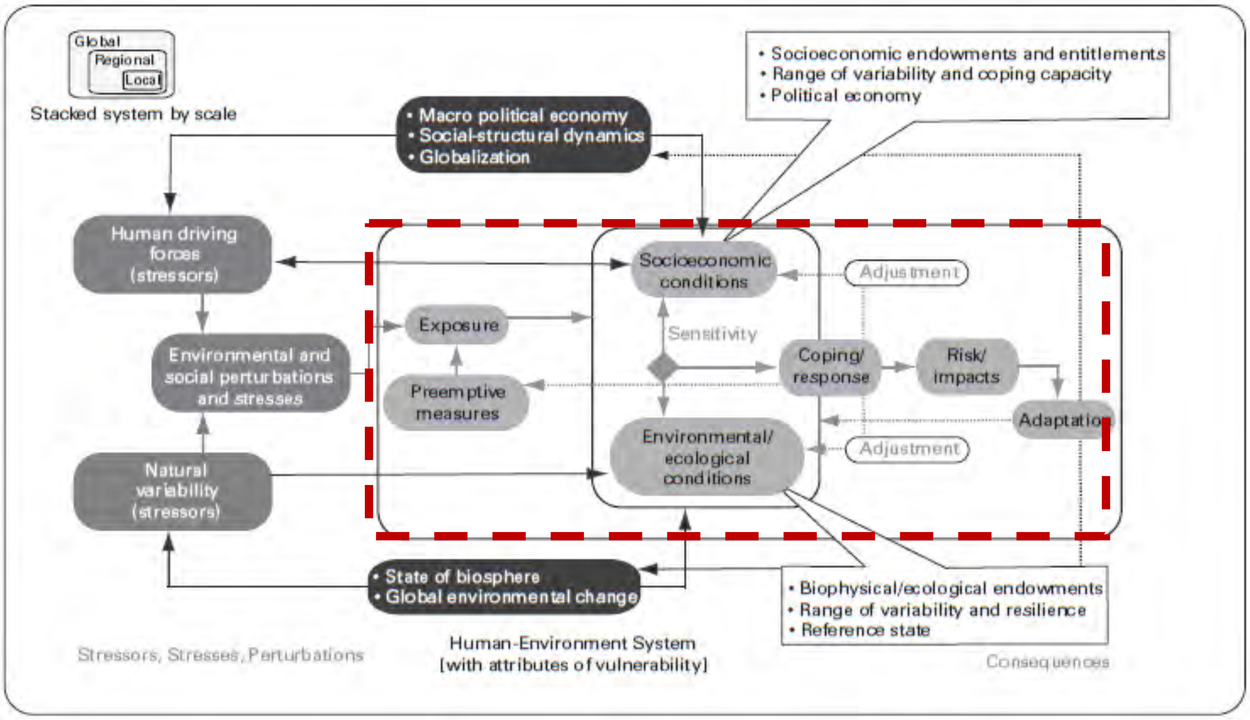


FIGURE 1: VULNERABILITY OF COUPLED HUMAN-NATURAL SYSTEMS (DASHED RED BOX, ADDED BY AUTHORS, HIGHLIGHTS CORE ELEMENTS OF FOCUS IN THIS ASSESSMENT (SOURCE: KASPERSON, KASPERSON, AND TURNER 2009)[15]

First, ***exposure*** is the nature and degree to which a system experiences a stress or hazard.[16] Examples of stresses that are familiar to coastal portions of the city include coastal flooding from storms, flooded roadways, impaired drainage backing up storm water into streets and homes, erosion of beaches and hillsides damaging beachfront property and recreational facilities. Many of these may be exacerbated by climate change. The levels of exposure from a stressor often are not distributed evenly across a geographic space or across populations (e.g., coastal areas will experience storms more, but extreme heat less than those inland). It is also important to note that climatic hazards can be one-time extreme events or slow creeping problems that are more chronic in nature, which – if not addressed – can eventually lead to a disastrous situation (e.g., a heavy precipitation event combined with an increase of sea level and high tides could create a disastrous flood or cause cliffs to fail compared to the hard-to-perceive slower changes in sediment movement and average sea-level rise). Thus, how exposure is distributed across space and populations, and the nature of the climate perturbation, are important for understanding local level vulnerability. The section on climate change projections summarizes the best available science at present on what climate changes and perturbations the county may be exposed to in the future.

The second dimension of vulnerability is ***sensitivity***, which refers to the degree to which the system is impacted by a given stressor, change or disturbance.[17] The effect may be direct (e.g., a single story home in low-lying coastal area with no flood-proofing) or indirect (e.g., climatic or non-climatic stressors may cause people to be more sensitive to additional extreme conditions from climate change than they would be in the absence of these stressors).[18] Thus, the sensitivity of a system is not just the result of

climate-stresses, but also influenced by non-climatic stresses. For example, those with existing illnesses may be more sensitive than healthy adults to water-borne bacteria that may spread during flooding. People already under significant amounts of stress for health, economic, or psychosocial reasons may be more susceptible to additional climate-related health stresses.

The third dimension of vulnerability is ***adaptive capacity***. This term encompasses the ability to cope with extreme events, to make adaptive changes, or to transform more deeply, including the ability to moderate potential damages (negative consequences) and to take advantage of opportunities (beneficial consequences) that may arise from climate change. While there are a number of ways to measure and evaluate adaptive capacity (and the scientific community does not agree on just one), this concept relates to the degree to which the system can adapt in order to deal with a stressors or change. Adaptive capacity can be assessed on any level of organization, from the individual to the national or international level. In this report we focus on the individual, neighborhood, and community (i.e. municipality) levels. The factors that tend to increase adaptive capacity include economic resources, highly functional institutions, adequate infrastructure, availability of technological options and capacities, sufficient information and high levels of education and skill among decision-makers and stakeholders, significant social capital among stakeholders, and equity in the access to these resources and capacities. These definitions of exposure, sensitivity and adaptive capacity illustrate why in this report we focus extensively on the social characteristics of the city's population and economic sectors[19].

Adaptation is frequently defined as any adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which minimizes harm or takes advantage of beneficial opportunities.[20] Strictly speaking, this broad definition includes mitigation actions, i.e., actions to reduce the causes of climate change. Many experts indeed view mitigation as the ultimate adaptation. Many others view them as separate sets of actions but both as equally necessary and complementary to each other. Mitigation thus limits the pace and ultimate degree of climate change by reducing the causes, thus making it possible for natural and social systems to adapt, while adaptation addresses the consequences of change that could not be avoided. For individuals familiar with disaster preparedness and management, "mitigating" potential impacts from disasters are among the actions one might take to prepare for and adapt to climate change. To avoid unnecessary confusion, in this report, we will refer to ***adaptation*** as including all those adjustments in planning, management and decision-making a government entity, business, or private citizen might make to prepare for and deal with the impacts of climate change.

Finally, ***resilience*** is the ability of a system to absorb some amount of change, including shocks from extreme events, bounce back and recover from them, and, if necessary, transform itself in order to continue to be able to function and provide essential services and amenities that it has evolved or been designed to provide.[21] In light of the potential risks from climate change, resilience has become a highly desirable outcome of adaptation for many. If adaptive actions can help a system be better prepared, able to bounce back faster and better from an extreme event, or deal with relative ease with changing conditions, continue to learn from such events and adjust over time, and provide the goods, services, functions and amenities that are desirable, then adaptation may be considered successful.

2.2 Methods to Assess Vulnerability

We use the three dimensions of vulnerability to reveal the different ways that communities are vulnerable to sea-level rise and related flooding during extreme events. Assessing potential direct effects on livelihoods, such as people's safety, health and well-being, and the ability to economically support them, can reveal first-order effects of climate change. Also contributing to social vulnerability is the ability of communities (or segments of populations) to collectively respond to a problem. Therefore, which groups have power – and which do not – and therefore can mobilize and obtain political attention also reveals insight into the social vulnerability in an area.

This assessment draws on publicly available reports, plans, and data repositories available from local (municipal and county), state and federal sources, peer-reviewed research papers, and phone conversations with representatives from coastal neighborhood councils and other organizations and researchers vested in assisting vulnerable populations.

The following section summarizes the threat of sea level-rise and the resulting growing risks from flooding during high tides and storms. Then the ocean-bordering coastal communities within the city limits are introduced in brief snapshots, providing basic geographic, demographic, and economic characterization of the areas of particular interest for this study. This is followed in Section 5 with a detailed description of the demographic characteristics that indicate one or more of the dimensions of social vulnerability. This section relies largely on data from the US Census (from 2010 where available, and also American Community Survey 2006-2010), and then summarizes these characteristics in two vulnerability indices that provide an integrated view of social vulnerability. Section 6 offers some recommendations for incorporating social vulnerability into an ongoing adaptation planning process, how the future assessments can be expanded to represent existing community concerns and other climate change-related stressors (increasing heat events, decreased water supply, fire, and landslides), and adaptation options that go beyond technical or infrastructure changes, such as governance and building staff and leaders' capacity.

3. Geography and Sea-Level Rise Projections for the City of Los Angeles

3.1 Expected Impact of Sea-Level Rise in Los Angeles

Sea-level rise – largely a result of warming ocean waters and melting ice caps – is among the most certain consequences of climate change, although considerable uncertainty remains over the exact extent of rise both globally and along different stretches of the coastline. Over the past century, sea level has risen by approximately 7 inches along the California coast, which is consistent with the observed global average. While an oceanographic oscillation of currents (Pacific Decadal Oscillation) in the Pacific Ocean has suppressed sea level from rising along the West Coast of the United States since the 1980s, scientists currently see this phase coming to an end, and thus agree that sea-level rise will resume a pace consistent with the global average in coming decades.[22] A National Research Council study released in June 2012, commissioned by California, Oregon, Washington and several federal agencies, concludes that sea level along California's coast will rise up to 9 inches by 2030, 1.5 feet by 2050, and 4.5 feet by 2100.[23] The rate of sea-level rise over the next several decades, thus, is expected to be four to eight times larger than the total rise over the entire 20th century.

Along the coast of Los Angeles (both city and county), sea-level rise could lead to the following impacts:

- Increased erosion of already retreating coastal bluffs and of beaches either naturally retreating or maintained in place by sand replenishment, increasing the risk of cliff failures and damage to the Pacific Coast Highway and other critical roads along the coast;
- Coastal flooding with higher storm surges and flood elevations during coastal storms, potentially inundating valuable transportation, commercial, energy, wastewater, and residential infrastructure in low-lying areas;
- Permanent inundation of the few remaining or restored coastal wetlands in the county
- Reduced capacity to absorb runoff and drain it away from inland areas as sea-level rise elevates the coastal groundwater levels; and
- Salt water intrusion into coastal groundwater basins through which freshwater is delivered to serve local residents.

3.2 Design of Floods Used in This Assessment

A set of maps created and provided by Patrick Barnard (USGS) were used to inform this assessment with an initial estimate of the areas and communities that could be impacted by sea-level rise inundation or storm-related flooding as the baseline elevation increases. The maps show the estimated extent of flooding from a relatively minor storm after 16 and 55 inches of sea-level rise, representing projections

for 2050 and 2100, respectively. The storm scenario is based on the January 2010 storm, which is considered "10 year flood," i.e. a flood with a 10% probability of occurring in any given year.

For the purposes of this assessment, the more commonly used planning scenarios by local communities – such as the 100- (1% chance) or 500-year flood (0.2% chance of occurring in any given year) – were not yet available.[24] A previous assessment (Heberger et al. 2009),[25] which used the 100-year flood scenario with sea-level rise of 16 and 55 inches, was based on a simplified inundation model that was not considered adequate by leaders of this project. However, a recent scientific study (Bromirski et al. 2012)[26] showed that while wind and waves are not expected to increase due to climate change, the storm surge will increase due to sea-level rise alone, causing the height and inland extent of floods to increase and thus have much larger impacts (i.e., more damage to infrastructure and putting more people at risk of flooding) than have been experienced historically. Another study by Tebaldi, Strauss, and Zervas (2012)[27] modeled how sea-level rise could affect storm surge, found that extreme water levels along the coast that are considered to be 100-year events are expected to become 10-year events within the next 40 years due to the expected increase in the base elevation (sea level) alone.

Bromirski et al. (2012) and Cayan et al. (2012) estimate that by the end of the 21st Century, these extremely high water levels that are currently considered "century" or "100-year" flood events will occur on average once per year along California's coast.[28] This means that a storm such as the January 2010 storm (a decadal or "10-year" storm at present) can be expected to occur at least annually well before the end of the century, and probably much sooner and far more frequently.

Finally, the National Research Council (2012) confirms these SLR projections and expectations of impacts on flooding (and concurrent coastal erosion and cliff failures). Thus, the finding on the extent of future flooding reported here should be considered a conservative estimate of minimum impacts. As sea-level rise driven flood risk maps are refined for the coast of Los Angeles in the future, including for higher flood risk levels such as the 100-year and 500-year flood, the extent of exposure to flood risk along the city's shoreline can be expected to expand considerably. Thus, the actual extent of flooding-exposed areas – and thus areas of concern with regard to social vulnerability – will be considerably larger. We therefore show maps of population variables contributing to social vulnerability that are outside the current or future 10-year flood risk zone to allow for a broader perspective and expect that the information presented in this report for populations currently residing outside the 10-year flood risk zone (at current or future sea level) will still be useful for future adaptation planning.

4. Snapshot of Coastal Neighborhoods of L.A.

The City of Los Angeles borders the coast in three different sections (Figure 2). These include Pacific Palisades, Venice/Playa del Rey, and San Pedro/Wilmington/Port of L.A. This section provides brief descriptions of each community, including the number of people living in each area and other defining characteristics. The primary infrastructure and services of concern that could be at risk from SLR and flooding are also briefly discussed to illustrate how their impairment would put populations at risk.[29] While the three communities within city limits are the primary foci of this assessment (because they are directly within city bounds), attributes of neighboring coastal neighborhoods and communities are also discussed (see Section 6) highlighting where coordination may prove useful and effective for preparing for and adapting to sea-level rise.

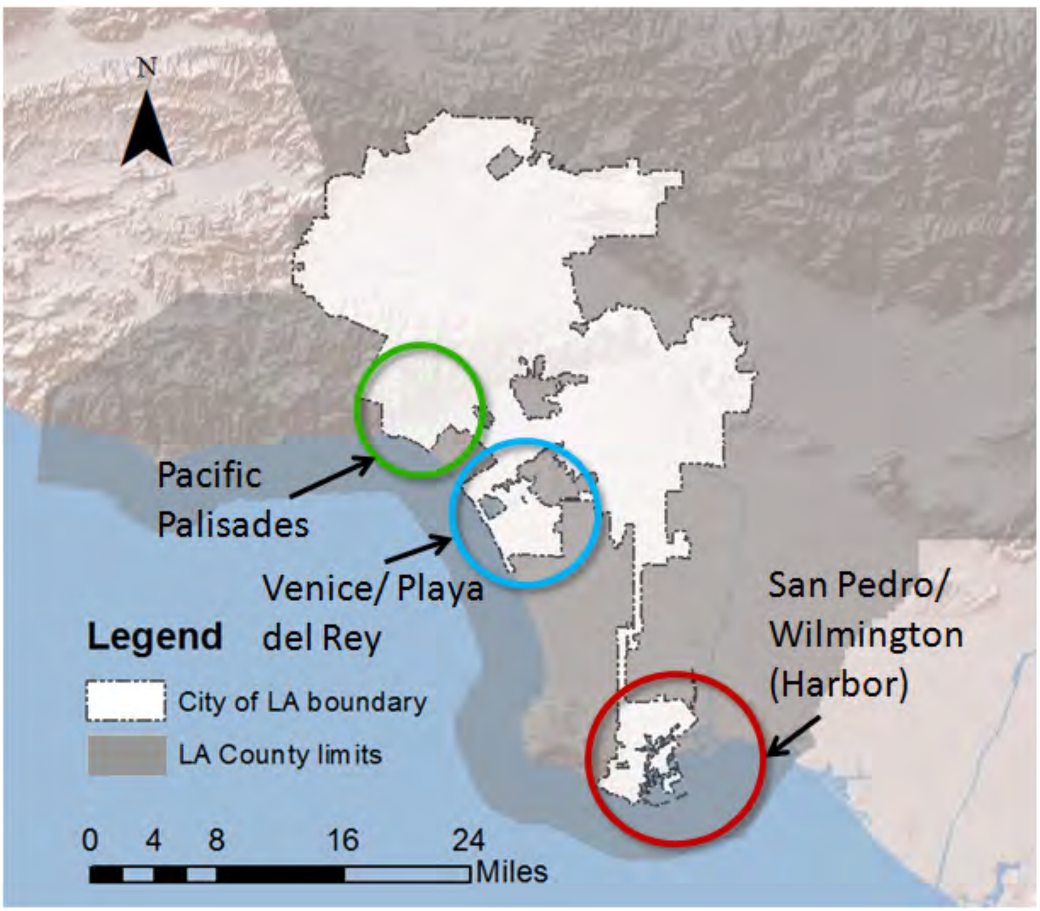


FIGURE 2. REGIONS IN THE CITY OF LOS ANGELES (WHITE) THAT TOUCH THE COAST AND THAT ARE DIRECTLY EXPOSED TO SEA-LEVEL RISE AND COASTAL STORM–RELATED FLOODING. AREAS WITHIN LOS ANGELES COUNTY THAT ARE OUTSIDE CITY LIMITS ARE SHADED GRAY.

4.1 Pacific Palisades

Pacific Palisades is the most northern coastal community located within the City of Los Angeles, situated on Santa Monica Bay, just south of Malibu and northwest of Santa Monica. This portion of the city's shoreline is approximately two miles long.[30] The community covers an area of 23,451 acres and has approximately 27,000 residents and 9,400 homes, residential units and business.[31] For the most part, the population residing in this community is rather wealthy[32], though there is also one mobile home park. The risks to the transportation routes and how they could affect the residential population are already a major concern in this area in terms of sea-level rise, flooding and wildfire.

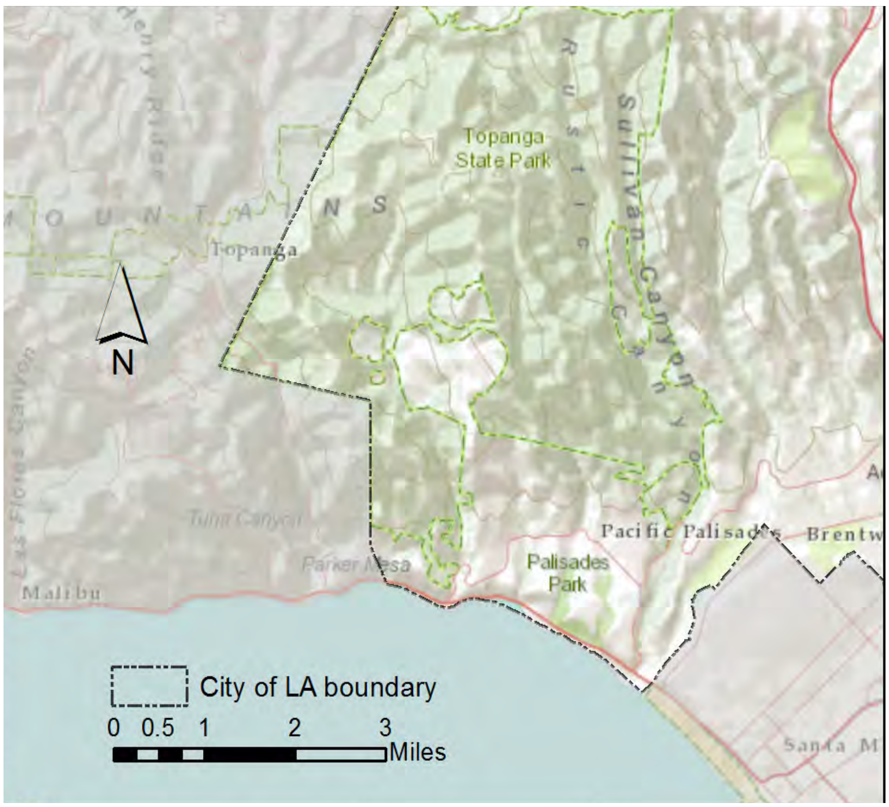


FIGURE 3: THE BOUNDARIES OF PACIFIC PALISADES (DOTTED LINES) INDICATE THE CITY OF LOS ANGELES' DIRECT JURISDICTIONALRESPONSIBILITY. PACIFIC PALISADES IS LOCATED SOUTHWESTOF MALIBU WITH SANTA MONICA AS ITS SOUTHERN NEIGHBOR. PACIFIC COAST HIGHWAY (IN RED ALONG THE COAST), WHICH ALREADY FLOODS FREQUENTLY DURING HEAVY STORMS AT CURRENT SEA LEVEL, IS A CRITICAL ACCESS ROUTE FOR GETTING IN AND OUT OF THE COMMUNITY.

Pacific Coast Highway runs along the community's coastline between the beach and several parking lots (for public beach access) lined on the landward side by residents on coastal bluff (Figure 4 and Figure 5). The beach has a long history of erosion challenges, and in efforts to maintain a desirable beach width, several breakwaters have been built, many along Will Rogers Beach. The shoreline has gotten dangerously close to the Pacific Coast Highway in some areas (see left portion of Figure 6 and Figure 7). In attempts to protect the Pacific Coast Highway from erosion, rip rap (rocks) have been placed along the highway's seaward base, which has exacerbated the sand loss and erosion of the beach. The Pacific Coast Highway already floods frequently when extreme high tides coincide with large storms.[33] The highway serves as a critically important infrastructure given that residents rely on this for evacuating the area, and tourists and recreationists rely on it for access to the public beach. For some residents, the

highway is the only evacuation route (and thus the only emergency responder route to access residences). The alternative emergency services access into -- and evacuation routes out of – the community are narrow, windy (i.e. slower), and few (i.e. easily congested).

FIGURE 4: THE PACIFIC COAST HIGHWAY IN PACIFIC PALISADES, SHOWING ITS LOCATION WEDGED BETWEEN THE SHORELINE AND THE HILLSIDE. MOST PORTIONS, LIKE THIS ONE, HAVE PARKING LOTS ALONG THE BEACH FOR PUBLIC ACCESS TO THE SHORE (SOURCE: GOOGLE MAPS)

FIGURE 5: PACIFIC COAST HIGHWAY LIES BETWEEN AN ERODING HILLSIDE (RETAINING WALL SHOWN ON THE RIGHT IN THE PHOTO) AND THE BEACH AT THE SOUTHERN PORTION OF THE CITY LIMITS ALONG PACIFIC PALISADES' STRETCH OF COASTLINE (SOURCE: GOOGLE MAPS).

FIGURE 6: BREAKWATERS BUILT ALONG THE SHORELINE TO PREVENT EROSION OF THE DESIRABLE WILL ROGERS BEACH IN PACIFIC PALISADES. THE PACIFIC COAST HIGHWAY IS THE ONLY EVACUATION ROUTE FOR SOME COASTAL RESIDENTS FROM THESE SHORELINE AREAS (HIGHWAY HIGHLIGHTED IN YELLOW). SOURCE: GOOGLE MAPS

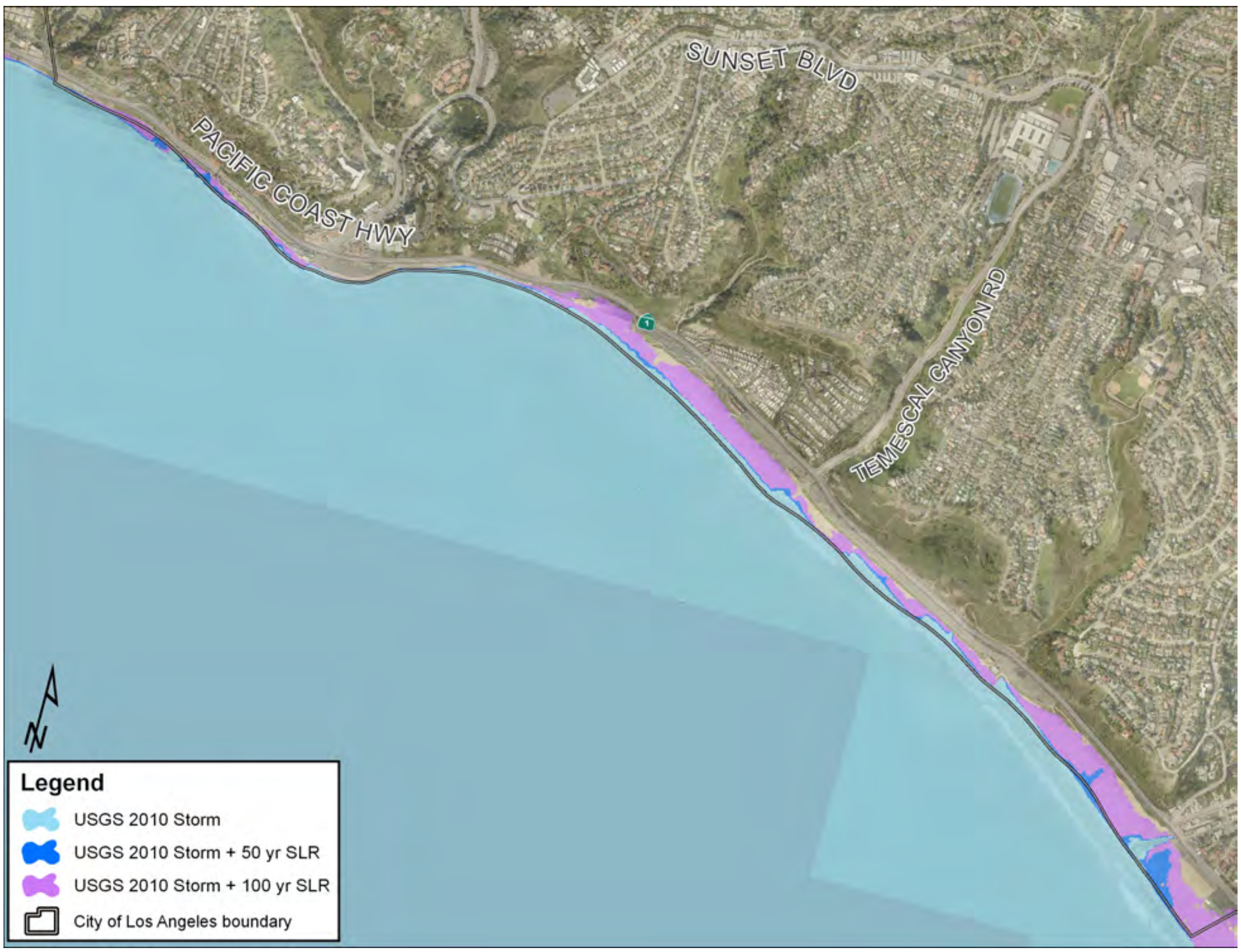


FIGURE 7. EXTENT OF FLOODING ALONG THE SHORELINE OF PACIFIC PALISADES IN A 10-YEAR FLOOD WITH SEA-LEVEL RISE OF 16 INCHES (ORANGE) AND 55 INCHES (RED). SOURCE: BARNARD USGS 2012.

4.2 VENICE AND PLAYA DEL REY

Venice and Playa del Rey are the communities in the central portion of where the City of L.A. touches the coastline (Figure 8). Marina Del Rey, a commercial and residential development in the

unincorporated part of L.A County, is nestled in between Venice and Playa del Rey. Venice, the northern one of the two communities, is located just south of Santa Monica and has a low-lying topography. Originally a marsh, this area is already highly susceptible to flooding even at current sea level. Playa del Rey is located south of Marina del Rey, and bordered on the east by the community of Westchester (and Loyola Marymount University) and the Los Angeles International Airport, and on the south by the City of El Segundo.

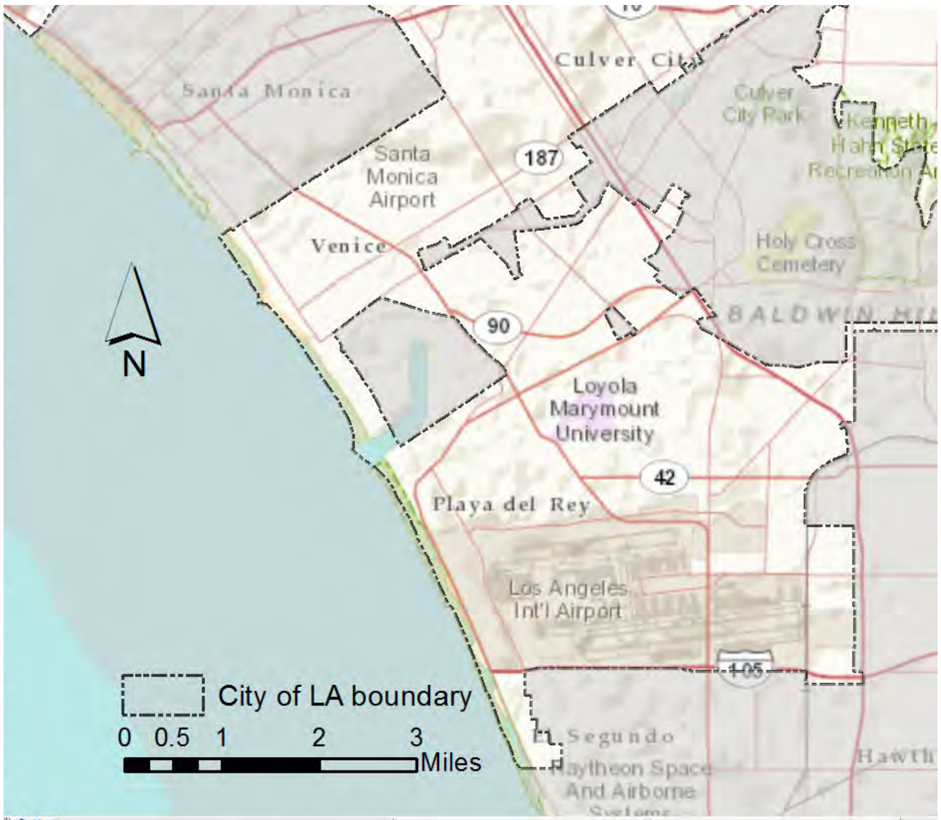


FIGURE 8: COMMUNITIES OF VENICE AND PLAYA DEL REY CONSTITUTE ANOTHER SECTION OF WHERE THE CITY OF LOS ANGELES TOUCHES THE COAST ALONG SANTA MONICA BAY. GRAY AREAS DENOTE AREAS OUTSIDE THE CITY'S JURISDICTIONAL BOUNDARIES.

The Ballona Creek (a flood control channel) and the Ballona Wetlands make up the northern border of Playa del Rey. Environmental groups have spent several decades protecting and restoring these wetlands (now a project under the auspices of the California Coastal Conservancy). These are the last remaining coastal wetlands in the Los Angeles Basin, all of which could be flooded by a 10-year storm by 2050 (Figure 9). The southern-most tip of the City of L.A.'s jurisdiction is marked by the Hyperion Wastewater Treatment Plant. Just south of Hyperion is an oil refinery, also right on the coast, though outside the bounds of the City of L.A. (in El Segundo).

The population of Venice in 2008 was approximately 40,885 people.[34] The area is home to a diverse population that ranges from high to low income. The socioeconomic status changes from block to block. The gentrification of the area is a common complaint and concern for some community members, as is gang violence. Playa del Rey is home to an estimated 11,317 people (as of 2008). [35] Several segments of

population are of concern in Venice (homeless, disabled, institutionalized or group homes, and low income) (Section5). Tourism is a large part of Venice's economy – viewed by some as "the second largest tourist attraction in California, after Disneyland."[36] Many middle and low income residents work in the industry and will therefore be economically impacted if sea-level rise takes a toll on the area's tourism.

Both Venice and Playa del Rey are highly exposed to flooding already and will be even more so as sea level rises (Figure 9). A high number of people and businesses are located in areas potentially exposed to flooding from sea-level rise, and flooding will be experienced outside the areas shown in the sea-level rise map because of the poor drainage during storms in Venice. The coastal area has a history of excessive flooding during storms coinciding with high tides, largely from drainage problems in low lying areas. Power outages are a concern for community members given that aging utility lines are buried underground and could directly be exposed to, and affected by, salt water. Already during heavy rainfall, water collects in utility basins causing potential public health hazards when they are not drained regularly (e.g. potential breeding ground for bacteria and disease vectors, such as mosquitoes). Many homes in low-lying areas already use sump-pumps in their basements or garages to cope with the frequent flooding.[37]

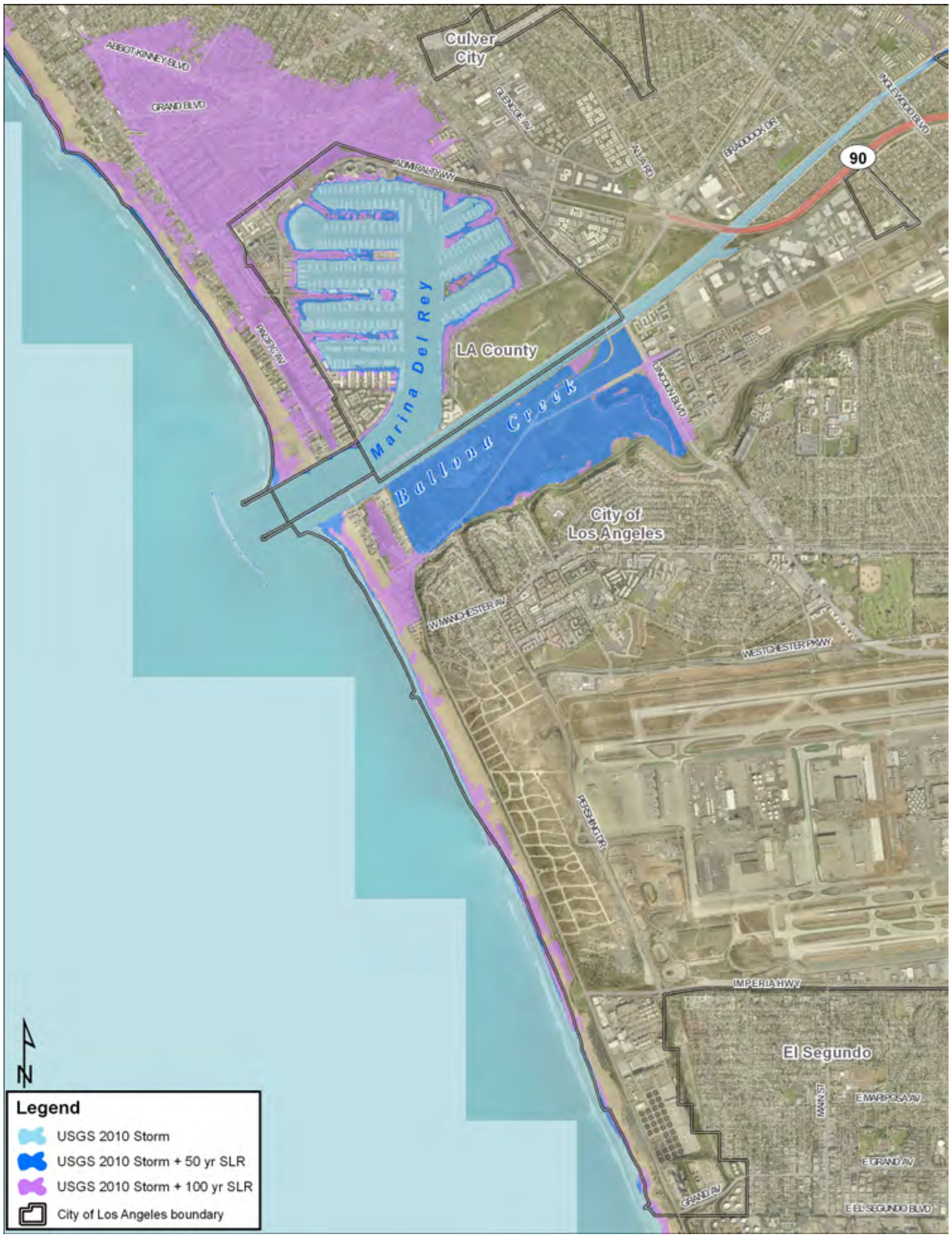


FIGURE 9. EXTENT OF FLOODING IN VENICE FROM SEA-LEVEL RISE (ORANGE REPRESENTS 16 INCHES AND RED REPRESENTS 55 INCHES OF SEA-LEVEL RISE), AS MODELED BY USGS (BARNARD 2012)[38] UNDER A 10 YEAR STORM. ADDITIONAL LAND WOULD BE AT RISK OF FLOODING DURING A 100 YEAR STORM. LARGE PORTION IN ORANGE COVERS BALLONA WETLANDS

An economic study conducted by San Francisco State University and the California Department of Boating and Waterways in 2011 on the economic impacts of sea-level rise on California beaches included a focus on Venice Beach.[39] Storm damage in Venice Beach is estimated by the study to increase with sea-level rise by nearly 640% compared to historical flood damage. The study estimates that flooding from a 5 ft. sea-level rise could result in a total of over $15 million in damages to structures and contents by 2050, and in and nearly $52 million in damages in 2100.[40] The majority of damage is expected to be from flooding damage to residential structures.

Venice

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

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

TABLE 1: ECONOMIC DAMAGES CAUSED BY 100- YEAR FLOOD EVENT WITH SEA-LEVEL RISE IN VENICE SOURCE: KING, MCGREGOR, AND WHITTET (2011)[41]

Based on the King et al. 2011 analysis, 24% of the beach area erodes with approximately 6 feet (2.0m) of sea-level rise, a small percentage compared to other beaches that may experience up to 100% of the beach eroding (e.g. Ocean Beach and Torrey Pines State Beach). Their economic estimates suggest that, "combined local and state spending losses amount to $608 million at Venice Beach following a 2.0m sea-level rise by 2100." This estimate is based on the modeled reduction in annual beach goers due to the reduced size (and thus carrying capacity) of the beach.[42] The study also reported that using beach replenishment (nourishment) to maintain the existing beach width would cost over $7 million annually. And costs for adding protective seawalls estimated for Venice Beach could amount to as much as $68 million, which would cost an estimated $2 million per year to maintain.[43]

4.3 San Pedro, Wilmington, and Port of L.A.

San Pedro, Wilmington and the Port of L.A. make up the southernmost part of the city's coastline. The Los Angeles Harbor is protected from direct wave action by a breakwater extending out from Cabrillo Beach at the point of San Pedro. San Pedro is situated between the Los Angeles Harbor (and port) to its east, Palos Verde Hills to its west, Wilmington to the north, and the Pacific Ocean to the south (Figure 10). San Pedro covers approximately 12 square miles and has an estimated 86,012 residents (as of 2008).[44] Wilmington, just north of the Port, is approximately 9 square miles and has a population of 54,512.[45] Over 85% of the population is Hispanic/Latino, whereas the neighboring community of San

Pedro is home to a population of just over 40% Hispanic/Latino.[46] Cabrillo Beach is one of the few publicly accessible beaches in the area and is a popular destination for families because the breakwater shelters the beach from direct wave action. The breakwater also prevents tidal circulation and, as a result, the beach on the harbor side has very poor water quality.[47] Alternatively, Cabrillo Beach on the open ocean side outside the breakwater has good water quality.

Wilmington is highly exposed to several environmental hazards and has a much lower average per capita income compared to San Pedro. It is situated directly behind (i.e., to the north of) the Port of L.A. with an oil refinery to its west. Both Wilmington and the low-lying portions of San Pedro (along the harbor) already flood during heavy rain events. Even if rain events remain the same, with sea-level rise, the drainage problems can be expected to be exacerbated, affecting these areas more often and severely and extending flooding to areas further inland than historically experienced. This is particularly problematic because residents in the new flood zones may be unprepared, unfamiliar with the risk, and without necessary flood insurance to assist them in recovery. In addition, none are likely to have made structural adjustments (flood proofing) to their homes.

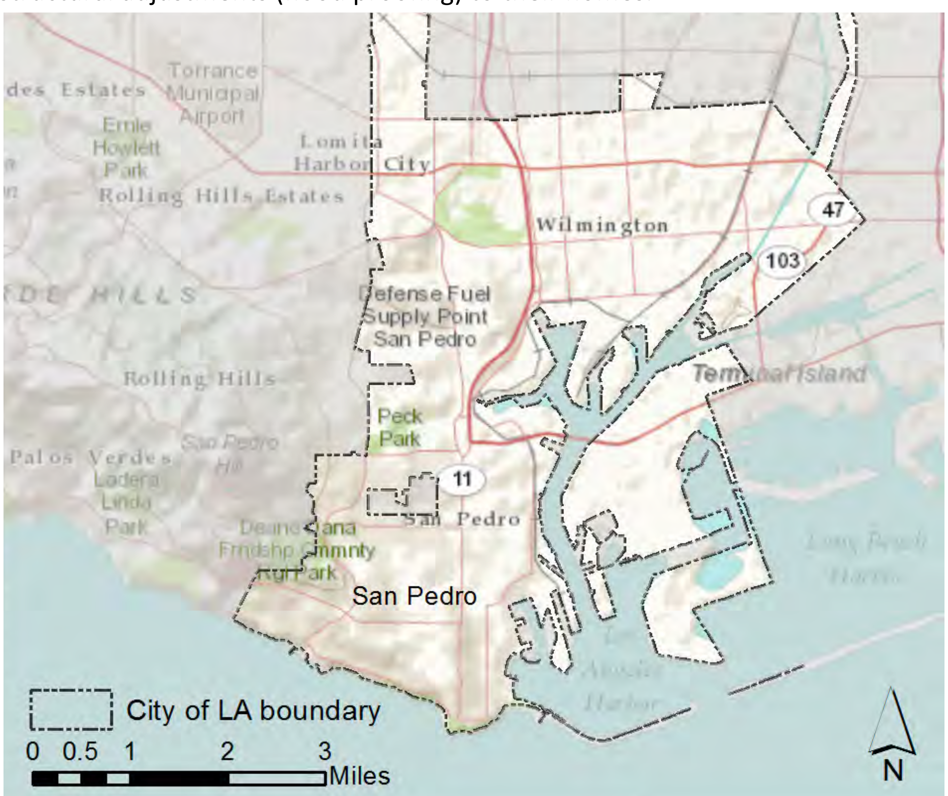


FIGURE 10: SAN PEDRO, WILMINGTON, AND THE PORT OF L.A. MAKE UP THE SOUTHERN COASTAL AREA IN THE CITY OF LOS ANGELES.

4.4 Infrastructure and Critical Services of Concern

As referred to briefly in the above community descriptions, in addition to direct exposure from coastal flooding and storm surge with sea level-rise, residents and employees of coastal communities may be at risk of and affected by flooding through infrastructure impairment. If floods damage, destroy or temporarily interrupt infrastructure, residences would be without critical services (emergency response,

electricity outages, communication outages, and lack of water supply or treatment). Impairment of such services disrupts daily life of residents but also jeopardizes their safety, health and well-being which can result in the flooding event turning into a disaster. In the community snapshots we briefly refer to several critical services and infrastructure at risk from sea-level rise within the communities. Other infrastructure of concern includes sea water barriers in the county (but outside city limits) that – if compromised – could lead to salinization of groundwater basins, which hold the city's water supply.[48] Other infrastructure and services at risk from flooding include wastewater treatment and drainage infrastructure, transportation routes, ports, the Los Angeles International Airport, and underground utilities.

5. Differential Vulnerability among Populations

This section presents basic statistics about the general makeup of the city population to provide essential background, but then focuses the specific population characteristics in the three coastal portions of the city and their implications of risks for flood events as sea level rises.

5.1 Population Overview

The City of Los Angeles, which is the largest city in Los Angeles County, is 469 square miles. According to the 2010 Census, the total population is 3.8 million people, making it the largest city in California. With an average of 8,092 people per square mile, the population density within the city varies widely from highly dense urban areas in the interior to less densely populated, more secluded areas in the Santa Monica Mountains. Based on the 2010 Census of its residents, 48.5% are Hispanic/Latino, 28.7% are White non-Hispanic/Latino, 11.3% are Asian American, 9.6% are African American, and less than 1% is Native American or Pacific Islander. Just over 10% of the population is 65 years and over and 6.6% is under five years old. Nearly 40% were foreign born and 60% speak a language other than English at home. Of its residents over 25 years old, 73.7% have graduated from high school, which is slightly lower than the state's average (80%).[49]

According to the American Communities Survey from 2006-2010, the homeownership rate found in the city is much lower than statewide at 38.9% (state 57.4%). Yet the median value of an owner-occupied housing unit is higher in L.A. at $553,900 (compared to $458,500 statewide). Average per capita income is $27,620, which is slightly lower than the statewide average of $29,188. The percentage of the population living below the federal poverty level is an estimated 19.5%, which is significantly higher than the proportion of people living below poverty level statewide (13.7%). The actual proportion of people living in poverty is much higher given that the threshold at which the federal poverty level is defined is a very low standard of living, at just over $11,000/year for an individual (or just over $22K for a family of four) and living expenses in L.A. are quite high. The National Economic Development and Law Center found that it takes at least $54,000 or more for a family of four to be self-sufficient in Los Angeles, which means that a much higher proportion of the city's population are struggling to make ends meet in Los Angeles than is reported by the Census.

5.2 Demographic Characteristics

5.2.1 Poverty

Lower income often correlates with lower access to the necessary resources to prepare for or evacuate in the case of a disaster, or to invest in actions required to adapt to climate change (e.g. moving out of a flood plain, elevating living space in one's house above a given flood elevation or purchase sump pumps to cope with floods). The Census 2006-2010 estimated median family income in the city to be $53,312.[50] However, incomes tend to be much higher along the coast than in the interior portion of the city and county (Figure 11). The Rolling Hills portion of the County (Palos Verdes Peninsula, outside the City of L.A.) has the highest average per capita income ($128,000) along the coast, while areas in Wilmington

and low-lying portions of San Pedro are closer to $13,000 per year as the lowest income areas along the coast (Figure 11). In 2010, based on Census data and the federal poverty level threshold, the geographic distribution of poverty was highly variable across the city (Figure 12).[51] As of April 2012 the U.S. Bureau of Labor Statistics reports that out of a total labor force of 1.9 million in the City of Los Angeles, an estimated 12.2% (231,658) are unemployed.[52]

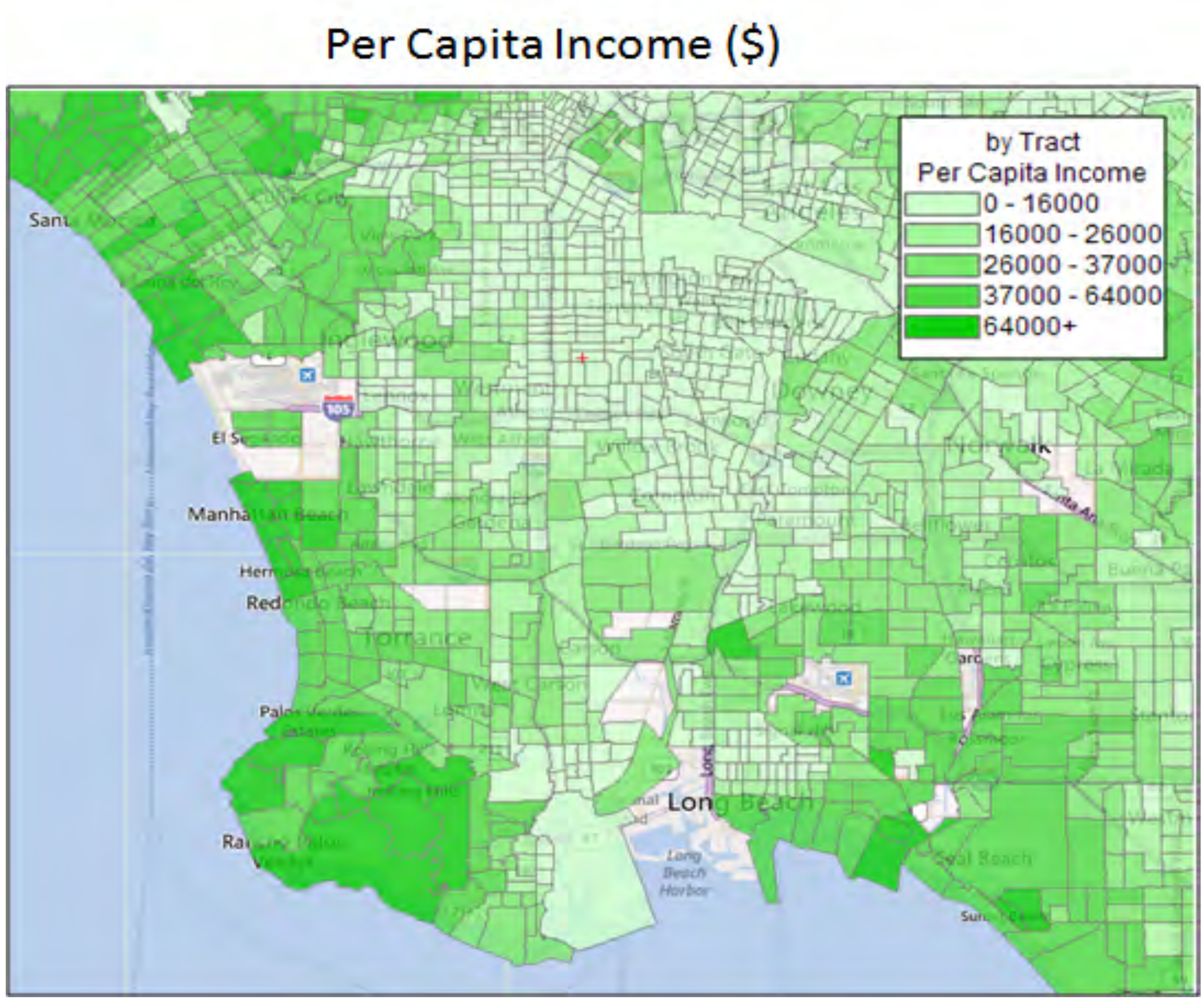


FIGURE 11: AVERAGE PER CAPITA INCOME TENDS TO BE HIGHER ALONG THE COAST AND LOWER IN THE INTERIOR PORTION OF THE CITY. THE EXCEPTION IS THE AREA AROUND THE PORT OF L.A. WHERE A LARGE PORTION OF HOUSEHOLDS FALL BELOW THE FEDERAL POVERTY THRESHOLD. (SOURCE: AMERICAN COMMUNITY SURVEY CENSUS 2006-2010, EPA EJVIEW 2012[53])

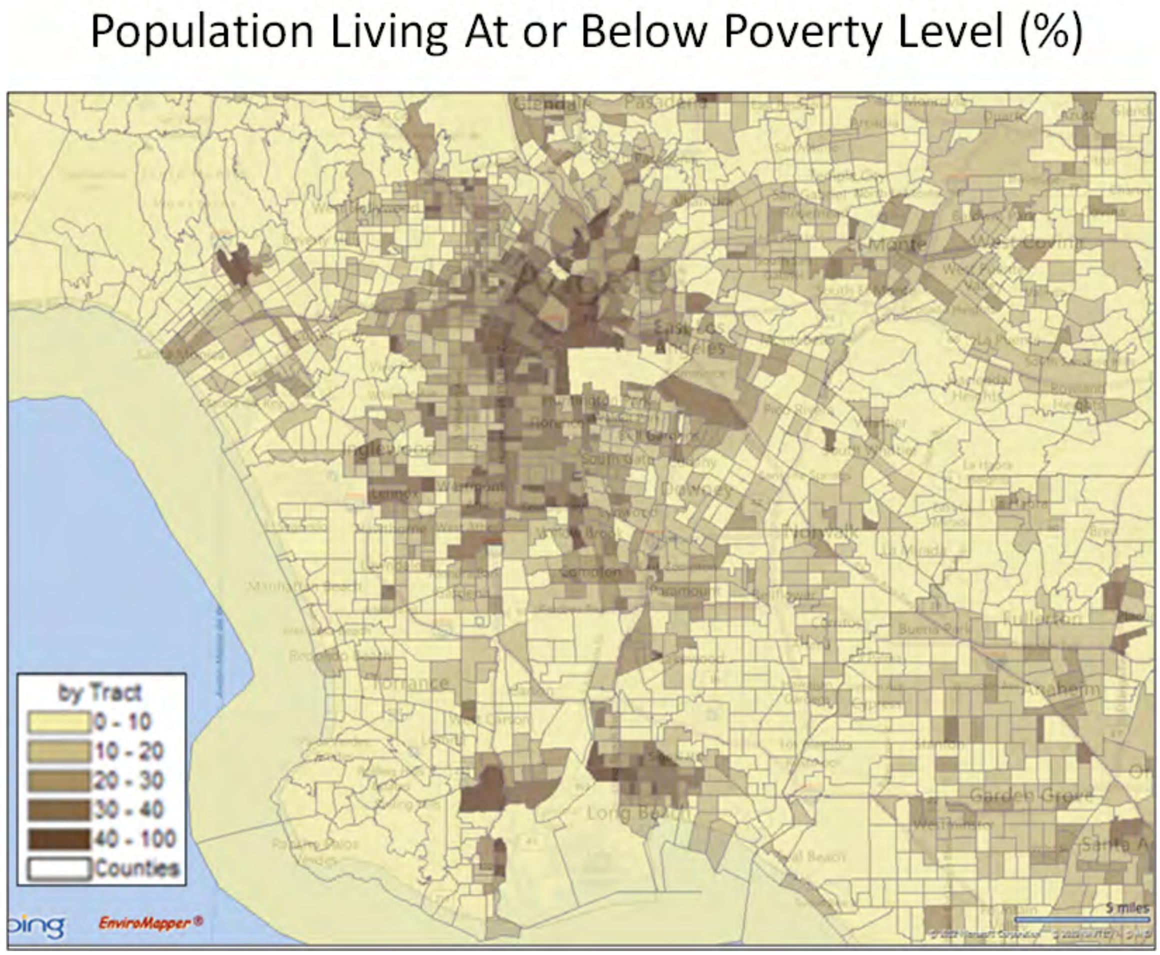


FIGURE 12. PERCENTAGE OF PERSONS LIVING AT OR BELOW THE FEDERALLY-DEFINED POVERTY LEVEL BY CENSUS TRACT ($17,500 FOR A FAMILY OF THREE). (SOURCE: AMERICAN COMMUNITY SURVEY CENSUS 2006-2010, EPA EJVIEW 2012[54])

What emerges from these two income-related maps (Figure 11 and Figure 12) is that the highest concentration of low income and poverty is in the central portion of the city and county, with the addition of the communities surrounding the Port of L.A. The 2006-2010 American Community Survey Census estimates that over 76% of the census tract population on the west side of Wilmington lives below the federal poverty level. Some residents counted as "low income" in L.A. County may include student populations, especially in areas adjacent to Los Angeles's many universities and colleges (e.g. UCLA in Westwood, USC southwest of Downtown Los Angeles, Loyola Marymount in Westchester, and Cal State Northridge). Detailed empirical work would be required to ascertain whether these student populations are truly low-income or have access to their parents' funds and so would have relatively high adaptive capacity to recover from a major flood event. However, during a disaster because they often live away from their families, students rely largely on their college or university to inform them of how to respond and where to go. Not all may have cars to leave at-risk areas.

In addition to students, low-wage labor employees in the service industry are particularly prevalent throughout the city, but especially in popular tourist destinations, including Venice Beach. Income is one

of the most important indicators of lower adaptive capacity, and can be addressed through special needs-related programs or by creating opportunities for low-income populations to make a better living (e.g., through education and training programs, providing a living wage, diversifying the economy). In many low income communities, active community-based organizations have strong relationships with the people in these neighborhoods and can provide a voice to express their needs and represent them in adaptation processes. Inviting representatives from these organizations or from the communities themselves can be useful to developing adaptation strategies that reduce impacts of sea-level rise on the most socially vulnerable.

5.2.2 Lower Education Can Undermine Adaptive Capacity

Some studies have found that lower educational attainment correlates with lower adaptive capacity to deal with extreme events. The connection between education and the ability to deal with disasters and change may link to lower income, a lower capacity to obtain and understand emergency preparedness and response information, lack of access to health care, and various types of insurance, and some degree of disenfranchisement from society. Figure 13 shows the distribution of individuals (in percent) in each Census tract over 25 years old that have not graduated from high school. As of 2012, in terms of education, 73.7% of the city's population 25 years and older were high school graduates (compared to 75.9% countywide, and 80.7% statewide).[55] People with less education require a different level of attention and assistance from public agencies than those with greater resources of their own. Focused investigation could inquire, for example, whether people's understanding of, and response to, flood risk is adequate so as to appropriately respond to warnings, or whether they have an understanding of measures they can take to protect themselves. Experience also shows that people affected by flood require additional attention working through the often bureaucratic language and process of applications for government assistance after a disaster.

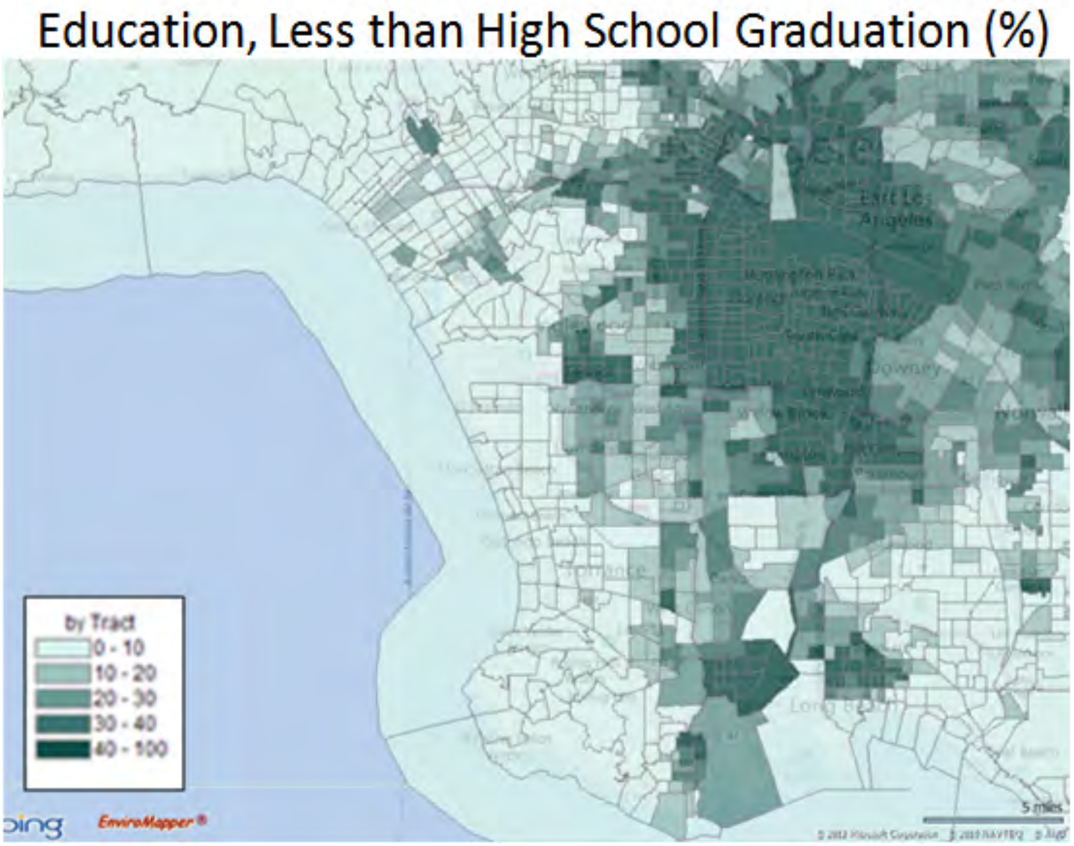


FIGURE 13: PERCENTAGE OF PEOPLE OVER 25 YEARS OLD THAT HAVE NOT GRADUATED FROM HIGH SCHOOL. (SOURCE: AMERICAN COMMUNITY SURVEY CENSUS 2006-2010, EPA EJVIEW 2012[56])

One segment of the population, often closely aligned with the spatial distribution of low income, involves women as head of the household. Women's capacity to prepare for flooding, cope with or evacuate during flooding or an associated hazard during a large storm, and recover afterward is particularly impaired when they are the sole providers for their household, especially when they have children.[57] Evacuating during a flood can be especially difficult for those who have young children. Figure 14 shows that a majority of single women with children reside in the interior of Los Angeles, but there are some higher concentrations in Wilmington and low-lying portions of San Pedro.

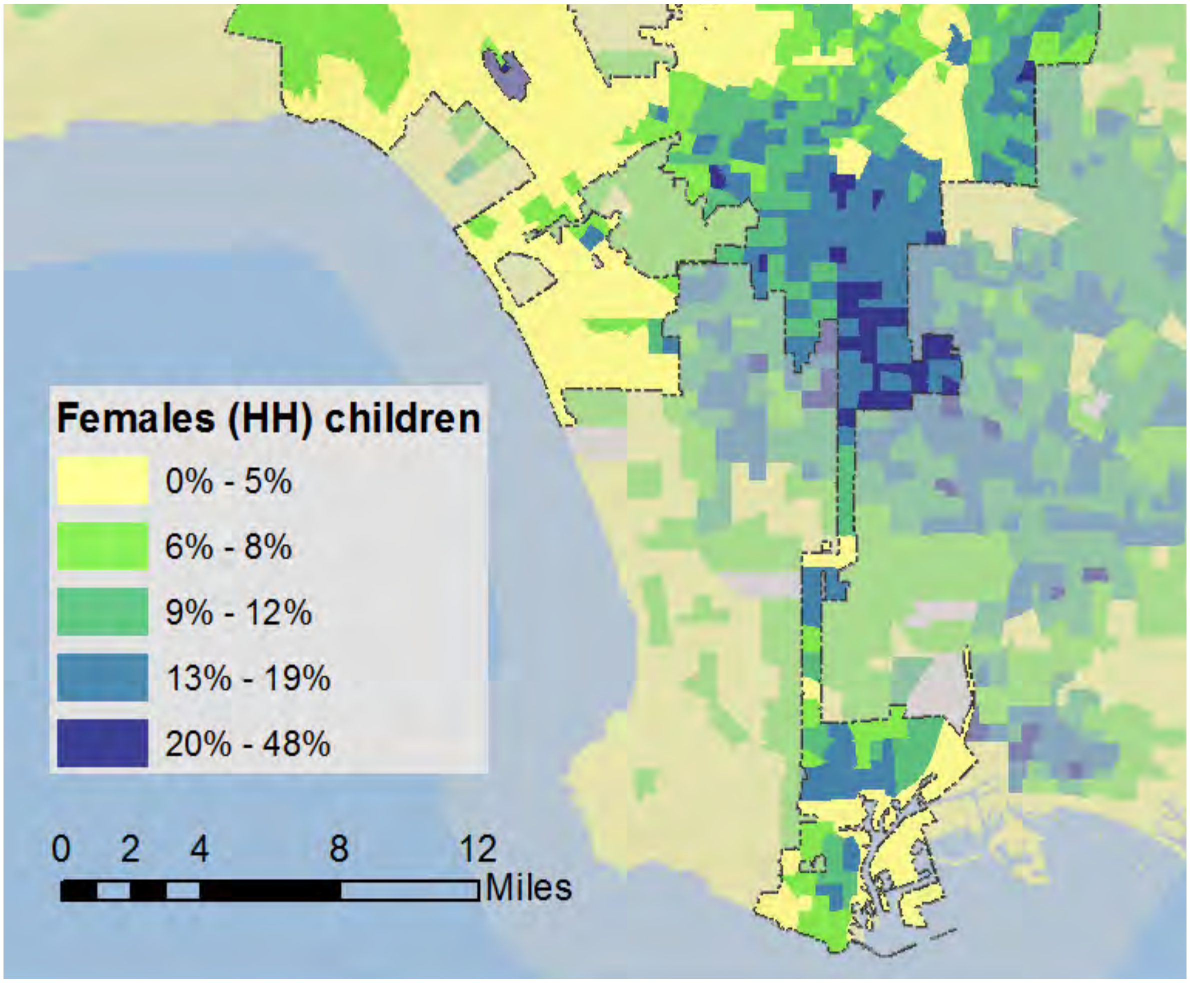


FIGURE 14: PROPORTION OF THE POPULATION WHO ARE FEMALE HEADS OF HOUSEHOLD AND WHO HAVE CHILDREN (SOURCE: CENSUS 2010 DATA).

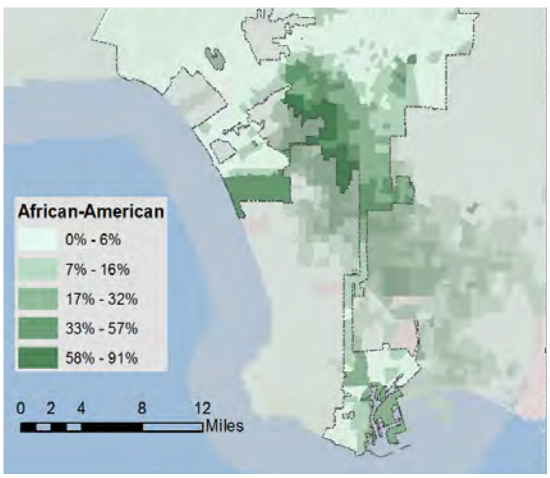
5.2.3 Race and Environmental Injustice in Adaptive Capacity

Studies of public health and vulnerability to disasters repeatedly indicate that minority populations tend to have lower capacity for responding to disasters and adapting to climate change than non-Hispanic whites.[58] This was true particularly in New Orleans after Hurricane Katrina that African Americans were less likely and able to evacuate and were then hit hardest in terms of trying to rebuild their lives in the aftermath of the disaster. Recent failures of emergency response in San Pedro and Wilmington during the January 2010 flood also demonstrate the importance of assistance during flooding events to be designed to the particular needs of different demographic groups in the community. In 2010 many residents in the low-lying areas of San Pedro and Wilmington were flooded out of their homes and needed shelter. The American Red Cross opened a shelter in a local home for the elderly, but the flood victims did not know about the shelter and those who did were not comfortable going there. Since very few came to the shelter, it was closed pre-maturely based on the assumption that no one needed assistance. Instead, the flood victims who were mostly of Hispanic/Latino descent, many of whom were undocumented and did not speak English, went to a local non-profit social services agency (the Toberman Settlement House/Neighborhood Center) that is set up to work with Spanish-speaking and

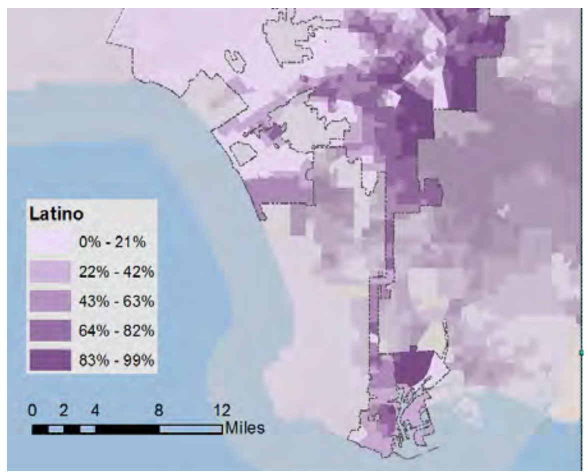
low-income communities. However, this center was not prepared to accommodate flood victims. The experience shows the value – and necessity – for emergency response planners to do important work to get to know and understand the community, in order to be better able to meet the needs of the population.[59]

Figure 15 (A, B, C and D) shows the distribution of African American, Hispanic/Latino, Asian American, and Pacific Islander/Native American segments of the population. In coastal communities within the City of Los Angeles, there are very high concentrations of Hispanic/Latino populations residing in the eastern, low-lying portion of San Pedro (closest to the inner Harbor/Port) and throughout Wilmington, as well as some small areas of Hispanic/Latino populations in Venice and El Segundo. African Americans are mainly concentrated in the interior of Los Angeles, but some higher concentrations (compared to the rest of the coast) reside in San Pedro, Wilmington and Long Beach (the latter outside of the City of Los Angeles' boundaries).

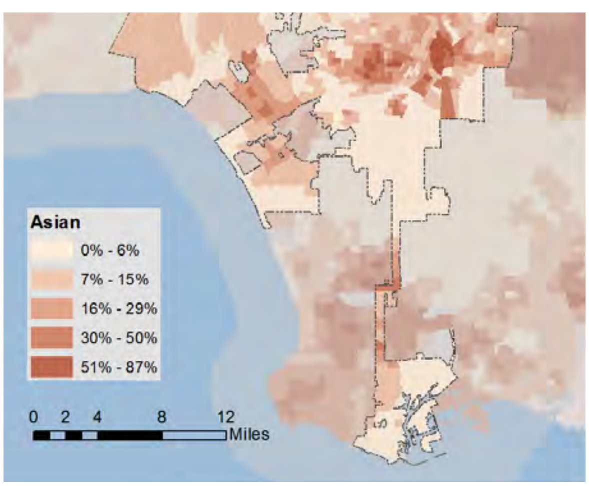
A. Percent African American



B. Percent Hispanic/Latino



C. Percent Asian



D. Percent Native American/Pacific Islander

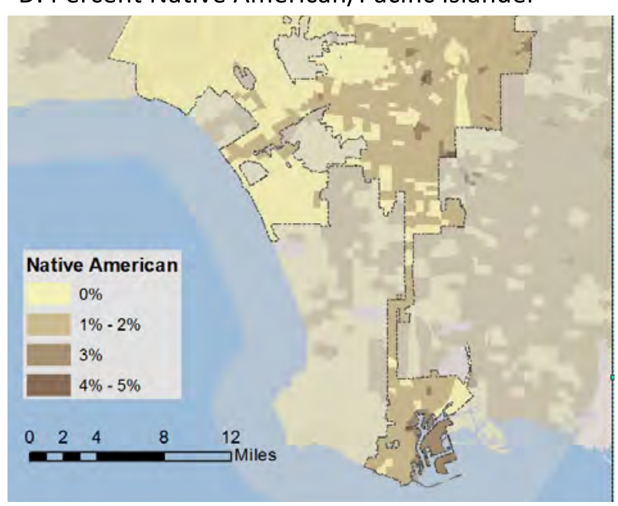


FIGURE 15: THE GEOGRAPHY OF RACE IN LOS ANGELES BY PERCENTAGE OF THE TOTAL POPULATION. THE BOUNDARIES OF THE CITY OF LOS ANGELES IS INDICATED BY THE BLACK DASHED LINE (SOURCE: CENSUS 2010).

Other studies have shown that the likely reason for the correlation between race and lower adaptive capacity is the disproportionate amount of poverty and lower incomes among African Americans and Hispanics compared to White/non-Hispanic segments of the population. Also, in minority populations where English is not the first language spoken, linguistic proficiency can also play a role, as noted above in the January 2010 flood response in San Pedro. Other factors, such as individuals and families being tightly embedded in social networks within a community, may compensate to some extent, and could either increase or decrease adaptive capacity (see below).

5.2.4 Inadequate Language Skills and Cultural Isolation Reduce Adaptive Capacity

Immigrants born outside the United States and/or individuals not fluent in English may be culturally and linguistically isolated. Among other social and economic disadvantages, this cultural and linguistic isolation can make it difficult to access or receive important information for preparing for and responding to weather- and climate-related emergencies. These linguistic and cultural differences of the Hispanic/Latino flood victims in San Pedro and Wilmington in January 2010 raise clear environmental justice concerns.

Between 2006 and 2010 an estimated 39.6% (1.5 million) of the city's population was foreign born compared to the county's 35.6% and the state's 27.2%.[60] The Census estimates show that of the foreign-born population, 73% have been here for at least ten years, giving them time to get settled, learn the language, and build a community support network. The remaining 27% should be of greater concern to emergency and adaptation planners. Of the foreign-born population, nearly 60% (just under 900,000) are not U.S. citizens.[61] Of the population 5 years and over, the Census estimates that in the 2006-2010 period, 59.6% of the city's population (approximately 2.2 million individuals) spoke a language other than English at home, and approximately 30% speak English less than "very well".

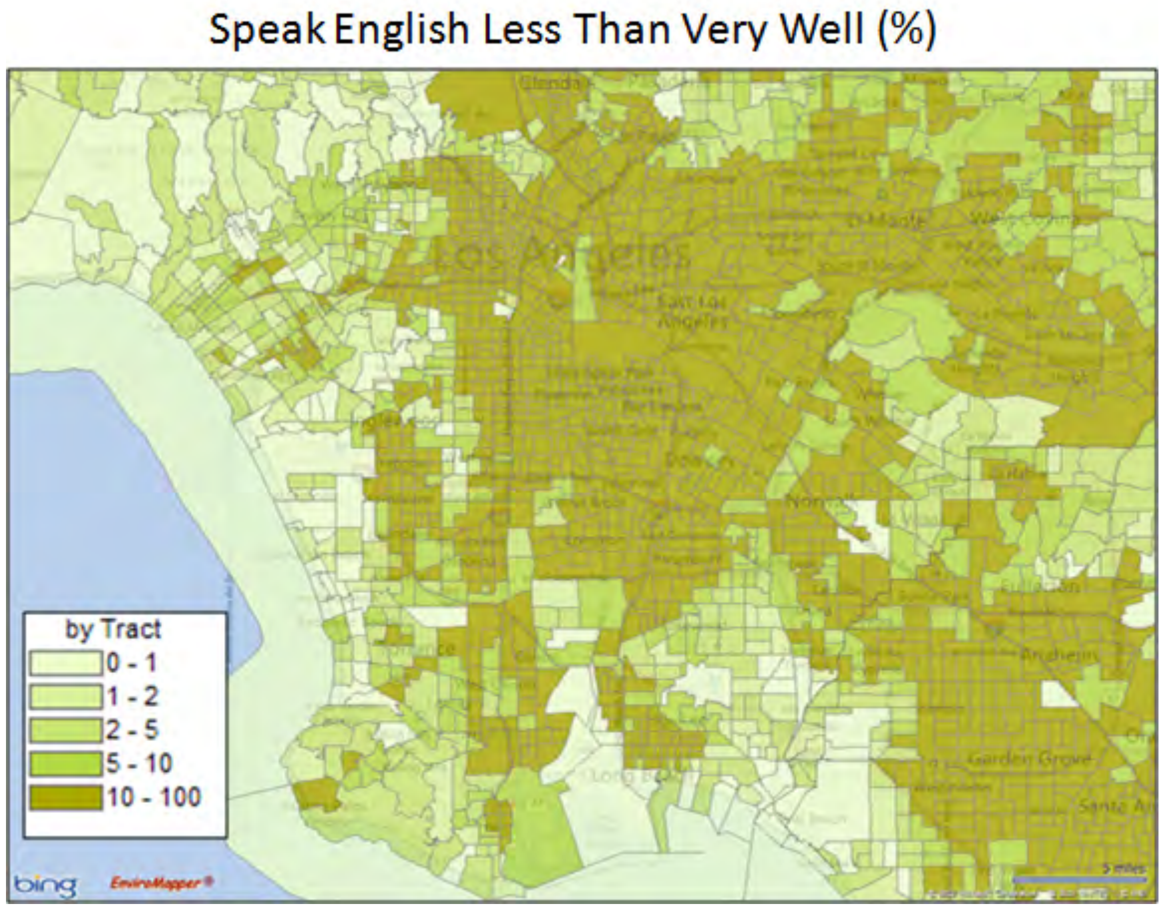


FIGURE 16: PERCENTAGE OF THE POPULATION (PER CENSUS TRACT) THAT SPEAKS ENGLISH LESS THAN VERY WELL. THE BOUNDARIES OF THE CITY OF LOS ANGELES IS INDICATED BY THE BLACK DASHED LINE.. (SOURCE: AMERICAN COMMUNITY SURVEY CENSUS 2006-2010, EPA EJVIEW 2012[62])

It is important that adaptation planning not neglect these populations and provide them with the necessary information, services, and engagement opportunities in their native language or with translators. Many who are not fluent in English may also be more shy to be proactive and publicly engaged in planning processes, so may require specific attention to be reached at all. During major rain or flooding events, especially as the sea rises, these individuals may require essential information in the language most familiar to them.[63] After disasters, non-native speakers may require special assistance working through difficult-to-understand disaster assistance applications and bureaucratic procedures. Relatively new arrivals in the community may not yet be socially connected and thus be easily forgotten, not noticed, and less familiar with available services. To begin to address the need to better prepare the San Pedro and Wilmington communities for such emergencies, the non-profit organization *COPE Preparedness* ran an all-Spanish language emergency preparedness workshop in July 2012.[64] Given that many residents do not have access to computers, outreach includes working with community organizations, such as *United Way* to get the message out through children (who will then help deliver those messages to their parents) at Boys & Girls Clubs and the *YMCA*, and through fliers targeting those who can read.

5.2.5 LIMITED MOBILITY OF THE ELDERLY LIMIT COPING CAPACITY IN DISASTERS

Age can play a role in coping and adaptive capacity as well. Infants and the elderly are less able to protect themselves from extreme conditions (e.g. in extreme heat or flood events) and may rely on others for special assistance in times of flooding. For example, the elderly are considered to be more vulnerable than the younger adults in emergency situations because of possible mobility challenges and may be less connected to email or other typical public outreach tools that inform residents about preparing for disasters. Cooler summers and better air quality also attract older populations to coastal communities all along California's coastline, including in Los Angeles. Thus, there are higher concentrations of elderly along the coast throughout the county's shoreline, especially in Pacific Palisades within the city boundaries, and also in Palos Verdes and Malibu (Figure 17).

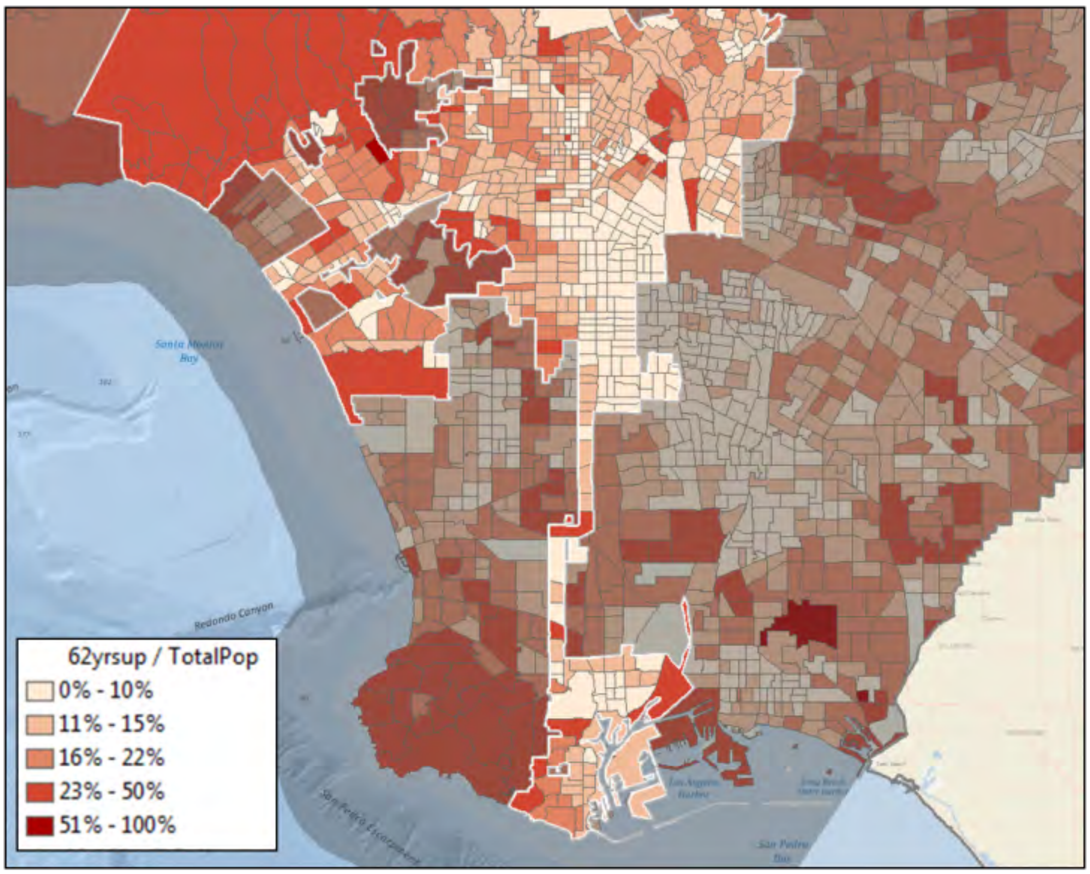


FIGURE 17: MAP SHOWING CONCENTRATION OF PEOPLE 62 YEARS AND OLDER (SOURCE: CENSUS 2010). ELDERLY POPULATIONS ARE ATTRACTED TO COASTAL LIVING BECAUSE OF THE COOLER SUMMER TEMPERATURES AND BETTER AIR QUALITY.

Special attention and services are needed to meet these communication and mobility challenges, as well as pre-existing health conditions that may inhibit the responsiveness of infants and older residents to emergency warnings.

5.2.6 HOUSING TYPE AND CONTROL OVER THE LIVING SITUATION AFFECTS ADAPTIVE CAPACITY

HOME OWNERSHIP VS. RENTING

Housing also tends to be a factor in people's ability to prepare, respond to, recover from flood events and adapt to sea-level rise. Home ownership versus renting indicates, again, income distribution. However, with regard to adaptive capacity, it also indicates how much control individuals have over their housing, e.g., to make structural adjustments to their home for flood protection.

In 2010, the Census estimated that there were a total of 1.4 million housing units in the city.[65] The median price of a house sold in between 2006-2010 was $553,900, although this varied considerably by section of the city with higher prices typically found along the coast. There were an estimated 814,305 renter-occupied housing units citywide (61.8% of all housing currently in use),[66] though with considerable variation: the interior portion of the city had the highest concentration of renters and much higher home ownership along the coast, especially in Pacific Palisades and other wealthy coastal areas outside of the City of L.A. (but within L.A. County). Wilmington and eastern portions of San Pedro have areas with very high proportion of renters (over 80%), as does Venice (between 45-80% for the area potentially flooded, see Figure 9). Other very high concentrations of renters along the coast can be found in Long Beach.

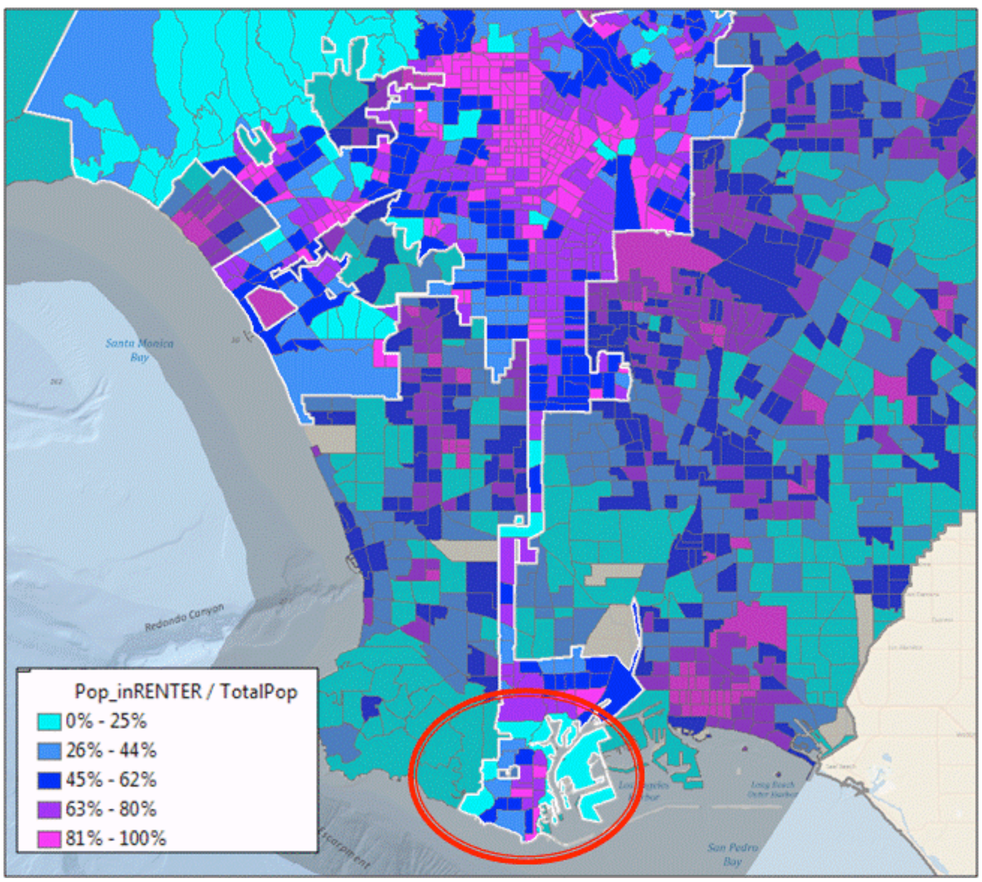


FIGURE 18: PERCENTAGE OF HOUSING UNITS IN USE THAT ARE RENTED. AREA SUURROUNDING THE PORT (CIRCLED IN RED) HAS A PARTICULARLY HIGH CONCENTRATION OF RENTERS (SOURCE: CENSUS 2010)

MOBILE HOMES

Another population that is of special concern includes those living in mobile homes because of those homes' sensitivity to flooding and potential inability of families living in those homes after the event (due to low income). The sensitivity of mobile homes is related to the manner in which they are constructed and to the lower degree of anchoring to the ground, which increases the risk of damage, dislocation, and debris-related damage in case of floods and storms. A rent-controlled mobile home park in Pacific Palisades, *Palisades Bowl*, is located along Pacific Coast Highway. By the same token that sensitivity to floods is high during storms (less stable construction and anchoring), long-term adaptation may be easier for structures that can be elevated and moved more easily, as long as road access and sewage is still functional. Thus, this type of housing requires locally targeted emergency response and long-term plans.

HOMELESS POPULATION

Another population that is at major disadvantage during a disaster or other hazardous event includes those people without a permanent home. Homeless individuals living in coastal areas could be directly exposed to flood events because of living in the streets or in a parked vehicle. Very little information is usually collected to document the location and living situation of this population, making it difficult for emergency response during a disaster to find and help this population. Public education and awareness campaigns or emergency preparations as pre-disaster planning often do not reach this population, and the homeless do not have adequate means to move to new unfamiliar locations. According to representatives from the Venice Beach Neighborhood Council, Venice has a particularly high concentration of homeless residing in that coastal community.[67] This segment of the population is also of particular concern given that they may not be able or willing to evacuate during a disaster, or go to shelters.

Del Playa (just south of Venice and Ballona Creek), as part of the Westchester/Playa Neighborhood Council, has demonstrated a growing concern about homeless individuals living in the streets and in vehicles. In collaboration with several government and non-governmental organizations, they conducted a survey of the homeless population over the course of one evening in September 2010.[68] They found 48 individuals, mostly white, male and less than 60 years old. Of the thirteen interviewed, the survey reported that 54% had serious health issues, 33% had mental health issues, and 33% reported to have substance abuse issues. Over half the interviewees were homeless because they had lost their housing. Most slept in either a vehicle or on the street. Organizations and community-based programs working with the homeless can be a vital resource in disaster preparedness, response and recovery to make sure those without permanent housing receive the assistance they need. This will be especially problematic for residents as sea level rises and flooding events extend further inland into new areas not prepared for such events.

AGE OF HOUSING

Another condition of concern is that the age of housing indicates a potential sensitivity to flooding and sea-level rise. Newer housing tends to be designed to deal with historical climatic conditions. Older housing, especially when owners do not have the income to make their homes flood-proof, can be more susceptible to flooding. Figure 19 shows the distribution of housing built before 1950.

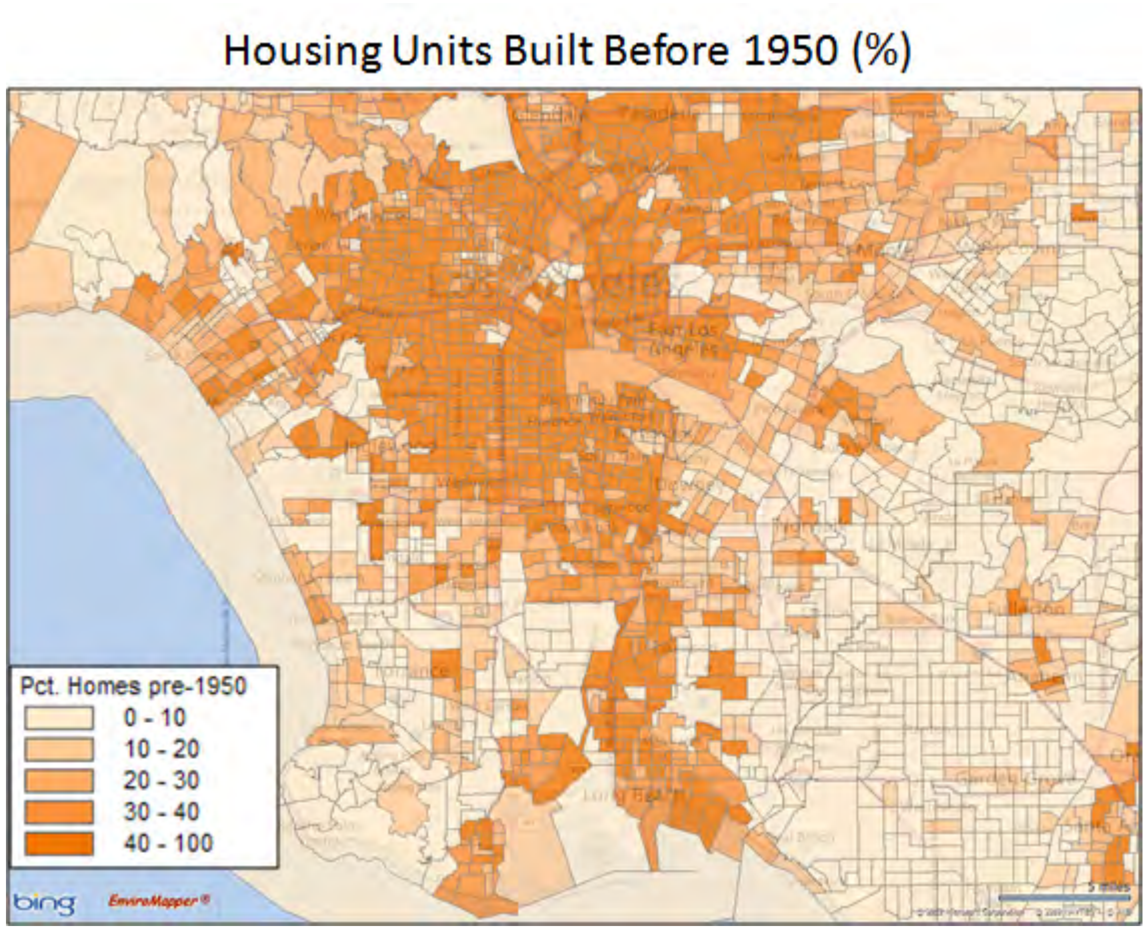


FIGURE 19: PERCENTAGE OF HOUSING UNITS BUILT BEFORE 1950 (SOURCE: AMERICAN COMMUNITY SURVEY CENSUS 2006-2010)

OF SPECIAL CONCERN: UNDOCUMENTED IMMIGRANTS AND INSTITUTIONALIZED POPULATIONS

Age of housing may also point to the prevalence of flood insurance policies although such data can be directly obtained from the Federal Emergency Management Agency and the National Flood Insurance Program (NFIP).[69] While compliance with NFIP requirements is historically lacking, homes that no longer have a mortgage are less likely to be insured under the flood insurance program. Thus, vulnerability of these older homes may also be increased because of the lack of insurance coverage which could help home owners rebuild after damage.

5.2.7 OF SPECIAL CONCERN: INSTITUTIONALIZED, HEALTH IMPAIRED, AND DISABLED POPULATIONS

Three additional populations are of special concern in the City of Los Angeles' coastal communities: the institutionalized populations, those with pre-existing health issues, and disabled populations.

INSTITUTIONALIZED POPULATIONS

Institutionalized populations (such as in prisons, hospitals, senior citizens homes, kindergartens, schools and colleges) are reliant on institutional emergency provisions, the facility's response measures during times of disaster for support, and the institution's long-term plans. The Federal Correctional Institution, *Terminal Island*, a low security facility for male inmates is located right along the coast at the entrance to the Los Angeles Harbor. It has a population of nearly 1,200 prisoners and is managed by the Federal Bureau of Prisons. Other organized group residences located in potential future flood areas include several group sober/rehabilitation and elder care homes in Venice Beach.[70] San Pedro also has several nursing homes for the elderly, two of which are located in low-lying areas near the harbor (*Harbor Tower* and *Harbor Terrace*). These group homes may be at higher and increasingly frequent risk of flooding as sea level rises, demanding appropriate preparatory measures from these institutions to address the particular vulnerability of their residents. A recent federal study published by the Office Health and Human Services Department of nursing home emergency preparedness found that they often have inadequate emergency plans for disaster response and recovery. Gaps identified in the report included lack of reliable transportation contracts, need for improved coordination with local emergency management, and lack of support for nursing home residents during disasters, especially for those needing long term care.[71] The concern for nursing home residents and other populations living in group homes has increased recently in Venice. The Venice Neighborhood Council in June 2012 discussed the need for emergency responders to know the locations of these group homes in and around Venice.[72]

MENTALLY AND PHYSICALLY IMPAIRED

Populations with physical and mental disabilities are of special concern for disaster planning and emergency response. People with physical and mental illnesses can have a greater sensitivity to high levels of stress during disasters. Permanent relocation for adaptation purposes may be equally stressful. Existing illnesses or disabilities may impair individuals' mental and/or physical abilities to respond to extreme events and make it especially difficult to recover. Facilities providing services for those with mental health issues and physical disabilities need to have a plan that is coordinated with the local emergency response, have pre-determined shelters to go to during a disaster, and ensure that emergency response is educated about the special needs of these populations (e.g. they may require more personnel and special assistance during an evacuation). It is important for emergency responders to know where these people reside, whether they live on their own or rely on a group living facility. The *Disability Rights Legal Center* in Los Angeles cites the city as having approximately 800,000 residents with some degree of disability.[73] Although the US Census from 2006-2010 collected information about disabled populations, we could find no readily available data for the City or County of Los Angeles to confirm this large number reported by the *Disability Rights Legal Center*. The City General Plan documents that 546,374 individuals ages 16-64 years have disabilities, making up 16% of the citywide population (in 2000).[74] As many as 22% of the adult population (16 to 64 years old, 546,374 persons) lives with a disability and does not live in an institutionalized home or in group living quarters. Nearly one quarter of disabled adults aged 16-64 years have some type of physical limitation, which could inhibit or slow these individuals' ability to get out of the flood zone in case of an emergency. Similarly, as many as two thirds of adults over 65 years have physical limitations, and 31% of those 65 years and older have a vision or hearing limitation that may reduce their ability to act swiftly and safely in case of a flooding emergency (further details in Table 2). Documenting where disabled persons reside would be a

useful step to make sure shelters and emergency response had appropriate provisions to meet victims' needs during an emergency. Since such location data is not easily available, it is up to the City or organizations representing the interests of these populations to document through an empirical survey or some other method where the disabled live, the nature of their disability, and what needs they may have in an emergency.

The City of Los Angeles is already making some efforts in its emergency response plan to accommodate the needs of physically disabled individuals. This effort has been encouraged by the *Disability Rights Legal Center*'s lawsuit filed in 2009 against the City for having inaccessible public spaces. The lawsuit was prompted by a then-negligent emergency response plan for the disabled, leaving many stranded during evacuations. Important planning for evacuation transit that can accommodate wheelchairs and making emergency shelters wheel-chair accessible are important concerns that the *Center* expressed. Even plans for assisting those disabled or with medical conditions who depend on extra medicines (and refrigeration for these), and medical instruments (e.g. dialysis, oxygen) need to be a part of emergency planning considerations.

TABLE 2: PREVALENCE OF DISABILITY BY TYPE OF DISABILITY IN CITY OF LOS ANGELES (SOURCE: GENERAL PLAN, HOUSING ELEMENT CITY OF LOS ANGELES 2009, P1-15[75], FROM CENSUS 2000)

Type of Disability	Ages 16 to 64	Ages 65+
Sensory limitation (includes vision and hearing limitations)	8%	31%
Physical limitation (includes any condition that limits physical activities such as walking, climbing stairs, reaching, lifting or carrying)	22%	66%
Mental disability (includes any physical, mental or emotional condition lasting six months or more that makes it difficult to learn, remember, or concentrate)	15%	32%
Self-care limitation (includes any physical, mental or emotional condition lasting six months or more that makes it difficult to dress, bathe, or get around inside the home)	8%	27%
Going-outside-home limitation (includes any physical, mental or emotional condition lasting six months or more that makes it difficult to go outside the home alone to shop or visit a doctor's office)	50%	54%
Employment limitation (includes any physical, mental or emotional condition lasting six months or more that makes it difficult to work at a job or a business)	68%	n/a

Source: Census 2000

5.2.8 An Integrated Perspective on Social Vulnerability

The demographic characteristics described above are well-known to the hazards and climate vulnerability research communities. Scholars of vulnerability have developed several ways to integrate multiple facets of vulnerability in a single index, as briefly described in the Introduction. Here we summarize a thoroughly vetted and widely used index, developed by the Hazards and Vulnerability Research Institute at the University of South Carolina and compare it to a Climate Change Population Vulnerability (CCPV) index recently developed by the California Department of Public Health, which integrates various climate change impacts and only a limited number of social factors. The results differ in a number of important ways, largely because of differences in the social variables used, the integration of physical and social factors (i.e. sensitivity, response capacity and exposure to the physical threats from climate change), and in the methods to calculate the index. While the definition of vulnerability differs between the two approaches, key aspects are quite similar (e.g., where poverty or age are dominant influences on vulnerability) and in those instances confirm our findings.

SOCIAL VULNERABILITY INDEX

The social vulnerability index (SOVI) is a method developed by Susan Cutter and colleagues at the University of South Carolina. It integrates 32 Census variables to create a picture of relative social vulnerability within a given region.[76] It does not integrate physical climate change factors as the DPH index does. The SoVI thus provides an objective snapshot of social factors causing vulnerability, i.e. of where the populations reside that are associated with low adaptive capacity and high sensitivity to hazardous events. It can be combined with maps of various physical risks (e.g., SLR-related inundation during flooding, wildfire, high heat) to obtain an integrated perspective on regional vulnerability. Results for the entire Los Angeles County area (Figure 21) show that overall, the highest *social* vulnerability is concentrated in the interior portion of the county – i.e. the center of the City of L.A. Pacific Palisades ranks as having low social vulnerability, as expected from the demographic and socioeconomic data described before. Venice Beach also ranks as relatively low, which is not entirely consistent with on-the-ground conditions, given numerous vulnerable populations and group housing.

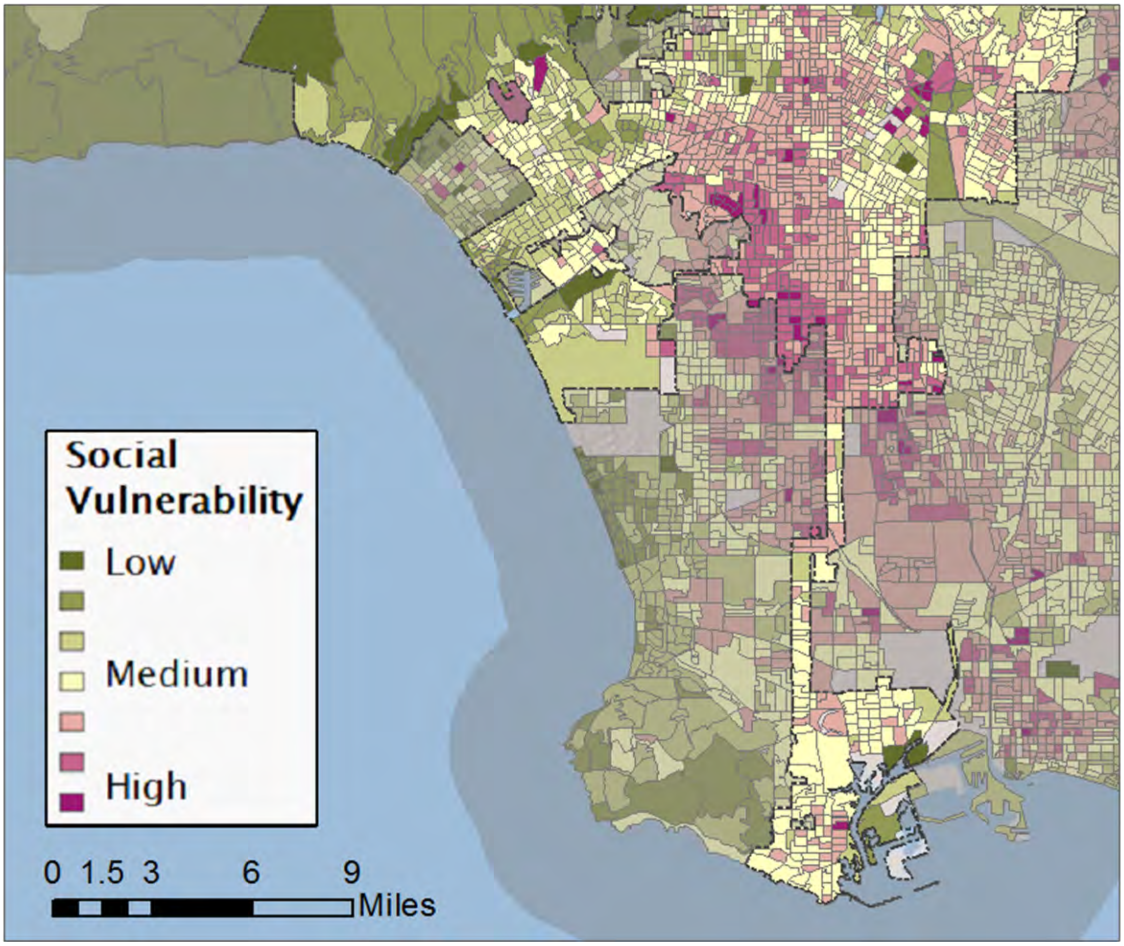


FIGURE 20. THE SOCIAL VULNERABILITY INDEX (SOVI) PROVIDES AN INTEGRATED VIEW OF A POPULATION'S SOCIAL VULNERABILITY. THE INDEX INTEGRATES 32 SOCIOECONOMIC AND DEMOGRAPHIC VARIABLES. THE SOVI CAN BE COMBINED WITH MAPS OF DIFFERENT PHYSICAL THREATS FROM CLIMATE CHANGE TO OBTAIN A COMPREHENSIVE OVERVIEW. (SOURCE: CENSUS 2000 DATA, INTEGRATED SUMMARY PROVIDED BY NOAA COASTAL SERVICES CENTER)[77]

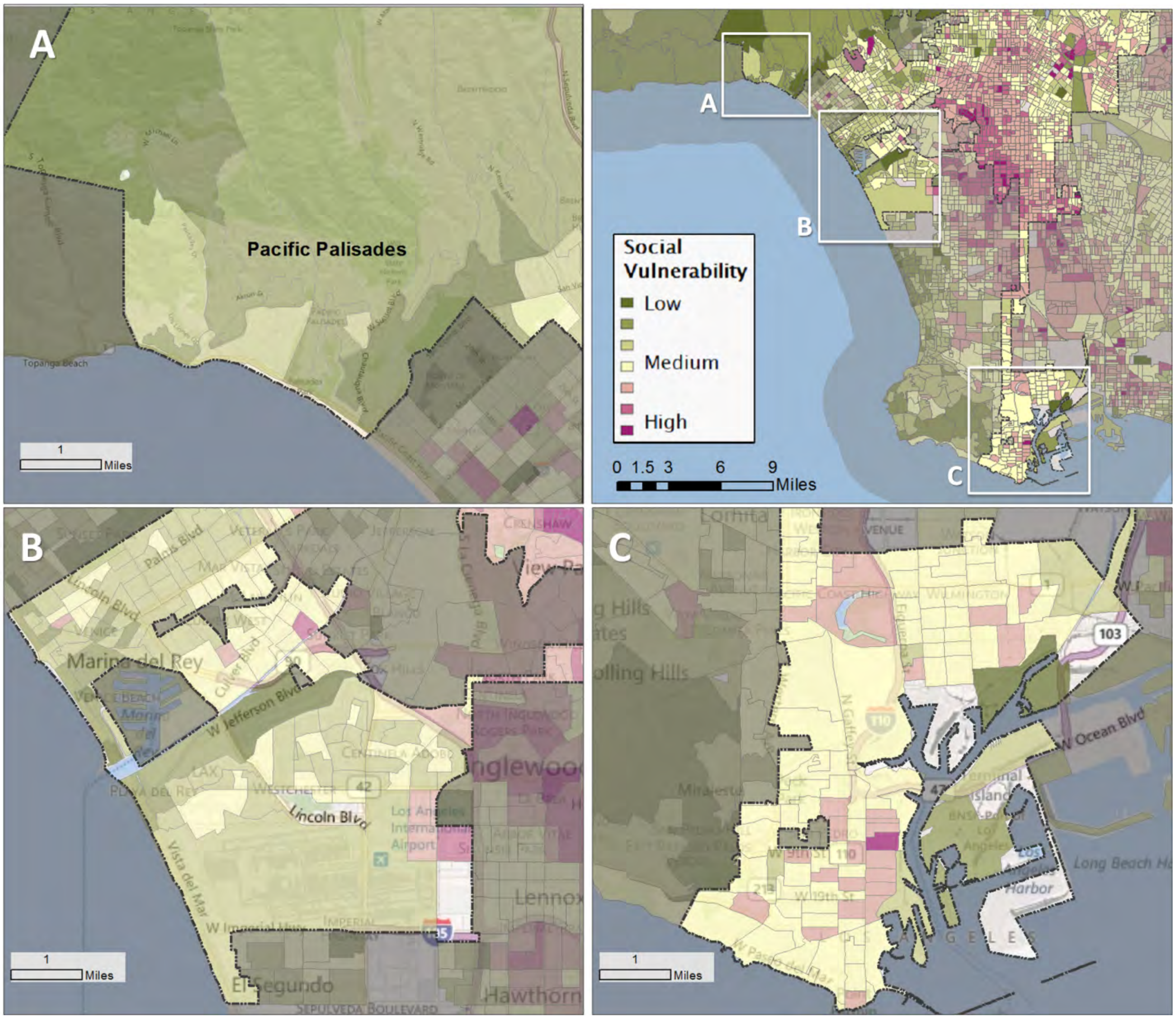


FIGURE 21: THE SOCIAL VULNERABILITY INDEX (SOVI) IN THREE SHORELINE COMMUNITIES IN THE CITY OF LOS ANGELES. PACIFIC PALISADES ("A" UPPER LEFT), VENICE AND PLAYA DEL REY ("B" LOWER LEFT), AND SAN PEDRO AND WILMINGTON SURROUNDING THE PORT OF LOS ANGELES ("C" LOWER RIGHT). (SOURCE: CENSUS 2000 DATA, INTEGRATED SUMMARY PROVIDED BY NOAA COASTAL SERVICES CENTER)[78]

Community Vulnerability to Climate Change Screening Tool

The California Environmental Health Tracking Program in the California Department of Public Health developed and piloted a different index of social vulnerability to identify vulnerable communities. This tool is particularly useful for the City's adaptation planning process because it was piloted in Los Angeles County. It takes into consideration a limited number of social factors that relate to increased sensitivity and reduced adaptive capacity and the physical threats that residents are exposed to, including flooding, heat waves, low air quality, and wildfires. It includes a more limited set of social factors compared to the SOVI (Figure 21) developed by Cutter and colleagues. The Climate Change Community Screening Tool (CCCST) also incorporates exposure to the risks associated with environmental justice issues (such as proximity to existing hazardous locations such as refineries and brownfields). Figure 22 shows the CCCST for L.A. County and reveals much higher vulnerability scores for coastal areas than those found in the SOVI. Based on their analysis, much of Venice and Playa del Rey are at "high risk" as is the coastal Census tracts of Pacific Palisades (Figure 22) because it integrates flooding risks from a 1.4m sea-level

rise (this is the high-end projection used in this report). The CCCST study also found clear racial disparities with African Americans and Hispanics/Latinos at higher risk of climate change stressors than Whites. Similar to the SoVI, they found that households with lower income are at higher risk from climate change stressors than those with higher incomes. Thus, in terms of the socioeconomic variables the two indices are highly consistent with each other. The only real difference is the integration of physical risks associated with climate change, which – logically – should and does result in higher vulnerability scores.

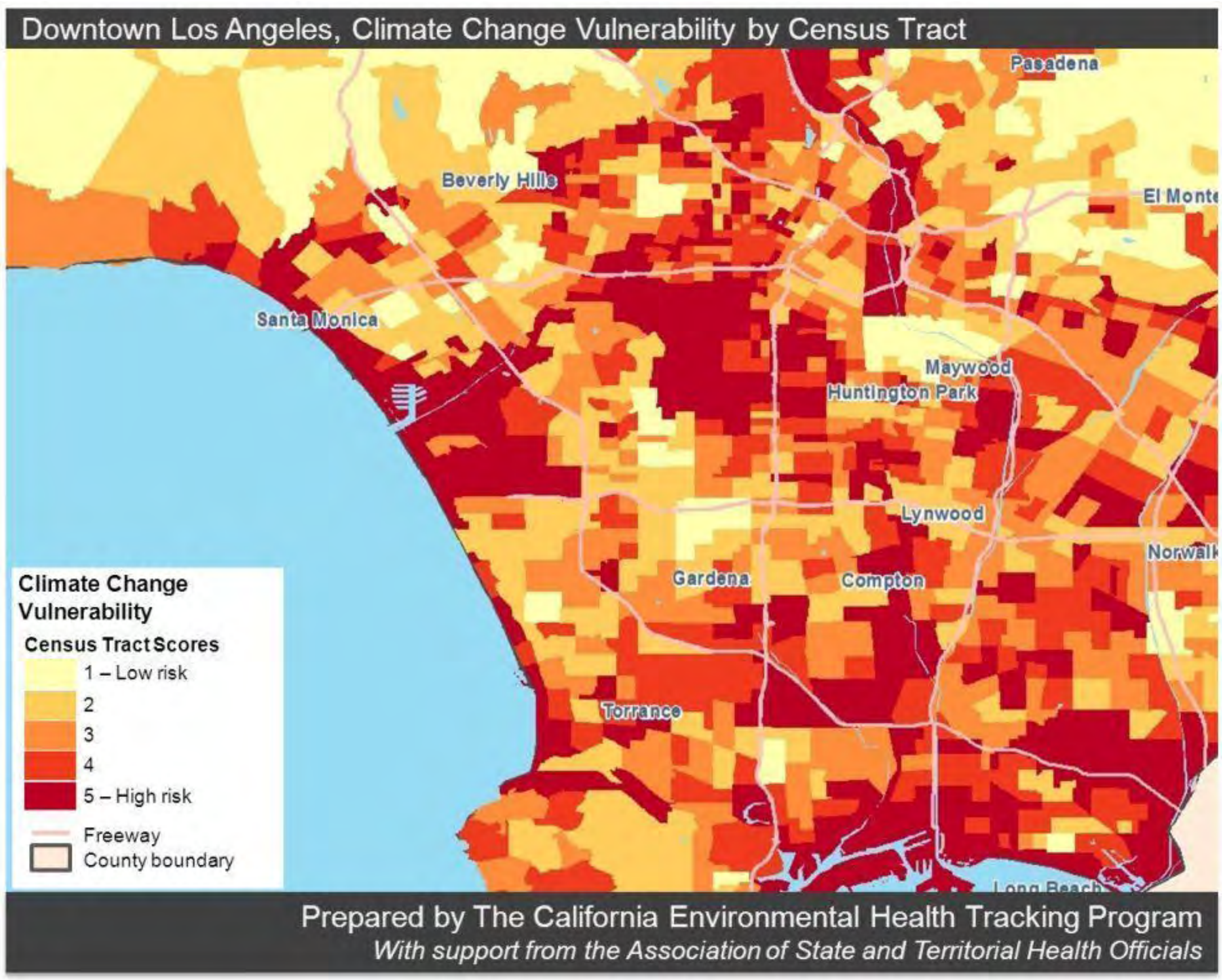


FIGURE 22: RESULTS FOR DOWNTOWN LOS ANGELES OF THE INTEGRATED CLIMATE CHANGE COMMUNITY SCREENING TOOL, DEVELOPED AND PILOTED BY THE CALIFORNIOA ENVIRONMENTAL HEALTH TRACKING PROGRAM (DPH). THIS MAP SHOWS A SET OF FACTORS COMBINED TO REPRESENT SENSITIVITY, ADAPTATIVE CAPACITY AND EXPOSURE TO A NUMBER OF CLIMATE CHANGE IMPACTS (SOURCE: CALIFORNIA DEPARTMENT OF PUBLIC HEALTH)[79]

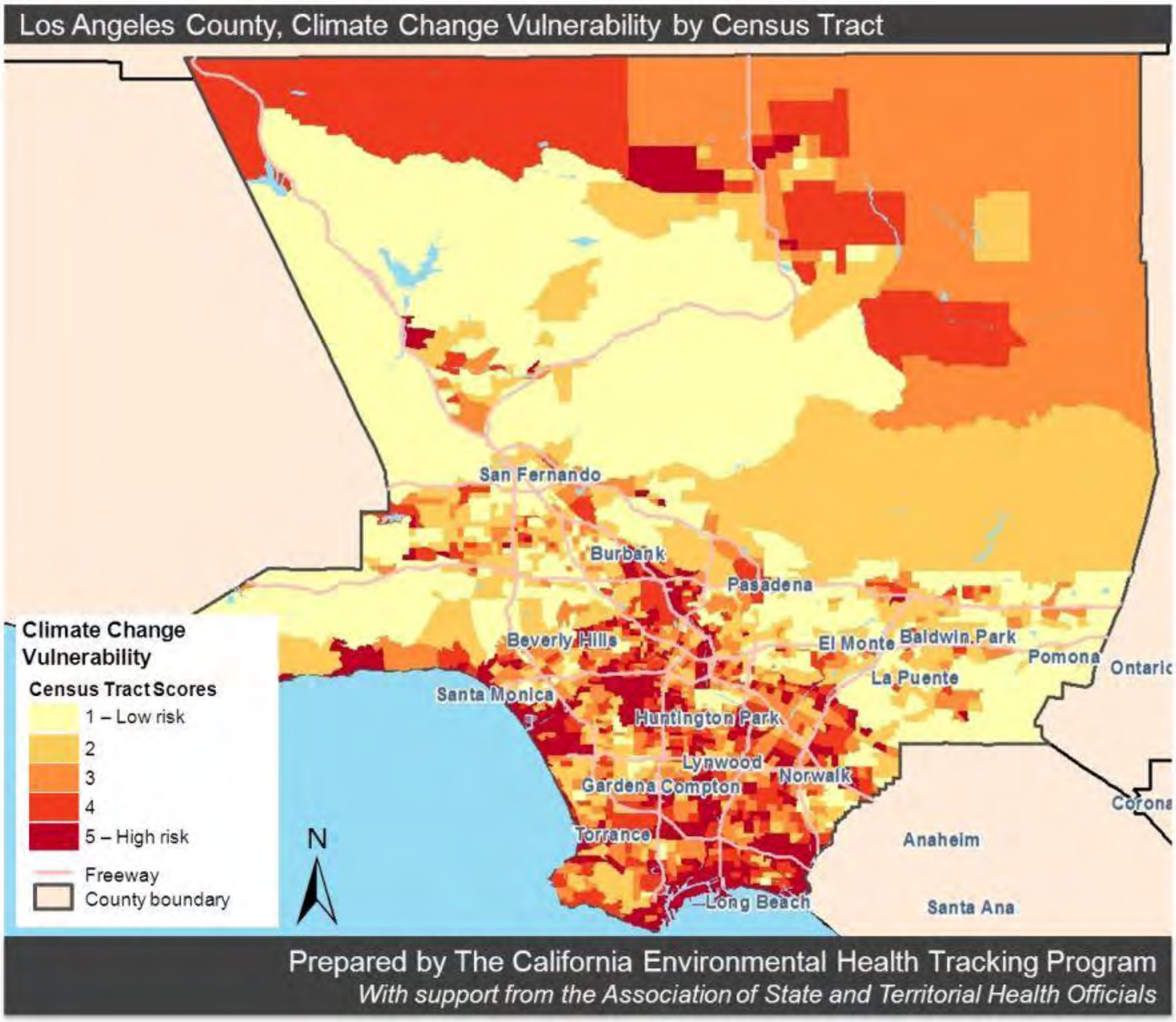


FIGURE 23: RESULTS FOR L.A.COUNTY OF THE INTEGRATED CLIMATE CHANGE COMMUNITY SCREENT TOOL, DEVELOPED AND PILOTED BY THE CALIFORNIOA ENVIRONMENTAL HEALTH TRACKING PROGRAM (DPH). THIS MAP SHOWS A SET OF FACTORS COMBINED TO REPRESENT SENSITIVITY, ADAPTATIVE CAPACITY AND EXPOSURE TO A NUMBER OF CLIMATE CHANGE IMPACTS (SOURCE: CALIFORNIA DEPARTMENT OF PUBLIC HEALTH, SEE ENGLISH 2012)[80]VI. CRITICAL COMMUNITY SERVICES

For analytical purposes, the use of the SoVI may provide the City with greater flexibility than the DPH Screening Tool, as different scenarios of physical risk can be combined with an index of social vulnerability as needed. Looking at the SoVI's underlying variables offers insights into possible levers of intervention to reduce sensitivity and increase adaptive capacity, while the as-needed addition of physical risk layer illustrates the relative importance of physical versus social vulnerability factors.

6. Critical Community Services

A number of services and supporting infrastructure are potentially at risk of impairment from short term or long term damage from flood events, erosion, and permanent inundation as sea level rises. These include impairment of drainage and treatment of wastewater and sewage, rapid emergency response, access to food and prescription medicines, risks of salinization of coastal groundwater reservoirs, and energy-related facilities, transmission, and transformers. For example, electricity outages can occur during storms when coastal flooding is at its worst. Such outages can make a flood event turn quickly into an emergency for people relying on electricity.[81] A description of these is beyond the purview of this social vulnerability assessment; however we provide a glimpse of some of the connections between infrastructure and service functionality (focus on drainage and emergency response) with particular reference to how these could exacerbate stressors to already vulnerable populations.

6.1 Drainage and Flooding

As sea level rises storm water drainage will be increasingly impaired, leading to increased flooding during rain events. The City of Los Angeles, more than 70% of which is located on an alluvial floodplain, has a long history with flooding from infrequent albeit major storms.[82] Flash floods caused by heavy rainfall within a short period of time can cause major flooding throughout many parts of the city. Most of the land is covered with impermeable surface (e.g. asphalt) meaning that water cannot filter into the ground, but instead rushes down streets and overloading the wastewater system, where it backs up back into the city. The Safety Element of the City's General Plan refers to major storms that cause "a high magnitude of water flow" as the "most dramatic and potentially the most hazardous water activity confronting the City."[83] The region receives the majority of its rain in heavy, short-duration storms. The Safety Element says that "in a 100 year storm, 10 to 24 inches of rain may fall within 24 hours or as much as one inch of rain in a minute for a brief duration." The impermeable surfaces lining the city make these strong storms more difficult to manage because the water cannot percolate into the soil. Instead it rushes through the streets or other pathways toward the ocean. There, this increased runoff is met by higher sea levels. While wind and waves are not estimated to increase with climate change, storms as strong as those experienced historically with higher sea levels will also cause higher storm surges. Thus, more coastal flooding and intense runoff from inland areas will combine to cause more severe damage and flooding because the inundation zone will extend much farther inland.[84] Impervious surfaces also lead to higher temperatures, referred to as the urban heat island effect. Impervious surfaces and lack of shading from trees are often most prevalent in low income and minority neighborhoods, leaving the socially most vulnerable populations to experience potentially greater physical risks as well.

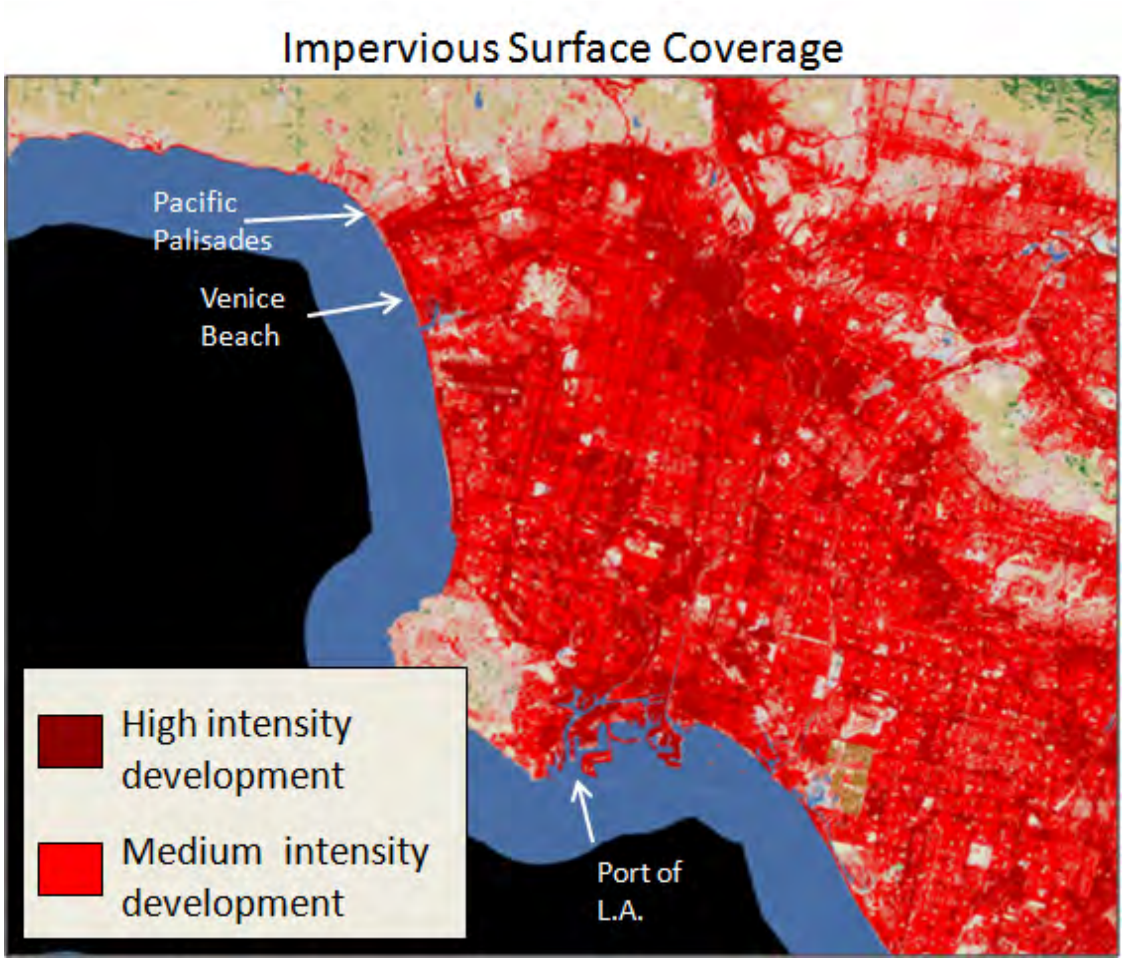


FIGURE 24: IMPERVIOUS SURFACE COVERAGE IN LOS ANGELES REGION. MUCH OF LOS ANGELES COUNTY IS COVERED BY IMPERVIOUS SURFACES, WHICH PREVENT EXCESS WATER (RAIN OR STORM SURGE) FROM INFILTRATING INTO THE GROUNDWATER AND, THUS, INCREASING FLOODING RISK. HIGH INTENSITY DEVELOPMENT IMPERVIOUS SURFACES (DARK RED) ACCOUNT FOR 80% TO 100% OF THE TOTAL COVER. MEDIUM INTENSITY DEVELOPMENT (LIGHTER RED) IMPERVIOUS SURFACES ACCOUNT FOR 50% TO 79% OF THE TOTAL COVER (SOURCE: NATIONAL LAND COVER DATABASE 2006[85]).

FEMA flood loss maps – based on historical experience – are an important additional information source, as they integrate both aspects of physical exposure (i.e., where flooding actually and repeatedly occurs, as opposed to maps based on calculated potential flood risk), sensitivity, and response capacity of affected buildings and households (e.g., building age or constructions, elevation off the ground, households' ability to take preventive measures). Such maps (Figure 25) can serve as ways to cross-check and validate other sources of information such as presented here and as a tool to prioritize flood risk management interventions.

FIGURE 25: FLOOD LOSS THROUGHOUT THE CITY – REPETITIVE LOSS PROPERTIES AND FEMA PAID CLAIMS (SOURCE: CITY OF L.A.FLOODPLAIN MANAGEMENT PLAN, APRIL 2010[86]

6.2 Emergency Response

Rapid emergency response is critically important during an emergency (Figure 26). Any lack of access to fire or police stations or impairment of the most direct transportation routes (due to flooding) increase the risk of additional loss of life. Flooding – even temporarily from heavy rainfall, combined with increasing sea level and coastal storm surge – can lead to increased time for emergency responders. Several important emergency routes, shown in Figure 27, are located along the coastline of Los Angeles – both within and outside City boundaries. Even areas that are outside of City boundaries can prevent emergency response from accessing the City's coastal neighborhoods. There are ten fire stations but no police stations in L.A.'s coastal areas at risk of flooding with sea-level rise. These include two fire stations in Pacific Palisades, one in Venice, one in Playa del Rey, six in San Pedro (and one emergency management service battalion).[87]

FIGURE 26: RAPID EMERGENCY RESPONSE CAN MEAN LIFE OR DEATH FOR SOME VICTIMS DURING A DISASTER. SEVERAL FIRE STATIONS ARE LOCATED ALONG THE COAST, AND IF FLOODED DURING HEAVY RAINS OR COASTAL STORMS AS SEA LEVEL RISES, THEIR ACCESS TO RESPOND TO FLOOD VICTIMS OR OTHERS IN NEED WILL BE IMPAIRED. (SOURCE: WIKIMEDIA COMMONS, AUTHOR "COOLCEASAR")

The access routes for emergency response (and evacuation of residents) can be jeopardized during flood events, especially as sea level rises. Figure 27 shows the important evacuation and emergency response routes in times of a disaster throughout L.A. County. Several "Highway Disaster Routes" run narrowly along the coast and are at risk of flooding with sea-level rise even during a 10-year storm. Moreover, these could be jeopardized as erosion (already a problem in many areas of the coast) increases as a result of sea-level rise. Flooding is the primary climate-related hazard that puts important highways at risk in Los Angeles' coastal communities (Figure 28), according to the modeled ArkStorm scenario conducted by the US Geological Survey.[88]

FIGURE 27. COASTAL PORTION OF DRAFT MAP OF EMERGENCY ROUTES IN LOS ANGELES COUNTY (SOURCE: LOS ANGELES COUNTY DRAFT GENERAL PLAN ACCESSED JUNE 20, 2012[89])

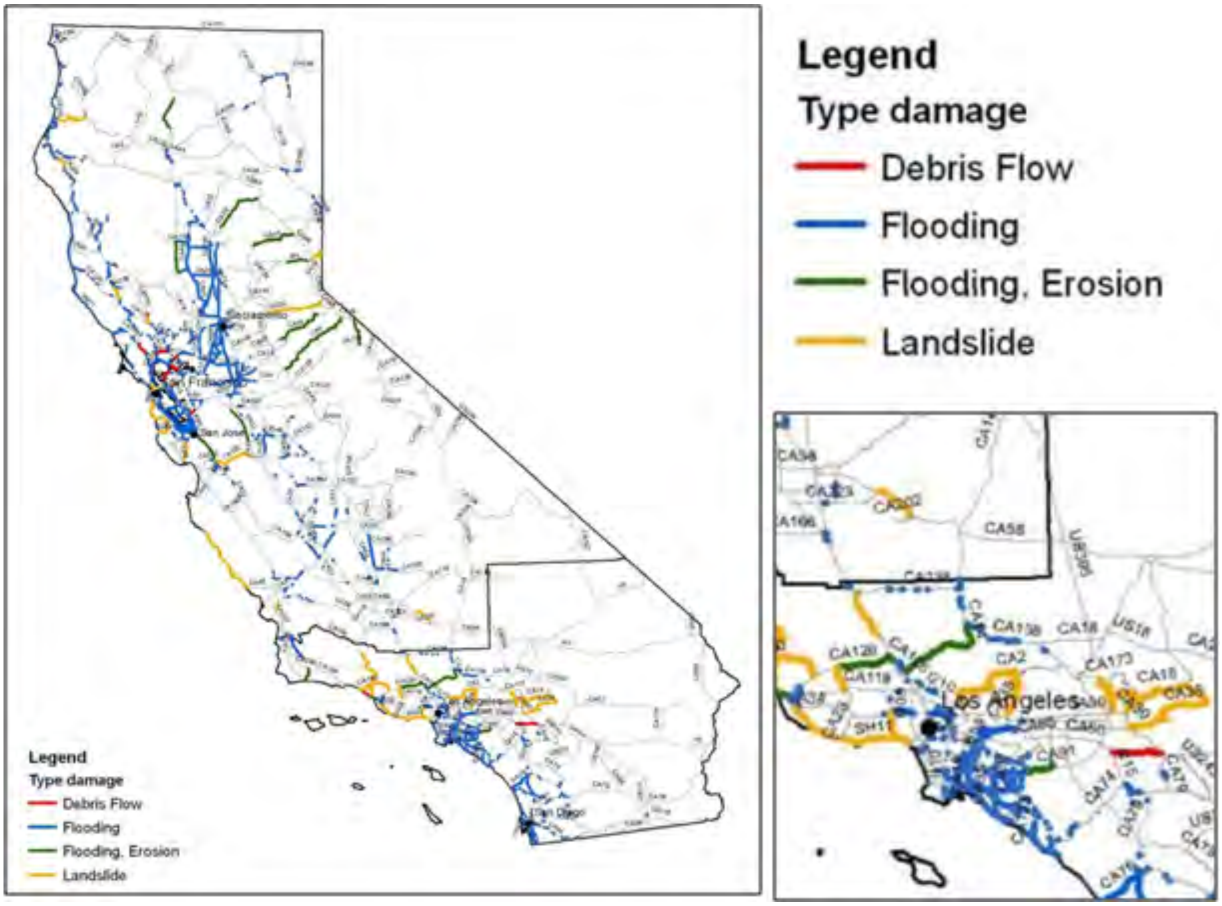


FIGURE 28. CUMULATIVE HIGHWAY DAMAGES PROJECTED FROM THE ARKSTORM SCENARIO. COASTAL LOS ANGELES COMMUNITIES ARE MAINLY AFFECTED BY FLOODING (BLUE) (SOURCE: ARKSTORM 2010 MAPS ON COPE PREPAREDNESS WEBSITE) [90]

6.3 Food Access

Proximity to supermarkets is at least as necessary during flooding emergencies as it is during other times. People rely on supermarkets not only for food and bottled water in times of emergency, but also for prescription medicines, batteries and other critical goods. For those with limited personal mobility (e.g., lack of a personal car), i.e. poorer and disabled populations, this is particularly relevant.

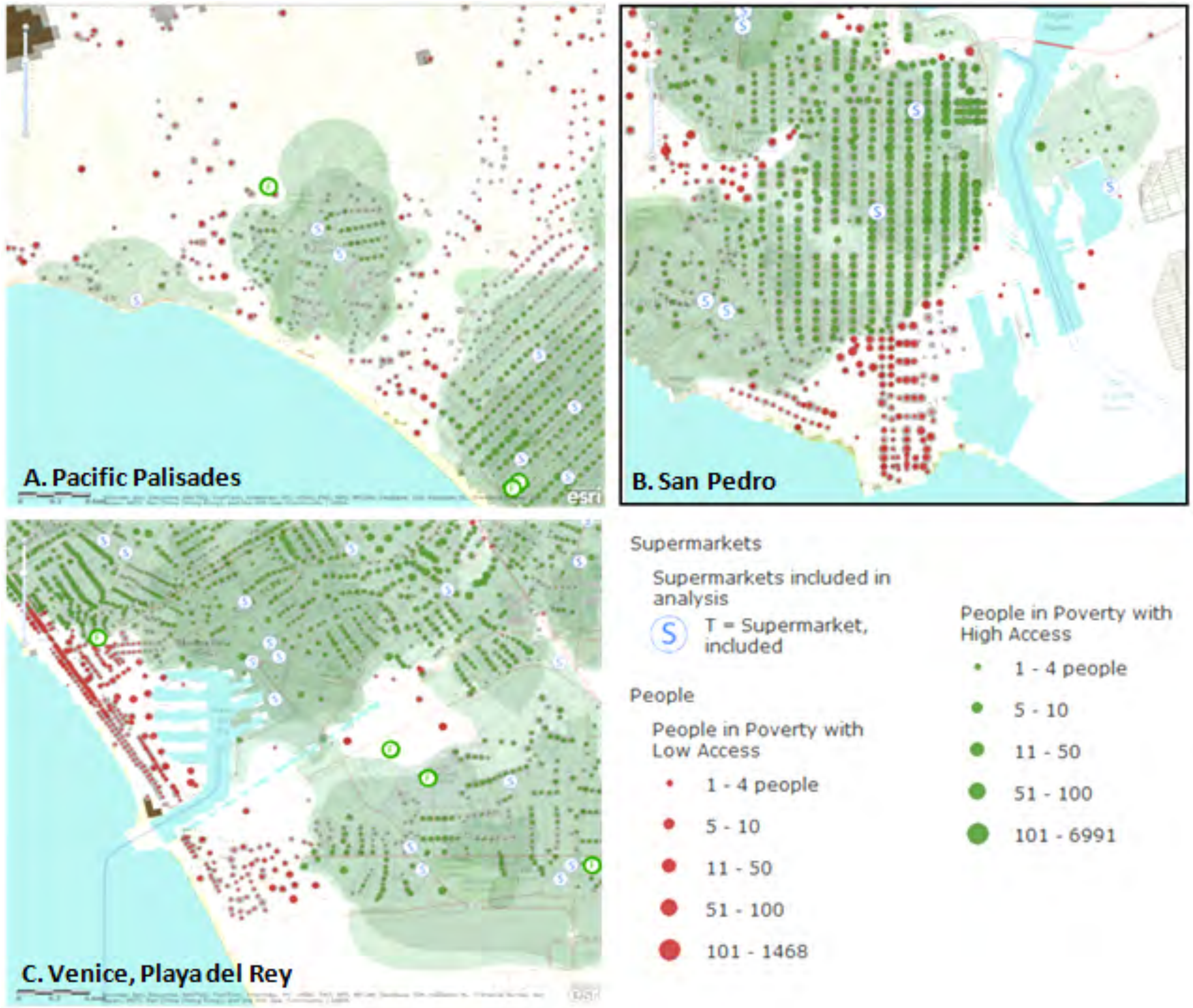


FIGURE 29: SUPERMARKET ACCESS FOR LOW-INCOME POPULATIONS IN SAN PEDRO AND HARBOR (TOP RIGHT MAP), PACIFIC PALISADES (TOP LEFT) AND VENICE AND PLAYA DEL REY (BOTTOM LEFT). GREEN AND RED DOTS INDICAT COASTAL POPULATIONS IN FUTURE FLOOD RISK ZONES THAT HAVE LOW OR HIGH ACCESS, RESPECTIVELY, TO CRITICAL GOODS, SUCH AS FOOD, BOTTLED WATER, PRESCRIPTION MEDICINES. AND OTHER EMERGENCY SUPPLIES (SOURCE: ARCGIS.COM)[91]

6.4 Beaches, Wetlands and Ecosystem Services

Coastal areas are popular destinations for the public to recreate and enjoy for swimming, relaxing, surfing, birding, hiking, sailing, canoeing, and so on. Reduction of easily accessible beaches and wildlife areas could mean some populations will no longer live within reach of accessible open space, which could create declines in well-being and quality of life for low income and minority communities that are already experiencing multiple stressors and have limited resources to travel further to alternative sites. In addition, beaches serve as important storm buffers, and wetlands also serve critical water purification functions. As discussed above in the Community Snapshots section, Cabrillo Beach, several beaches along Pacific Palisades, and Venice Beach historically all have received sand replenishment. The loss of sand at these beaches may increase markedly as sea level rises. This means that to maintain these important public beaches, the City would need to commit to more frequent beach replenishment in the future and develop the necessary financial means to do so.

Ballona Wetlands, discussed in the Venice Community Snapshot, is expected to flood regularly with 16 inches of SLR (see Figure 9 above). This area provides a unique wildlife and nature experience for urban residents, which is the only one of its kind in L.A. County. In addition to the potential threat to this resource as a recreation and educational area, the wetland also provides unique habitat for a variety of bird, plant and other species. Friends of Ballona Wetlands reports that about 300 species of birds have been cited in the wetlands, including Belding's savannah sparrows, least terns (endangered), least bitterns, great blue herons, and Canadian geese.[92] Demonstrating the ecological and social value this wetland to California, in January 2012 the state approved $6.5 million for planning a large-scale restoration of the Ballona Wetlands.[93]

7. SUMMARY & RECOMMENDATIONS

Above we have described the elements of social vulnerability as they relate to sea-level rise flooding risks and the City of L.A.'s residents. We provided brief snapshots of the three coastal areas within the City of L.A., followed by a description of population characteristics that indicate how and where some segments of coastal communities are more socially vulnerable than others. Characteristics of importance for social vulnerability included: income, poverty, education, females as head of household, race, linguistic isolation, age, housing type and age, and physical and mental illnesses and disabilities.

We integrated these characteristics into a social vulnerability index (SOVI) and compared it with another recently developed index. The two indices were developed using two slightly different methods, thus producing somewhat different results. The Social Vulnerability Index (SOVI), based on combination of population characteristics representing adaptive capacity and sensitivity, shows a relatively low overall social vulnerability along the coast in Los Angeles with some variation. In contrast, the highest social vulnerability is concentrated in the interior of the city and county. Still, based on this SOVI measure, portions of San Pedro, Wilmington, and one census block in Venice score with relatively high social vulnerability compared to the rest of the county. The second index, the Climate Change Community Screening Tool (CCCST), was developed by the California Department of Public Health specifically for climate change impacts. The mapped results of overall climate change vulnerability from this tool show a much higher measure of overall vulnerability along the coast of L.A. This measure incorporates the exposure dimension of vulnerability in the cumulative vulnerability score by including risk of climate change impacts such as heat extremes, flooding, wildfires and others (whereas the SOVI focuses only on sensitivity and adaptive capacity indicators). This difference partially explains the differences in results and highlights the importance of understanding the methods and variables used to calculate integrated snapshot vulnerability in Los Angeles.

Integrated scores of vulnerability can be useful as a first-order tool to help prioritize areas of concern for climate adaptation planning, but the review of individual characteristics that cause the overall vulnerability are more appropriate to inform the development of specific adaptation strategies. Here we provide a brief summary of findings seen in the presentation of individual population characteristics.

First, income is one of the most important indicators of adaptation capacity. Per capita income in Los Angeles overall tends to be higher along the coast than in the interior. However, there is a pocket of the population located around the Port of L.A., where a high proportion of households lives below the federal poverty level L.A. High proportions of the population with low education levels (e.g. those over 25 years old who did not graduate from high school) – also associated with lower adaptive capacity – reside in San Pedro and Wilmington. In these same neighborhoods Census data shows that high proportions of the population are linguistically isolated (speak English less than "very well") and are largely of Hispanic/Latino descent. This information can inform emergency response planning for flooding and sea-level rise, and for developing strategies to engage community members in active climate adaptation planning. This might include, for example, conducting workshops and preparing public outreach materials in Spanish and, given low education and high poverty levels, using alternative methods that do not require literacy or internet access.

Other characteristics that indicate high social vulnerability include housing type and control over living situation. Census data shows high proportion of older housing, which tends to be more sensitive to flood (less flood-proof), in Venice and again in neighborhoods surrounding the Port of L.A. These same communities have high proportion of renters, which tend to not have the means or incentives to flood proof their homes.

Segments of the population that may need special assistance in emergencies because of a lack of mobility or other disadvantages include the elderly, children, the homeless, those with existing physical or mental illness, and those living in group quarters. An important first step in preparing special assistance for these populations is to document where they reside so that emergency response preparations and long-term adaptation plans can be made to help these populations when the time comes.

RECOMMENDATIONS

Invest in strong foundation for climate adaptation: Climate adaptation is a complex process, involving decision-makers at all levels of government (even if the focus of adaptation is a local community), as well as in civic society and the private sector; it is not a one-time effort, but an ongoing process with periods of lesser and more intense activity; it requires periodic updates of information and scientific understanding, and including such new information in the decision-making process; and it goes far beyond technical and structural solutions, but involves policy changes, creative financing, capacity building among key staff and decision-makers, and effective public engagement. At this early stage in adaptation for most communities, including Los Angeles, it is therefore important to lay a strong foundation for such an ongoing process. Elements of such a foundation include:

- Acquisition of the best available science and developing a timeline and formal strategy for periodic updates of scientific information in planning and decision-making procedures;
- Assessing and ascertaining the capacity and willingness of local government departments, agencies, commissions, and boards to integrate information on climate change and related infrastructure and social vulnerability into their planning, budgetary, and policy decisions;

- Initiating 'soft' adaptation strategies, such as staff training, developing trusting relationships with community organizations, identifying and supporting local champions in government, business, and civic organizations, and building governance structures across sectors and jurisdictional boundaries to increase adaptive capacity, foster buy-in, and generate the necessary institutional and political support;
- Creating opportunities for periodic, meaningful public engagement that gather information about affected neighborhoods and communities' concerns, vulnerabilities, and constraints; to educate about climate change related risks; and to jointly develop strategies that are designed to meet current and future needs. Such engagement should also offer opportunities for communities to express any concerns and needs around procedural justice and equitable burden sharing and outcomes of adaptation.

Define clear adaptation goals: Most adaptation planning processes to date in the US have been undertaken without clearly defining what "success" would look like. Goals could focus on both procedural and outcome intentions. Failing to define success has several important implications, directly relevant to local decision-making: It is difficult to prioritize and justify expenditures when a goal or purpose is not identified, and it is politically difficult to sell when people cannot visualize the intended outcome (even if just a temporary outcome). It is also difficult to show that a strategy made a positive difference or to measure progress toward the desired goal. The City would therefore be well advised in not just stating a "pie in the sky" goal, but to spend concerted effort both internally and with community involvement to define desirable and feasible outcomes of adaptation. Strategies flow more clearly from identified goals.

Develop clear prioritization and selection criteria for choosing among possible adaptation strategies: A corollary to the need for a clearly defined goal is the establishment of criteria that help select options from the universe of potential adaptation strategies. Such criteria would help with prioritization when budgets, timelines, technical considerations, and social concerns and political feasibility inevitably place constraints on preferred solutions. Again, such criteria are best selected in consultation and agreement with affected stakeholder communities, as exclusion from defining *how* decisions will be made can lead to political resistance and lack of buy-in to the ones that *are* being made. That, of course, could endanger the ultimate success of the entire effort.

Updating the vulnerability assessment as better flood risk models and maps become available: As stated in this report (Section 3), the use of a 10-year flood scenario with sea-level rise was a pragmatic choice in light of the best available, most defensible physical science at this time. Ten-year floods, however, are not the common planning standards (100- and 500-year floods are benchmarks for FEMA for example). In addition, SLR scenarios may change over time, as the science advances, as will land use, the level of coastal protection, and the demographic and socioeconomic situation of coastal populations. Thus, the City would be well advised to closely track scientific developments and update the current vulnerability assessment as needed to ensure its adaptation plans and preparedness measures are up-to-date.

Expand partnerships in developing adaptation options: Much adaptation that addresses social vulnerability and public concerns requires close collaboration with the affected groups. Thus, to the extent collaborative ties are not yet established, it would be important to establish working relationships with marginalized groups or organizations that represent them (e.g. using *Emergency Network LA* to include climate change training; see Wisner and Uitto[94]), expand the network of adaptation stakeholders to include those already working on increasing community resilience in the face of disasters.

> **A case in point:** The *L.A. County Community Resilience Project*, funded by the Center for Disease Control, is a three year project that aims to improve community resilience and disaster preparedness throughout L.A. County. This collaborative project between UCLA, the Emergency Network of Los Angeles (ENLA), and the L.A. Department of Public Health exemplifies what it may take to build the needed relationships within communities before a disaster occurs. The upcoming phase of the project will select 16 communities in the county to test out a toolkit to help communities prepare for disasters. The project includes a working group focused on vulnerable populations.[95] While the communities piloting the toolkit may not be coastal, the project could have valuable contributions to the city's and region's climate adaptation planning process.

More detailed community-based information: To develop adaptation options that are most strategically designed to address the communities' needs, it would be beneficial to expand on this vulnerability assessment by providing a more detailed assessment that involves affected communities. Community representatives could participate in developing adaptation options. Also, recognizing that this social vulnerability assessment will likely be expanded beyond City boundaries or to other climate impacts beyond sea-level rise and flooding, other useful resources for finding geographic data related to issues of environment justice are listed in a report published by the CALFED Environmental Justice Subcommittee.[96]

> **A case in point:** The Pacific Institute, funded by the California Energy Commission, conducted a community-level vulnerability assessment in the City of Oakland demonstrating how working with representatives of disadvantaged groups could reveal social vulnerabilities that were grounded in the concerns and needs of the residents themselves.[97] Another model demonstrating the strength of engaging communities themselves in the adaptation process was undertaken as a partnership between non-governmental organizations and the counties of San Luis Obispo and Fresno. The non-governmental organizations provided climate projections, important coordinating and meeting facilitation, and framing for ways to think about and design adaptation options. An initial social vulnerability assessment was first conducted by outside experts, which was then used as a foundation (framing and data) from which stakeholders could provide more detailed information about the issues and vulnerabilities of their sectors.[98]

Coordinate adaptation with neighboring communities beyond the City borders: Climate change impacts on neighboring cities and unincorporated areas, as well as their adaptation responses, will inevitably affect the success of adaptation strategies implemented within the City's boundaries. This is true for sea-level rise and other climate change impacts. Therefore, expanding the planning process sooner rather than later to collaborate with those communities will help ensure that consistent science is used, and coherent and coordinated adaptation strategies are developed and chosen for L.A.'s coastline. This may help build up adaptive capacity in the region more quickly, and possibly involve cost sharing and savings for all involved.

APPENDIX A. USEFUL CONTACTS FOR FUTURE STAKEHOLDER ENGAGEMENT

The table below contains a list of people and contact information who either were helpful to us in providing information for this assessment directly, who were mentioned as being interested in future opportunities to be involved in the adaptation process, or who are involved in complementary work that could be very useful to informing/coordinating with the adaptation process led by the City of Los Angeles. This should not be considered a complete list, but these valuable contacts should be maintained or sought for the ongoing adaptation process in Los Angeles.

Name	Affiliation	Related work	Contact information
Alix Stayton	Program Manager, Emergency Network L.A. (ENLA)	ENLA and L.A. County Community Resilience Project	info@enla.org, 213-739-6888 , www.enla.org
Robin Rudisill	Venice Neighborhood Council	Knowledgeable about Venice, flooding, and community issues, and interested in working with climate adaptation planning process	wildrudi@mac.com
Lonna Calhoun	President of COPE Preparedness (www.COPE-Preparedness.org), San Pedro Neighborhood Council	Expert on working with communities for disaster preparedness; knowledgeable about San Pedro and Wilmington community needs for emergency preparedness and flooding; On 7/21/12 conducting emergency preparedness workshop in all Spanish in Wilmington; wants to be involved in future assessments of vulnerability (infrastructure or social)	Lonna@cope-preparedness.org, 310-982-1180
David Eisenman	Associate Professor of Medicine and Public Health Director, UCLA Center		310-794-2452 deisenman@mednet.ucla.edu

	for Public Health and Disasters		
Dede Audet	Venice Neighborhood Council	Very knowledgeable about the history of flooding in Venice	daudet@ca.rr.com, ddaudet@comcast.net
Darryl DuFay	Venice Neighborhood Council	Worked on the flood assessment for the community	darryldu@pobox.com

REFERENCES AND ENDNOTES

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[1] Hispanic/Latino and non-White Hispanic are Census Bureau-defined terms used throughout this report. According to the Office of Management and Budget, to qualify as "Hispanic" (the overarching term used) means to be of Hispanic or Latino ethnicity (i.e. any person of Cuban, Mexican, Chicano, Puerto Rican, South or Central American, or other Spanish culture or origin regardless of race) (see: http://www.census.gov/newsroom/cspan/hispanic/2012.06.22_cspan_hispanics.pdf).

[2] Note that the 2010 Census data, while more up-to-date, often contain far less detailed information (fewer demographic variables) than the 2000 Census. This makes the tracking of social vulnerability over time more difficult.

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Finzi Hart, J. A., P. M. Grifman, S. C. Moser, A. Abeles, M. R. Myers, S. C. Schlosser, J. A. Ekstrom. (2012) *Rising to the Challenge: Results of the 2011 Coastal California Adaptation Needs Assessment*. USCSG-TR-01-2012. Available at: http://www.usc.edu/org/seagrant/research/climateadaptsurvey/SurveyReport_FINAL_OnlinePDF.pdf

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Martinich, J., J. Neumann, L. Ludwig, and L. Jantarasami. 2012. Risks of sea level rise to disadvantaged communities in the United States. *Mitig. Adapt. Strateg. Glob. Change*, pp1-17; Available at: doi:10.1007/s11027-011-9356-0

[14] http://www.climatechange.ca.gov/adaptation/; see in particular the Appendix in which key concepts are defined. The State's terminology reflects common understanding in the scientific literature, especially the (social scientific) climate change literature.

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Appendix 4: Economic Vulnerability Assessment

Economic Impact of Sea level Rise to the City of Los Angeles

by

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Final Report

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Economic Impact of Sea-level Rise to City of Los Angeles

Dan Wei and Samrat Chatterjee[1]

Executive Summary

Sea level rise is among the most profound effects of global climate change. It can be caused by the melting of glacier and massive ice sheets around the world and the thermal expansion of the ocean when the average global temperature increases. According to the IPCC Fourth Assessment Report, there is strong evidence showing that the sea level has been gradually rising in the past century. Many studies predict that sea level rise will be accelerating over the coming decades. Moreover, sea level rise is also expected to increase the intensity and severity of extreme coastal disasters, such as high tides, strong storms, and coastal flooding (IPCC, 2007). A recent study by National Research Council (NRC) projects that sea level rise for California coast can reach 0.12 to 0.61 m by 2050 and 0.42 to 1.67 m by 2100 (NRC, 2012).

Given its long shoreline and increasing exposure to risk and potential damage from sea level rise, California has been putting great efforts in incorporating sea level rise considerations into regional and local coastal development planning. California Executive Order S-13-08, which was signed by Governor Schwarzenegger in 2008, requires the California Natural Resources Agency to coordinate with public agencies at different levels and with private entities to develop a climate adaptation plan for the state.

This study is part of a larger effort to evaluate the vulnerability of City of Los Angeles to sea level rise caused by climate change. The focus of this study is the potential economic losses from coastal flooding events, which can be amplified by sea level rises. Together with the physical and social vulnerability assessments that are performed in parallel to this study, these coordinated research efforts aim to help the policymakers and planners of the City better plan and address sea level rise issues for the coastal communities.

The analysis in the study is performed based on the application of two modeling tools. HAZUS MH 2.1, FEMA's standardized modeling tool for estimating potential losses from hazards, is used to evaluate the property damage to building stocks (including both buildings and their contents) and the direct business interruption losses in the flooding affected region. The Input-Output (I-O) model, one of the most widely used tool of regional impact analysis, is then applied to calculate the total business interruption losses based on the direct loss estimates from the HAZUS model.

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In this study, we model two scenarios of sea level rise: 1) 0.5 meters by 2050; and 2) 1.4 meters by 2100. For each of these scenarios, we evaluate the economic impacts of two coastal flood events: a) a 10-year coastal flood; and b) a 100-year coastal flood.

The simulation results indicate that building exposure values (values of building at risk) of a 10-yr flood event increases from $2.5 billion in the Base Case to $2.7 billion in the 0.5 m sea level rise scenario, and increases further to $3.3 billion in the 1.4 m sea level rise scenario. For a 100-yr flood event, the building exposure values are $3.1, $3.4, and $4.5 billion for the Base Case, 0.5 m sea level rise, and 1.4 m sea level rise scenarios, respectively.

Building exposure values of a 10-yr flood event increases from $2.5 billion in the Base Case to $2.7 billion in the 0.5 m sea level rise scenario, and increases further to $3.3 billion in the 1.4 m sea level rise scenario. For a 100-yr flood event, the building exposure values are $3.1, $3.4, and $4.5 billion for the Base Case, 0.5 m sea level rise, and 1.4 m sea level rise scenarios

Table ES-1 presents the summary results of building stock losses for the scenarios analyzed. For a 10-yr flood event, the direct building losses are expected to be $410.3 million with 0.5 m sea level rise, and nearly doubled with 1.4 m sea level rise. For a 100-yr flood event, the building losses increase from $820.2 million to $1,441 million when sea level rises from 0.5 m to 1.4 m. Losses to residential buildings comprise about 50% of the total losses. The other 50% losses are split evenly between the commercial buildings and industrial buildings in most simulated scenarios.

Table ES-1. Summary Results of General Building Losses (millions of 2010$)

Category	Base Case		0.5 m Sea Level Rise		1.4 m Sea Level Rise	
	10-Yr Flood	100-Yr Flood	10-Yr Flood	100-Yr Flood	10-Yr Flood	100-Yr Flood
Building Losses	103.3	260.9	179.4	364.4	315.0	649.9
Content Losses	132.6	312.1	219.6	435.5	380.2	759.9
Inventory Losses	6.8	15.5	11.3	20.3	19.7	31.5
Total Building Losses	**242.7**	**588.6**	**410.3**	**820.2**	**714.9**	**1,441.3**

Table ES-2 presents the summary results of building-related business interruption losses for the study scenarios. The business interruption losses are relatively small compared with the building stock losses. For a 10-yr flood event, the total output losses in the City are expected to be $5.8 million to $9.1 million under the two simulated sea level rise scenarios. For a 100-yr flood event, the total output losses are expected to be $10.5 to $21.9 million. The major reason of the relatively low business interruption losses caused by the coastal flood events is that over 95% of the damaged buildings are residential buildings, rather than the buildings of producing sectors. Another important reason is that the HAZUS direct output loss estimation has taken into consideration the production recapture factor, which refers to the ability of businesses to recapture lost production by working overtime or extra shifts once their operational capability is restored. This is the most effective resilience measure that has been widely

documented in the literature that can help reduce the potential business interruption losses in the aftermath of natural disasters.

Table ES-2. Summary of Business Interruption Losses

Category	Base Case		0.5 m Sea Level Rise		1.4 m Sea Level Rise	
	10-Yr Flood	100-Yr Flood	10-Yr Flood	100-Yr Flood	10-Yr Flood	100-Yr Flood
Output Losses (M 2010$)	$3.4	$7.4	$5.8	$10.5	$9.1	$21.9
Income Losses (M 2010$)	$2.3	$4.9	$3.8	$6.6	$5.9	$13.6
Employment Losses (Jobs)	24	52	41	74	64	158

Our simulation shows that the transportation system and the utility system in the City would suffer very limited damages from the flooding in the scenarios evaluated in this study.

Our estimates on the potential economic impacts of sea level rise to the City should be considered on the conservative side. The analysis only focuses on the potential impacts from the temporary flooding in the coastal area due to extreme coastal storms, and how those impacts can be amplified by sea level rise. Any impacts caused by long-term and permanent coastal erosion and beach area losses of sea level rise are not covered in this study.

I. Introduction

Sea level rise is among the most profound effects of global climate change. It can be caused by the melting of glacier and massive ice sheets around the world and the thermal expansion of the ocean when the average global temperature increases. According to the IPCC Fourth Assessment Report, there is strong evidence showing that the sea level has been gradually rising in the past century. With the availability of satellite technology in the past twenty years, more accurate rates of sea level rise have been recorded. Satellite observation data indicate that since early 1990s, the average rate of global sea level rise was about 3 mm per year (IPCC, 2007). Various forecasts of sea level rise for the future have been undertaken by various studies based on alternative scenarios of Greenhouse Gas (GHG) emission projections. For example, with respect to the IPCC SRES A1B scenario, the projected global sea level rise by mid 2090s can reach 0.22 to 0.44 m relative to the 1990 sea level (IPCC, 2007). In addition, sea level rises vary across different regions. A recent study by National Research Council (NRC) projects that sea level rise for California coast can reach 0.12 to 0.61 m by 2050 and 0.42 to 1.67 m by 2100 (NRC, 2012).

Sea level rise is also expected to increase the intensity and severity of extreme coastal disasters, such as high tides, strong storms, and coastal flooding (IPCC, 2007). Studies focusing on the eastern coast of the U.S. and Canada have found that in the past century, there was a trend of reducing return periods of extreme coastal disasters due to sea level rise (Zhang et al., 2000; William et al., 2009).

Given its long shoreline and increasing exposure to risk and potential damage from sea level rise, California has been putting great efforts in incorporating sea level rise considerations into regional and local coastal development planning. California Executive Order S-13-08 was signed by Governor Schwarzenegger in 2008, which requires the California Natural Resources Agency to coordinate with public agencies at different levels and with private entities to develop a climate adaptation plan for the state. In particular, the Executive Order requires that an independent panel convened by the National Academy of Sciences to develop the first Sea Level Rise Assessment Report for California.

This study is part of a larger effort to evaluate the vulnerability of City of Los Angeles to sea level rise. The focus of this study is the potential economic losses of coastal flooding events, which can be amplified by sea level rises. Together with the physical and social vulnerability assessments that are performed in parallel to this one, these studies aim to help the policymakers and planners of the City better plan and address sea level rise issues for the coastal communities. The economic impacts analyzed in this study include both property damage losses, and direct and indirect business interruption losses. The two sea level rise scenarios evaluated in this study are 0.5 meters by 2050 and 1.4 meters by 2100. They are consistent with the climate change and sea level rise scenarios evaluated for the California Energy Commission's Public Interest Energy Research (PIER) Climate Change Research Program by the California Climate Change Center (Cayan et al., 2009). The same scenarios are also used in a recent USGS study, which models the impact of severe winter storms, especially due to sea level rise, to the Southern California Coastal Region.

The analysis in the study is performed based on the application of two modeling tools. HAZUS MH 2.1, FEMA's standardized modeling tool for estimating potential losses from hazards, is used to evaluate the property damage to building stocks (including both buildings and their contents) and the direct business interruption losses in the flooding affected region. The Input-Output (I-O) model, one of the most widely used tool of regional impact analysis, is then applied to calculate the total business interruption losses based on the direct loss estimates from the HAZUS model.

This report is divided into eight sections. In the next section, we first provide a brief summary of studies on socioeconomic impact analysis of sea level rise. In Section III, we present an overview of basic concepts related to economic impacts of disasters. The two modeling tools used in this study are then introduced in Section IV. Section V presents the sea level rise and coastal flood scenarios evaluated. Section VI gives a brief introduction to the study region. The analysis results are presented in Section VII. The report concludes with Section VIII.

II. Socioeconomic Impact Analysis on Sea Level Rise

Since the early 1990s, there has been an increasing number of studies that examined the socioeconomic cost of sea level rise. Many of the early studies estimated the economic losses of sea level rise in terms of values of property that would be vulnerable under alternative sea-level rise scenarios as well as the potential cost of protection (IPCC, 2001). Several early studies (e.g., EPA, 1989 and Nordhaus, 1991) estimated that with a doubling of GHG concentration towards the second half of the 21th century, the expected cost to the U.S. economy in 2065 can reach $7 to $9 billion (in 1990 dollars) in terms of property damages and cost of protection. The cumulative losses can exceed $100 billion. Several following studies, including Yohe et al. (1996) and Yohe and Schlesinger (1998) presented much lower loss estimates, at about $0.2 to $0.4 billion (also in 1990 dollars) annually, or a cumulative of over $30 billion by 2065, after taking cost-reducing effects such as natural, regulative, and market-based adaptation potentials into consideration. In most of these early studies, cost-benefit approach was widely used. Sea level rise can also increase the frequency and severity of extreme coastal storms, which can cause even higher damages to the coastal and low-lying properties. West et al. (2001) indicated that extreme coastal storms can increase total losses from sea level rise by 20%.

More recent studies have expanded the scope of sea level rise economic impact analysis to include impacts on coastal businesses, erosion impacts, values of lost wetland, consumer surplus losses from reduced beach visits, etc. The Heinz Center (2000) study found that the accelerating coastal erosion caused by sea level rise can result in losses to property owners to more than $500 million per year. Michael et al. (2004) evaluated the economic cost of sea level rise to three communities (Shady Side, Piney Point, and Hooper Island) in the Chesapeake Bay area. The total economic impacts, including property damages to residential properties, damages to roads and bridges, and wetland losses resulted from inundation in a two-foot sea level rise scenario by 2100, as well as damages caused by increasing number of episodic flood events, were estimated to be $27 million of the three communities.

Since 2009, several studies were undertaken to evaluate the economic impacts of sea level rise for California. Heberger et al. (2009) analyzed the impacts of sea level rise along the 1,100 miles coast of California and the 1,000 miles of shoreline around the San Francisco Bay. Inundation and erosion geospatial data, under the assumption of three sea level rise scenarios (0.5m, 1.0m, and 1.4m), are integrated with the HAZUS software to estimate the consequences of a coastal flooding event with a 100-year return period. This study estimated that nearly 500 thousand people and $100 billion worth of property in the state will be at risk; much of the critical infrastructure, including hospitals, power plants, wastewater treatment plants, schools will be at risk of damage; building new or enhancing existing coastal protection structures would cost $14 billion, with an additional annual maintenance cost of $1.4 billion (in 2000 dollars).

With an integration of a beach attendance model and a beach sediment model, and based on the analysis of 51 public beaches in Los Angeles County and Orange County, Pendleton et al. (2011) evaluated the economic impacts of permanent beach loss caused by sea level rise and temporary beach inundation by extreme coastal storms. The study indicated that a 1 m sea level rise by 2100 can reduce more than 500 thousand beach visits by Southern California local residents in each year. This can be translated into an economic welfare loss of $40 to $63 million annually. In addition, severe wind storms can also result in substantial reductions in beach attendance and related spending. An extremely stormy year is expected to reduce beach visits by more than 300 thousand, and the economic welfare loss can reach $37 million.

King et al. (2011) conducted a comprehensive economic impact analysis of sea level rise of five representative California coastal communities. Three sea level rise scenarios by 2100 are evaluated in terms of three categories of coastal region impacts: 1) temporary flooding from coastal storms with a 100-year return period; 2) long-term beach erosion; and 3) long-term upland erosion. Using Venice Beach as an example, the economic impacts of structure and content damages stemming from a 100-year coastal flooding with 1.4 m sea level rise by 2100 are estimated to be over $50 million. In addition, annual losses in beach benefits (including recreational value, habitat value, beach-related spending, and tax revenue), which is caused by slow and steady beach width decrease from a 1.4 m sea level rise by 2100 can reach nearly $500 million.

In this study, we analyze the economic impact of sea level rise to the City of Los Angeles. Our analysis is focused on temporary flooding in the coastal area caused by extreme coastal storms. Economic impacts evaluated in this study will include property losses (building and content losses), as well as direct and indirect business interruption losses due to extreme coastal flooding events. Potential impacts to transportation system and utility system will also be evaluated. Any impacts caused by long-term and permanent beach area losses from sea level rise are not covered in this study. There are three areas of the City that are located along the Pacific Coast: Pacific Palisades, Venice/Playa del Rey, and San Pedro/Wilmington. When we compute the property losses and the direct business interruption losses, we focus on the coastal regions within the City that are directly affected by the coastal flooding events. As for the indirect business interruption losses, they include not only the multiplier (ripple) effects of the direct business interruption losses taking place within the City, but also the indirect effects to the City

stemming from the losses to the coastal regions that are outside of the City but within the boundary of the LA County.

III. Basic Concepts

For many years, the main focus of disaster loss estimation has been focusing on property damage to structures. All other types of impacts (economic, sociological, psychological, etc.) were classified into a category termed "indirect" or "secondary" losses. By the mid-1990s, there was a growing appreciation of the role of business interruption losses, which refer to the reduction in the flow of goods and services produced by property (capital stock). This stock vs. flow distinction is a basic concept in economics, and both the losses on capital stock and goods flow have direct and indirect versions. *Direct property damage* relates to the effects of natural phenomena, such as fault rupture, ground shaking, landslides, tsunami, wave surge, etc., while *collateral*, or *indirect*, *property damage* is exemplified by ancillary fire caused by ruptured pipelines, or loss of fresh water supply due to sea water intrusion, etc. *Direct Business Interruption* refers to the immediate reduction or cessation of economic production in a damaged factory or in a factory, though not experienced through property damage, but is suffered from service disruptions for at least one of its utility lifelines, or curtailed in one of its key production inputs. *Indirect Business Interruption* (referred to as contingent BI by the insurance industry) stems from the “ripple,” or “multiplier," effects associated with the supply chain or customer chain of the directly affected business (see, e.g., European Union, 2003; Rose, 2004; National Research Council, 2005; Rose et al., 2007).

An important consideration to emphasize is that nearly all direct property damage takes place at a given point in time, and that ancillary (or indirect) property damage takes place during a fairly short time span. Business interruption, on the other hand, being a flow variable, is time-dependent. It begins when the ground shaking starts or the building structures are hit by flooding and continues until the built environment is repaired and reconstructed to some desired or feasible level (not necessarily pre-disaster status) and a healthy business environment is restored. As such, business interruption is complicated because it is highly influenced by the choices of private and public decision makers about the pattern of recovery, including repair and reconstruction.

IV. Analytical Models

A. FEMA HAZUS Model

HAZUS-MH 2.1, the FEMA modeling tool for estimating potential losses from hazards, is used in this study to analyze the potential physical damages and some social impacts of the flood disasters. Specifically, the HAZUS-MH 2.1 Flood Model is applied. This is a large expert system that contains census block data on the built environment, a set of damage functions, and GIS capability. The HAZUS-MH Flood Model is widely used by planners and policy analysts to perform flood impact analyses. The

methodology used by HAZUS to estimate flood losses includes two modules: Flood Hazard Analysis and Flood Loss Estimation Analysis. The former uses inputs, such as frequency, ground elevation, and other ground characteristics, to estimate the depth and velocity of the flood hazard. The results are then used by the Flood Loss Estimation Module to calculate resulting physical damage and direct business interruption, which are in turn translated into direct dollar values of building replacement costs and business downtime costs, respectively (FEMA, 2011b).

In HAZUS, loss estimation from floods is calculated based on the inventory data of the building stock, infrastructure, and population within the study region that are exposed to the simulated flood event. For this initial economic impact study, we largely use the inventory data for the City of Los Angeles contained in the HAZUS database. For residential structures, census data are used as the main data source, while for the non-residential structures, Dun & Bradstreet (D&B) data are used (FEMA, 2011a).

Appendix A presents a detailed summary of the analytical steps undertaken in our HAZUS modeling.

In this study, losses that will be estimated through the HAZUS modeling tool include:

- Physical damage to building stocks (residential and non-residential), essential facilities, transportation system and utility system.
- Debris generation.
- Social impacts such as estimates of shelter requirements.

B. Input-Output Model

Input-Output (I-O) analysis, developed by Nobel laureate Wassily Leontief, is the most widely used tool of regional impact analysis in the U.S. and throughout the world. Moreover, it has been used extensively to analyze the economic impacts of natural hazards (see, e.g., ATC, 1991; Rose and Lim, 2002; Rose et al., 2011). It is especially adept at estimating ripple, or multiplier, effects. I-O can be defined as a static, linear model of all purchases and sales between sectors of an economy, based on the technological relationships of production. In an I-O analysis, it is important to distinguish two types of second-order effects. The first is "indirect" effects, which represent the interaction between producing sectors. The second is "induced" effects, which represent the interaction between households and producing sectors; production generates income paid to households, who in turn spend a major portion of this income on produced goods and services, thereby generating additional multiplier effects.

For this study, we use the most widely used source of regional I-O tables, the Impact Analysis for Planning (IMPLAN) System (MIG, 2012). This source consists of three components: 1) a study region (can be state, county, sub-county) data base, 2) a set of algorithms capable of generating I-O tables for any state, county or sub-county group, and 3) a computational capability for calculating multipliers and performing impact analyses. The IMPLAN sectoring scheme is currently based on the North American Industrial Classification System (NAICS), and includes the details of 440 sectors. When performing the analysis, the user has the flexibility to aggregate the IMPLAN sectors according to the study needs.

I-O model has both demand-side and supply-side versions. The demand-side I-O model is the standard version, where a change in final demand affects the economy by causing product supply to respond through a multiplier process. The supply-side I-O model is a variant of the standard model in which the impacts to the economy takes place through the production side of the economy. This can be a change in primary factors (e.g., labor) of individual sector economic activity that ripples throughout the economy through marketing patterns of sales of one sector to another (Rose and Wei, 2011). In this study, both demand-side and supply-side I-O models will be applied to provide a more comprehensive evaluation of the potential economic losses stemming from a flood event to the City.

I-O has been used successfully in conjunction with HAZUS (see, e.g., Rose et al., 2007; Rose et al., 2011; FEMA, 2012). In fact, the Indirect Economic Loss Module (IELM) of HAZUS is based on an I-O methodology. However, in this study, we use the IMPLAN I-O model, rather than the HAZUS IELM for two main reasons. First, using IMPLAN I-O data enables us to construct a model at a finer level of sectoral detail than is available in HAZUS. Second, through our previous experience, we conclude that the IELM involves some assumptions regarding interregional trade that would exaggerate the ability of the economy to adjust to the hazards and would thus underestimate the impacts.

Outputs from I-O analysis include business interruption impacts in terms of:

- Gross Output
- Personal Income
- Employment

The business interruption impacts are analyzed at both the economy-wide level and the sectoral level.

Figure 1 presents the overall framework of the modeling system used in this study.

In the figure, the blue shaded section represents the analysis performed in HAZUS and the outputs obtained from the HAZUS simulations. After providing the characteristics of the coastal flooding event, such as the return period of the flood and the still water level associated with alternative sea level rise scenarios, the Flood Hazard Analysis Module is run to model the depth and velocity of the flood. Then based on the coastal inundation results and building exposure in the affected region, the Flood Loss Estimation Module estimates the direct structure and economic damage through the use of vulnerability curves (FEMA, 2011a). The direct property damages estimated from HAZUS include general building stock damage, essential facility damage, and the impacts on the functionality of the lifeline and transportation systems. The building-related direct business interruption losses will also be estimated. These losses are calculated based on the results of building damages and business loss of function time, and the default sectoral output per square feet per day data provided in the HAZUS model. In the HAZUS Flood model, induced damage from a flood event includes debris generation.

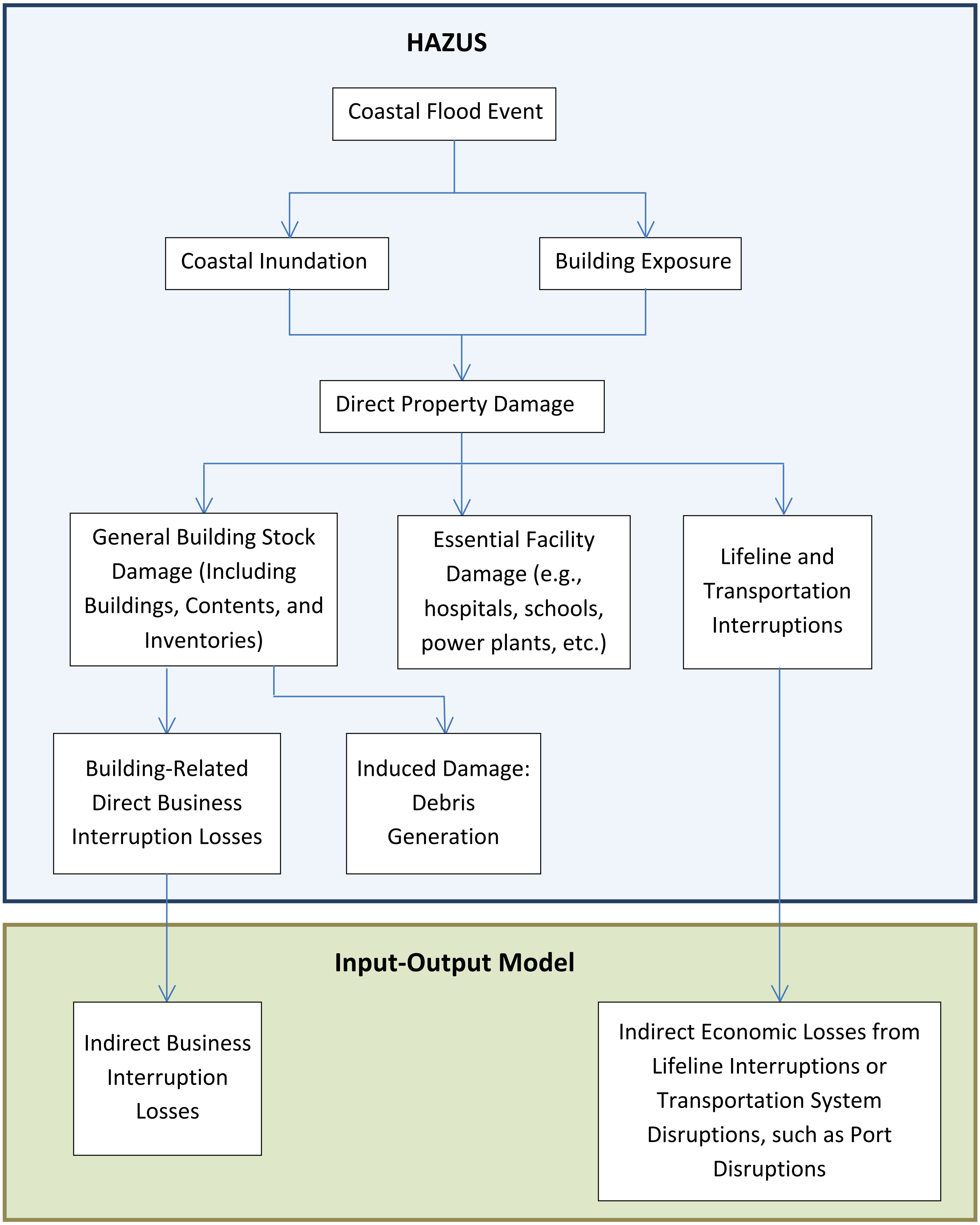
HAZUS
Coastal Flood Event
Coastal Inundation
Building Exposure
Direct Property Damage
General Building Stock Damage (Including Buildings, Contents, and Inventories)
Essential Facility Damage (e.g., hospitals, schools, power plants, etc.)
Lifeline and Transportation Interruptions
Building-Related Direct Business Interruption Losses
Induced Damage: Debris Generation
Input-Output Model
Indirect Business Interruption Losses
Indirect Economic Losses from Lifeline Interruptions or Transportation System Disruptions, such as Port Disruptions

Figure 1. Schematic Diagram of the Modeling Framework

The green shaded section in the figure represents the analysis performed in the Input-Output Model. Both the demand-side and supply-side I-O approaches are applied to the building-related direct business interruption losses obtained from HAZUS to compute the total (including direct, indirect, and induced) business interruption losses. Interruptions to lifeline and transportation systems can also generate direct and indirect economic impacts. For example, if the extreme storm event and the subsequent flooding would cause any disruptions to the port operation, disruptions to the movement of both imports and exports through the port will affect not only the direct import using sectors and export producing sectors, but also sectors along the supply and demand chains of those directly affected sectors (Rose and Wei, 2011). However, since as will be presented below that the HAZUS results indicate that the impacts from the coastal flooding events simulated in this study would result in only very small impacts to the lifeline and transportation systems, we did not perform their indirect economic impact analysis using the I-O model.

V. Analysis Scenarios

Sea level rise will increase the occurrence of extreme events such as storm surge, high tides, coastal flood. For example, in January 2010 a severe winter storm, equivalent of a hundred-year storm or worse (NBC news, 2010), hit San Pedro and Long Beach region, which led to street flooding in this area. According to recent studies, with sea level rise, storm and flood events similar to the January 2010 Southern Los Angeles flood (which represented a 10-year flood) are likely to occur more often (Bromirski et al., 2012). The likelihood of the City of L.A. experiencing more severe flood hazards, such as a 100-year flood would also be expected to increase with sea level rise.

In this study, we analyze the physical damage and economic impacts from sea level rise based on two temporary coastal flood scenarios: 1) A 10-year coastal flood (10% chance of happening in any single year); and 2) A 100-year coastal flood (1% chance of happening in any single year).

For each flood scenario, we also analyze the effects of two sea level rise scenarios: 0.5-meter sea level rise by 2050 and 1.4-meter sea level rise by 2010. In order to obtain an assessment on the incremental impacts on building stock and business operation from flooding due to sea level rises, we also run the simulations assuming no sea level rise (which is referred to as the Base Case scenario).

Thus, six scenarios are analyzed in this study, namely:

1. 10-yr coastal flood without sea level rise
2. 100-yr coastal flood without sea level rise

3. 10-yr coastal flood with 0.5 meter sea-level rise
4. 100-yr coastal flood with 0.5 meter sea-level rise
5. 10-yr coastal flood with 1.4 meter sea-level rise, and
6. 100-yr coastal flood with 1.4 meter sea-level rise

VI. Study Region

A. Economy of City of Los Angeles

In order to analyze the economic impact of sea level rise to the City, we have constructed the Input-Output model for the City based on the zip code level economic data gathered from IMPLAN. The sectoring scheme used in the I-O table is presented in Appendix B. The constructed LA City I-O table is shown in Appendix C. In the I-O table each row represents the dollar value of sales of the sector listed at the left (row labels) to the sectors of the economy listed at the top (column labels). The total sales of a sector include not only the delivery of intermediate inputs to other production sectors of the economy, but also final goods and services consumed by government, households, and the production of goods for capital formation. Each column represents the dollar value of purchases of inputs from other sectors of the economy used to produce the output of the sector listed at the top. The column also includes the dollar value inputs of the primary factors, such as labor and capital, in the production. The row and columns labels are identically labeled and ordered, and the total uses of each good and service equals the total production of each in the economy, with the designation "Total Gross Output."

According to the LA City I-O table, in 2010, the total gross output of the city is $438 billion and total value-added is $269 billion.[2] Total employment in Year 2010 is about 2.7 million. In terms of gross output, the top five sectors are Professional and Technical Services, Entertainment and Recreation, Banks and Financial Institutions, Government Services, and Real Estate. These five sectors combined account for more than 50 percent of the total gross output of the City.

B. Building Stock

The geographical size of the City is about 470 square miles. It contains 838 census tracts and 29,426 census blocks. According to the 2010 Census, the City has over 1.2 million households and has a total population of nearly 3.8 million.

Tables 1 and 2 present the HAZUS default data on values of building stocks in the City. It shows that there are in total 831,612 buildings within the region, which have a total replacement value of $283

[2] Gross output measures the total revenue received from the sale of a good from a given sector. It includes all costs of production--both returns to primary factors of production (including a normal rate of return on investment) and payments for intermediate goods. Value-added pertains to the returns to primary factors of production (labor, capital, and natural resources), which provide the basis for a net measure of economic activity. Essentially value-added is equivalent to Gross Domestic Product (GDP), or Gross Regional Product (GRP).

billion. Among various occupancy classes, residential buildings account for over 75% of the total replacement values of buildings in the City. In terms of building type, wood structures account for more than 70% of the total.

Table 1. Building Exposure by Occupancy Type for City of Los Angeles

Occupancy	Exposure (million 2010$)	Percent of Total
Residential	213,028	75.30%
Commercial	51,249	18.10%
Industrial	9,641	3.40%
Agricultural	281	0.10%
Religion	3,563	1.30%
Government	1,236	0.40%
Education	3,975	1.40%
Total	**282,972**	**100.00%**

Table 2. Building Exposure by Building Type for City of Los Angeles

Building Type	Exposure (million 2010$)	Percent of Total
Concrete	32,530	11.50%
ManufHousing	445	0.16%
Masonry	28,419	10.04%
Steel	18,238	6.45%
Wood	203,341	71.86%
Total	**282,973**	**100.00%**

C. Transportation System and Utility System

Tables 3 and 4 present the HAZUS inventory data on transportation system and utility system dollar exposure in the entire study region. The dollar exposure values are computed based on the replacement cost of the infrastructures and facilities. The transportation system includes highway, railway, light rail, bus facility, ports, ferries, and airport. Highway system comprises the majority of the total transportation system dollar exposure. Utility system includes potable water, wastewater, oil, natural gas, electricity, and communication. Electric power facilities comprise about 60% of the total value exposure of the utility system. Wastewater treatment facilities account for another 28%.

Table 3. Transportation System Dollar Exposure (in million 2010$)

	Highway	Railway	Light Rail	Bus Facility	Ports	Ferries	Airport	Total

Segments	14,725.3	342.6	178.6	0.0	0.0	0.0	285.7	15,532.1
Bridges	4,764.0	7.5	1.6	0.0	0.0	0.0	0.0	4,773.2
Tunnels	9.1	0.0	0.0	0.0	0.0	0.0	0.0	9.1
Facilities	0.0	34.4	117.4	18.0	199.7	2.9	34.4	406.6
Total	19,498.4	384.5	297.6	18.0	199.7	2.9	320.1	20,721.1

Table 4. Utility System Dollar Exposure (in million 2010$)

	Potable Water	Waste Water	Oil Systems	Natural Gas	Electric Power	Communication	Total
Facilities	211.2	507.0	1.4	1.4	1,116.5	2.7	1,840.2

VII. Analysis Results

A. Replacement Value of Property at Risk

Increasing number and values of property will be at risk from flooding (for both 10-yr and 100-yr flood events) as a result of sea level rise. Table 5 presents the building exposure (in terms of replacement values) for various sea level rise and flood event scenarios. Building exposure values of a 10-yr flood event increases from $2.5 billion in the Base Case to $2.7 billion in the 0.5 m sea level rise scenario, and increases further to $3.3 billion in the 1.4 m sea level rise scenario. For a 100-yr flood event, the building exposure values are $3.1, $3.4, and $4.5 billion for the Base Case, 0.5 m sea level rise, and 1.4 m sea level rise scenarios, respectively. Residential buildings account for more than 60% of the total exposure values.

Table 5. Building Exposure by Occupancy Type by Scenario (million 2010$)

Occupancy	Base Case		0.5 m Sea Level Rise		1.4 m Sea Level Rise	
	10-Yr Flood	100-Yr Flood	10-Yr Flood	100-Yr Flood	10-Yr Flood	100-Yr Flood
Residential	1,527	1,968	1,727	2,209	2,101	2,922
Commercial	607	736	672	848	804	1,114
Industrial	273	281	276	300	292	366
Other	52	68	62	73	71	86
Total Building Exposure	**2,458**	**3,052**	**2,738**	**3,430**	**3,268**	**4,488**

B. General Building Stock Losses

HAZUS estimates the direct physical damage (in terms of repair costs) to the general building stock in the study region for each flood and sea level rise scenario. We used the default general building inventory for the study region and the damage functions provided by the HAZUS Flood Model in our analysis. General building inventory data provided in HAZUS include information on the foundation type,

first floor elevation, presence of basements, and number of stories of the buildings. For every census block, the water depth results computed by the Flood Analysis Module are used together with the damage function for specific occupancy class to determine the percentage damage of the buildings and contents (FEMA, 2011b). Tables 6-9 present the expected building damages by general occupancy type and by building type for the two sea level rise scenarios. In HAZUS, three “damage states” are defined based on the percent damage of the building: damages ranging between 1% and 10% are considered slight; damages of 11% to 50% are considered moderate; damages exceeding 50% are considered substantial.

The results in Tables 6-9 indicate that for a 10-year flood event, the total number of damaged buildings increases from around 1,000 buildings to nearly 1,700 buildings when the sea level rises from 0.5 m to 1.4 m. For a 100-year flood event, the building damage number increases from nearly 1,900 for the 0.5 m scenario to nearly 3,500 for the 1.4 m scenario. In all scenarios, most of the buildings are moderately damaged. In terms of occupancy class, residential buildings account for more than 95% of the total damaged buildings. In terms of building type, majority (over 95%) of the damaged buildings are wood structures.

Table 6. Expected Building Damage by Occupancy and by Building Type, 10-Yr Flood for 0.5 m Sea Level Rise Scenario

	Slight Damage		Moderate Damage		Substantial Damage		Total
	Count	%	Count	%	Count	%	Count
by Occupancy							
Residential	1	0	994	99	6	0	1,001
Commercial	0	0	7	100	0	0	7
Industrial	0	0	6	100	0	0	6
Other	0	0	0	0	0	0	0
by Building Type							
Concrete	0	0	4	100	0	0	4
ManufHousing	0	0	0	0	5	100	5
Masonry	0	0	8	100	0	0	8
Steel	0	0	4	100	0	0	4
Wood	1	0	978	100	1	0	980

Table 7. Expected Building Damage by Occupancy and by Building Type, 100-Yr Flood for 0.5 m Sea Level Rise Scenario

	Slight Damage		Moderate Damage		Substantial Damage		Total
	Count	%	Count	%	Count	%	Count
by Occupancy							
Residential	0	0	1,803	97	55	3	1,858
Commercial	3	13	20	87	0	0	23
Industrial	0	0	9	100	0	0	9
Other	0	0	0	0	0	0	0
by Building Type							
Concrete	1	7	14	93	0	0	15

ManufHousing	0	0	0	0	5	100	5
Masonry	0	0	23	100	0	0	23
Steel	0	0	7	100	0	0	7
Wood	0	0	1,763	97	49	3	1,812

Table 8. Expected Building Damage by Occupancy and by Building Type, 10-Yr Flood for 1.4 m Sea Level Rise Scenario

	Slight Damage		**Moderate Damage**		**Substantial Damage**		**Total**
	Count	**%**	**Count**	**%**	**Count**	**%**	**Count**
by Occupancy							
Residential	0	0	1,597	97	47	3	1,644
Commercial	0	0	16	94	1	6	17
Industrial	0	0	11	100	0	0	11
Other	0	0	0	0	0	0	0
by Building Type							
Concrete	0	0	11	100	0	0	11
ManufHousing	0	0	0	0	6	100	6
Masonry	0	0	17	100	0	0	17
Steel	0	0	7	100	0	0	7
Wood	0	0	1,564	98	40	2	1,604

Table 9. Expected Building Damage by Occupancy and by Building Type, 100-Yr Flood for 1.4 m Sea Level Rise Scenario

	Slight Damage		**Moderate Damage**		**Substantial Damage**		**Total**
	Count	**%**	**Count**	**%**	**Count**	**%**	**Count**
by Occupancy							
Residential	3	0	3,275	97	83	2	3,361
Commercial	4	4	80	89	6	7	90
Industrial	0	0	25	100	1	4	26
Other	1	0	5	0	0	0	6
by Building Type							
Concrete	2	4	46	96	0	0	48
ManufHousing	0	0	0	0	8	100	8
Masonry	1	2	48	96	1	2	50
Steel	0	0	22	100	0	0	22
Wood	3	0	3,203	98	74	2	3,280

The expected building damages in dollar values are estimated in HAZUS for each occupancy class. This is calculated by multiplying the percent damage of the buildings by the full replacement value of the buildings of the specific occupancy class. In addition, the losses caused by the damage of building contents and business inventory are also estimated. Table 10 presents the summary results of building losses for the study scenarios. Direct property losses with respect to buildings include: 1) building repair and replacement costs (including both structural and non-structural damage); 2) building contents losses; and 3) building inventory losses. In order to obtain a better assessment on the potential incremental

building damages caused by flood events due to sea level rises, we also run the simulations assuming no sea level rise (which is referred to as the Base Case scenario in the table). Tables 11-16 present the building losses by general occupancy class for each individual scenario.

The direct building-related losses can be substantial. The results indicate that the expected general building losses increase with the increase in sea level and the severity of the flooding. For a 10-year flood event, the total building losses are $242.7 million in the Base Case. The losses increase to $410.3 million in the 0.5 m sea level rise scenario, and to $714.9 million in the 1.4 m sea level rise scenario. For a 100-yr flood event, the building losses increases from $588.6 million in the Base Case to $820.2 million and $1,441.3 million in the 0.5 m and 1.4 m sea level rise scenarios, respectively. Losses to residential buildings account for about 50% of the total losses. The other 50% losses are split evenly between the commercial buildings and the industrial buildings in all the scenarios except for the scenario of a 100-yr flood with 1.5 m sea level rise. For this scenario, the losses to the commercial buildings are over 60% higher than the losses to the industrial buildings.

Table 10. Summary Results of General Building Losses (millions of 2010$)

	Base Case		0.5 m Sea Level Rise		1.4 m Sea Level Rise	
Category	**10-Yr Flood**	**100-Yr Flood**	**10-Yr Flood**	**100-Yr Flood**	**10-Yr Flood**	**100-Yr Flood**
Building Losses	103.3	260.9	179.4	364.4	315.0	649.9
Content Losses	132.6	312.1	219.6	435.5	380.2	759.9
Inventory Losses	6.8	15.5	11.3	20.3	19.7	31.5
Total Building Losses	**242.7**	**588.6**	**410.3**	**820.2**	**714.9**	**1,441.3**

Table 11. General Building Losses, 10-Yr Flood for the Base Case (millions of 2010$)

Category	Residential	Commercial	Industrial	Others	Total
Building Losses	72.7	17.9	11.4	1.2	**103.3**
Content Losses	50.2	37.9	38.8	5.7	**132.6**
Inventory Losses	0.0	0.7	6.0	0.0	**6.8**
Total Building Losses	**122.9**	**56.5**	**56.3**	**6.9**	**242.7**

Table 12. General Building Losses, 100-Yr Flood for the Base Case (millions of 2010$)

Category	Residential	Commercial	Industrial	Others	Total
Building Losses	189.5	40.4	28.4	2.6	**260.9**
Content Losses	126.3	85.2	90.1	10.6	**312.1**
Inventory Losses	0.0	1.9	13.5	0.1	**15.5**
Total Building Losses	**315.8**	**127.5**	**132.0**	**13.3**	**588.6**

Table 13. General Building Losses, 10-Yr Flood for the 0.5 m Sea Level Rise Scenario (millions of 2010$)

Category	Residential	Commercial	Industrial	Others	Total
Building Losses	129.9	27.8	19.9	1.8	**179.4**

Content Losses	87.5	58.6	65.5	8.1	**219.6**
Inventory Losses	0.0	1.2	10.0	0.1	**11.3**
Total Building Losses	**217.4**	**87.6**	**95.4**	**10.0**	**410.3**

Table 14. General Building Losses, 100-Yr Flood for the 0.5 m Sea Level Rise Scenario (millions of 2010$)

Category	Residential	Commercial	Industrial	Others	Total
Building Losses	266.1	58.5	35.7	4.1	**364.4**
Content Losses	179.4	126.1	114.0	16.0	**435.5**
Inventory Losses	0.0	2.8	17.4	0.2	**20.3**
Total Building Losses	**445.5**	**187.4**	**167.0**	**20.2**	**820.2**

Table 15. General Building Losses, 10-Yr Flood for the 1.4 m Sea Level Rise Scenario (millions of 2010$)

Category	Residential	Commercial	Industrial	Others	Total
Building Losses	230.0	49.6	32.1	3.2	**315.0**
Content Losses	154.7	104.7	107.8	13.0	**380.2**
Inventory Losses	0.0	2.4	17.2	0.1	**19.7**
Total Building Losses	**384.8**	**156.7**	**157.2**	**16.3**	**714.9**

Table 16. General Building Losses, 100-Yr Flood for the 1.4 m Sea Level Rise Scenario (millions of 2010$)

Category	Residential	Commercial	Industrial	Others	Total
Building Losses	461.8	123.9	56.0	8.3	**649.9**
Content Losses	305.7	263.2	160.8	30.1	**759.9**
Inventory Losses	0.0	6.5	24.7	0.3	**31.5**
Total Building Losses	**767.5**	**393.7**	**241.5**	**38.7**	**1441.3**

Figures 2 to 5 present total building-related (including building, contents, and inventory) loss maps for the County and City of Los Angeles for the different scenarios in this study.

C. Business Interruption Losses

In addition to the building stock losses, immediate reduction or cessation of economic production will occur in a damaged factory building. If a firm has to stop or cut back its production because of the building damages from flooding, it will demand fewer inputs for their production. This in turn reduces the production of all of its suppliers, who in turn reduce their orders through a successive round of upstream demands. The direct business interruption losses also magnify themselves downstream along successive supply chains in a similar manner. The sum total of all these chain reactions is referred to as multiplier effects in the I-O analysis. When we compute the multiplier effects of the direct business interruption, we include not only the multiplier (ripple) effects of the direct losses taking place within the City, but also the indirect effects to the City stemming from the direct business losses to the coastal regions outside of the City but within the boundary of the LA County.

Table 17 presents the direct building-related output damages (direct business interruption losses) for each scenario simulated in this study. It presents the losses to both the City and Rest of County. The Rest of County results are needed to compute their indirect impacts to the City economy.

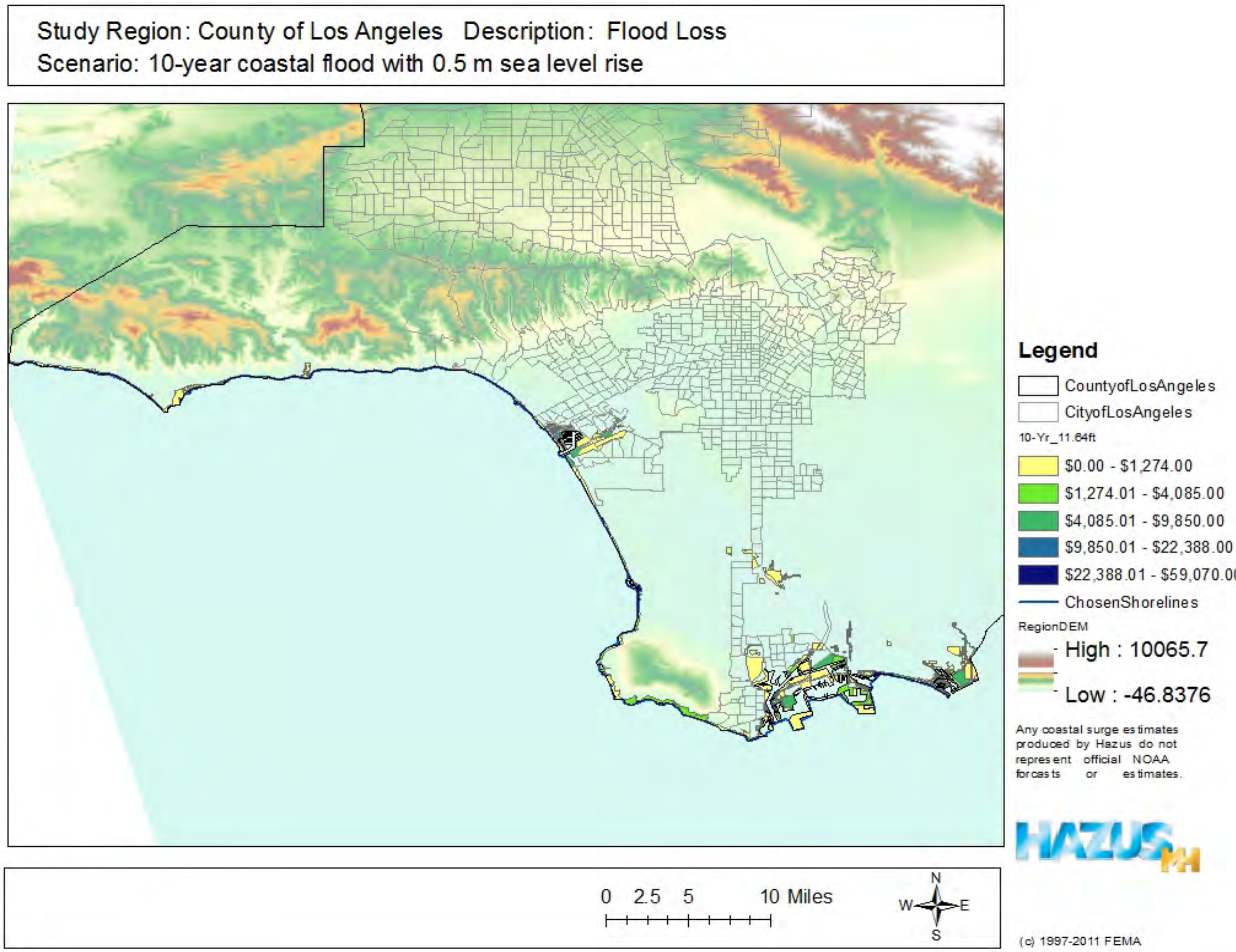

Figure 2. Building Losses for 10-year Coastal Flood with 0.5 Meter Sea Level Rise

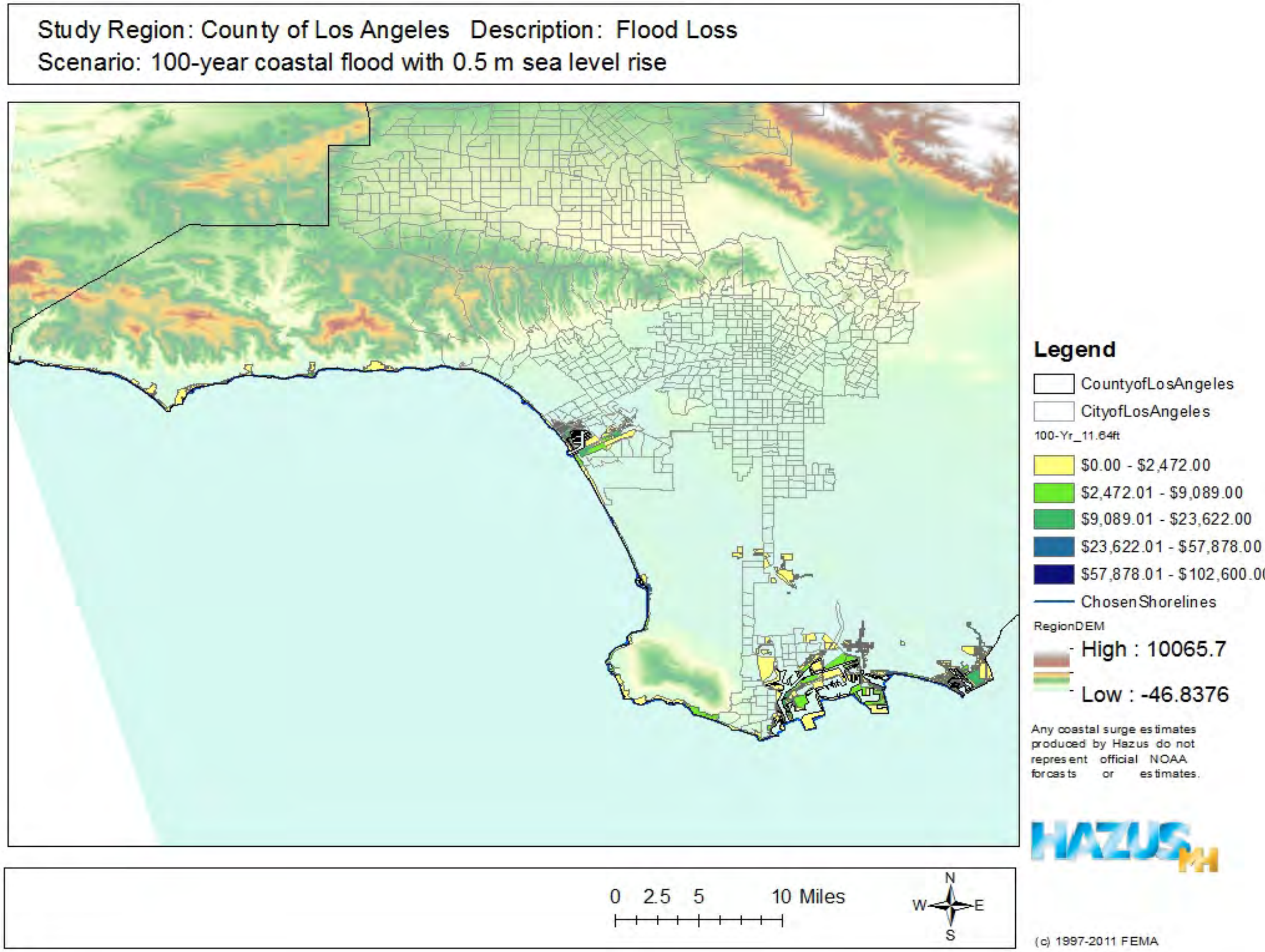

Figure 3. Building Losses for 100-year Coastal Flood with 0.5 Meter Sea Level Rise

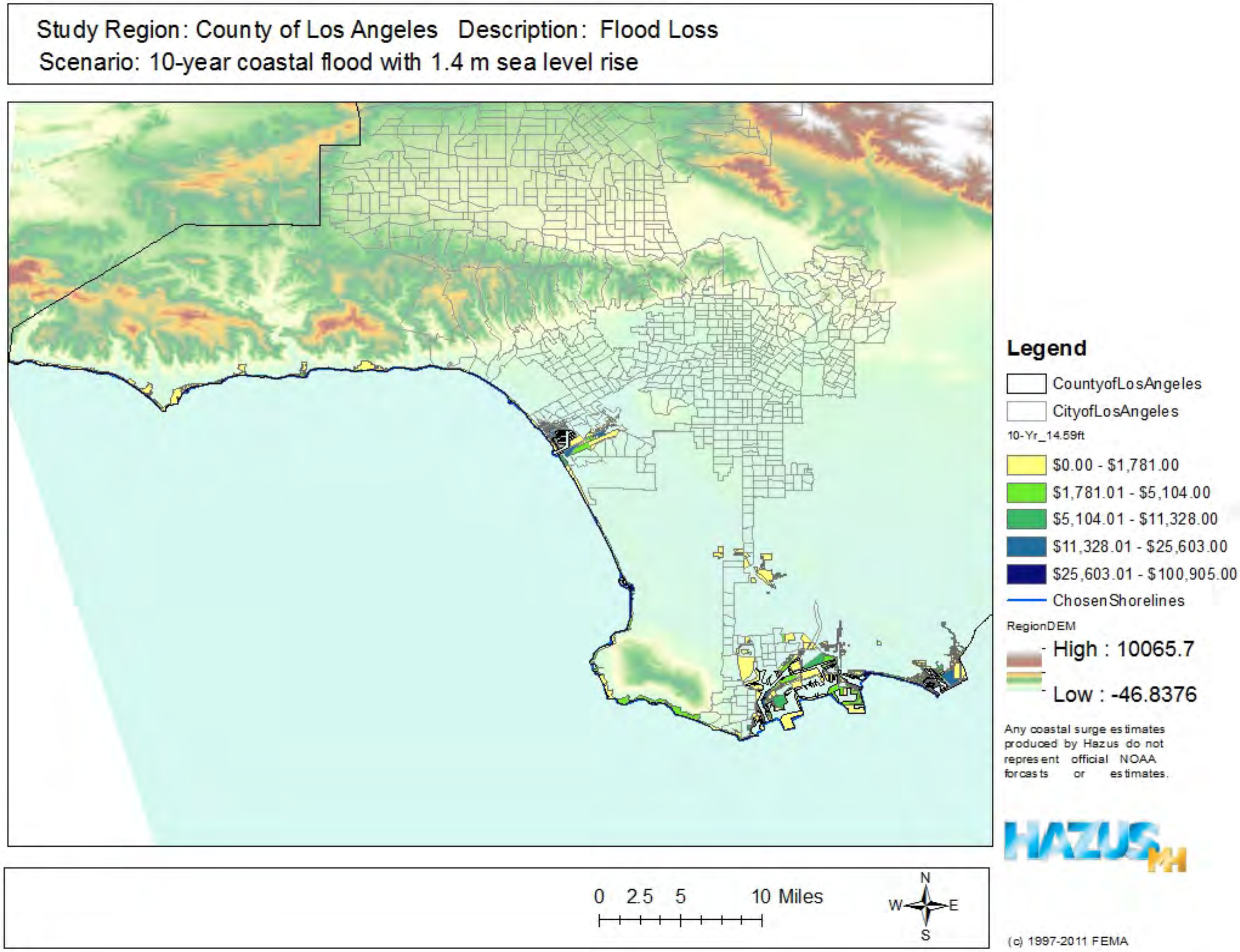

Figure 4. Building Losses for 10-year Coastal Flood with 1.4 Meter Sea Level Rise

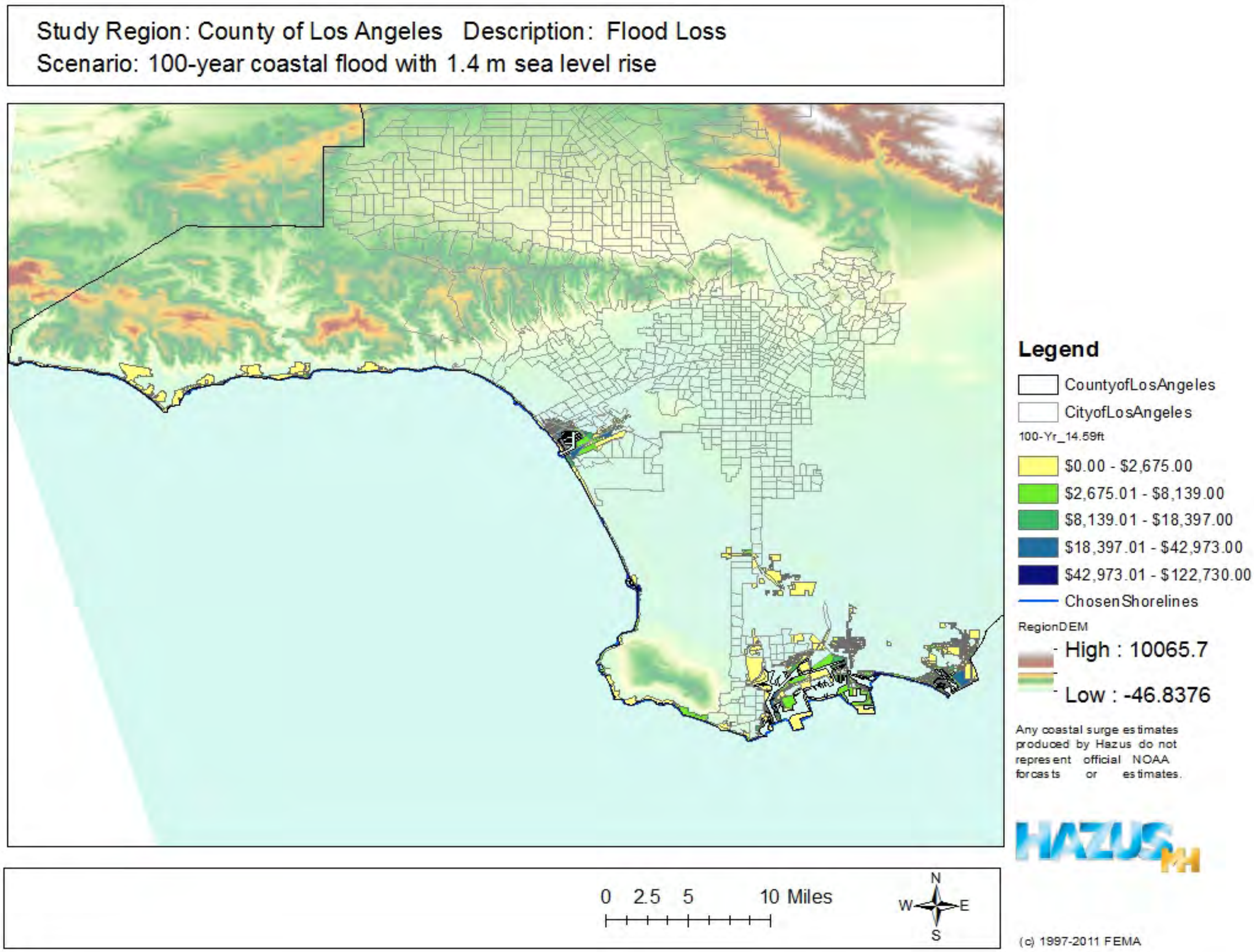

Figure 5. Building Losses for 100-year Coastal Flood with 1.4 Meter Sea Level Rise

Table 17. Direct Output Losses for Study Scenarios

Occupancy Class*	City of Los Angeles (thousand 2010$)						Rest of County of Los Angeles (thousand 2010$)					
	10-yr-Base Case	100-yr-Base Case	10yr-0.5m	100yr-0.5m	10yr-1.4m	100yr-1.4m	10-yr-Base Case	100-yr-Base Case	10yr-0.5m	100yr-0.5m	10yr-1.4m	100yr-1.4m
RES1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RES2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RES3A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RES3B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RES3C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RES3D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RES3E	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RES3F	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RES4	38.7	65.6	50.5	84.9	80.6	128.0	410.7	583.4	531.2	724.7	623.6	1,515.0
RES5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RES6	0.0	0.0	0.0	0.0	0.0	1.1	5.4	6.5	6.5	7.5	6.5	10.8
COM1	7.5	32.3	26.9	49.5	40.9	129.0	63.4	175.5	94.6	184.9	182.8	282.8
COM2	60.2	155.9	103.2	232.2	191.4	501.1	44.1	176.7	115.0	315.0	249.4	538.7
COM3	74.2	146.2	129.0	262.4	194.6	663.4	111.8	290.7	195.7	459.1	346.2	782.8
COM4	123.6	254.8	209.7	395.7	311.8	819.3	365.6	666.5	509.7	839.7	791.4	1,304.2
COM5	4.3	8.6	5.4	15.1	8.6	31.2	15.1	39.8	20.4	53.8	40.9	101.1
COM6	3.2	10.8	10.8	22.6	12.9	226.9	0.0	0.0	0.0	0.0	0.0	8.6
COM7	45.2	134.4	102.1	171.0	175.3	396.8	173.1	345.6	261.3	473.1	402.1	861.2
COM8	131.2	284.9	240.8	468.8	367.7	938.7	793.5	1,485.6	1,076.3	1,823.6	1,640.8	2,467.6
COM9	0.0	0.0	0.0	0.0	0.0	0.0	23.7	85.0	52.7	98.9	82.8	121.5
COM10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IND1	2.2	3.2	2.2	4.3	4.3	14.0	0.0	5.4	3.2	21.5	11.8	35.5
IND2	1.1	2.2	2.2	3.2	3.2	8.6	0.0	0.0	0.0	0.0	0.0	5.4
IND3	61.3	138.7	101.1	182.8	196.8	230.1	0.0	2.3	0.0	8.6	2.2	10.8
IND4	0.0	0.0	0.0	1.1	0.0	4.3	0.0	0.0	0.0	0.0	0.0	0.0
IND5	0.0	0.0	0.0	1.1	1.1	2.2	0.0	0.0	0.0	0.0	0.0	0.0
IND6	2.2	3.2	2.2	4.3	4.3	7.5	3.2	4.3	4.3	5.4	5.4	9.7
AGR1	1.1	3.2	2.2	4.3	3.2	5.4	0.0	1.1	0.0	5.4	3.2	7.5
REL1	65.6	162.4	150.5	258.1	202.1	479.5	300.0	612.6	520.4	851.6	752.7	1,516.1
GOV1	16.1	25.8	22.6	45.2	30.1	69.9	15.1	31.2	22.6	41.9	34.4	102.1
GOV2	22.6	39.8	32.3	47.3	44.1	119.3	43.0	90.4	75.3	124.7	107.5	207.5
EDU1	49.5	128.0	107.5	309.7	227.9	643.0	107.5	328.4	181.7	318.3	293.5	973.1
EDU2	19.4	31.2	29.0	45.2	35.5	87.1	1.1	16.2	18.3	35.5	17.2	406.4

* Please refer to Appendix Table B2 for the description of the occupancy classes.

The detailed steps adopted to compute the total business interruption losses are presented in Appendix D.

Table 18 presents the summary results of the total business interruption losses. Compared with the general building stock losses, losses caused by building-related business interruption are much smaller, only at the scale of about 1.3-1.5% of the building stock losses. One major reason is that over 95% of the damaged buildings are residential buildings, rather than buildings of producing sectors. Another important reason is that the HAZUS direct output loss estimation has taken into consideration the production recapture factor. Production recapture or rescheduling refers to the ability of businesses to recapture lost production by working overtime or extra shifts once their operational capability is restored. This is the most effective resilience measure that has been widely reported in the literature that can help reduce the potential business interruption losses in the aftermath of natural disasters. The third reason is that the flood events with the two sea level rise scenarios simulated in this study would only cause very limited impacts to the utility systems. According to our simulation, for the worst case scenario (the 100-yr flood event under the 1.5 m sea level rise scenario), there are only moderate damages to two wastewater treatment facilities and three oil refineries. As for the other critical lifeline facilities, including water, natural gas, and electricity, the simulations indicate no damages in all the scenarios.

The results in Table 18 indicates that for a 10-year flood event, the total output losses increases from $3.4 million in the Base Case to $5.8 million in the 0.5 m sea level rise scenario, and to $9.1 million in the 1.4 m sea level rise scenario. For a 100-yr flood event, the output losses increases from $7.4 million in the Base Case to $10.5 million in the 0.5 m and $21.9 million in the 1.4 m sea level rise scenarios. The impacts to income and employment have similar patterns across the scenarios.

Tables E1-E6 in Appendix E presents the business interruption losses by sector for each individual scenario.

Table 18. Summary of Business Interruption Losses

	Base Case		0.5 m Sea Level Rise		1.4 m Sea Level Rise	
Category	10-Yr Flood	100-Yr Flood	10-Yr Flood	100-Yr Flood	10-Yr Flood	100-Yr Flood
Output Losses (M 2010$)	$3.4	$7.4	$5.8	$10.5	$9.1	$21.9
Income Losses (M 2010$)	$2.3	$4.9	$3.8	$6.6	$5.9	$13.6
Employment Losses (Jobs)	24	52	41	74	64	158

D. Damages to Essential Facilities

The HAZUS model contains the dataset for essential facilities in the study area. These data, together with other inventory data, such as demographics, transportation systems, and lifeline systems, are used in the estimation of damages and direct economic losses related to general building stock. In addition, HAZUS also reports on the impact to the functionality of the essential facilities caused by the flood event.

Essential facilities, whose operation is essential to the daily life of the community, include hospitals, police stations, fire stations, and schools. The HAZUS Flood model determines the damage to the essential facilities based on the location of the facility and the depth of flooding (FEMA, 2011b).

Table 19 presents the expected damage to the essential facilities in the City for the two flood events under the two sea level rise scenarios. The numbers in the table represent the number of essential facilities being damaged at two different levels: moderately damaged or substantially damage. The results also show whether or not the facility loses functionality because of the damage. The results indicate that only a limited number of essential facilities would suffer damages from flooding in our simulated scenarios. For example, it estimated that only one fire station will experience at least moderate damage under the two simulated flood events. It will not be functional in the 100-yr flood event or in the 10-yr flood event under the 1.4 m sea level rise scenario.

Table 19. Expected Damage to Essential Facilities

	10-Yr Flood with 0.5 m Sea Level Rise			100-Yr Flood with 0.5 m Sea Level Rise		
	At Least Moderate	At Least Substantial	Loss of Use	At Least Moderate	At Least Substantial	Loss of Use
Fire Stations	1	0	0	1	0	1
Hospitals	1	0	1	1	0	1
Police Stations	0	0	0	0	0	0
Schools	0	0	0	1	0	1
	10-Yr Flood with 1.4 m Sea Level Rise			**100-Yr Flood with 1.4 m Sea Level Rise**		
	At Least Moderate	**At Least Substantial**	**Loss of Use**	**At Least Moderate**	**At Least Substantial**	**Loss of Use**
Fire Stations	1	0	1	1	0	1
Hospitals	1	0	1	2	0	1
Police Stations	0	0	0	1	0	1
Schools	1	0	0	4	0	4

E. Transportation System

The simulation results indicated that there are minimal impacts to the transportation system in the city. Therefore, we did not perform further economic impact analysis on the potential damages to the transportation system. A more in-depth analysis of the economic consequences of the potential damages to the transportation systems should be undertaken in future studies.

F. Debris Generation

HAZUS estimates induced damages from the flooding in terms of the generation of building-related debris. Major forms of estimates include flood-damaged building finishes (e.g., dry wall, insulation,

carpet, etc.), structure components (e.g., wood, brick, etc.), and foundation materials (e.g., concrete slab, concrete block, etc.). The distinction among the three categories is made in the HAZUS model because different types of materials would require different handling equipment to clean up. HAZUS estimates the debris generation for each census block within the study region. The results are presented as the weight of debris in tons. Note that different from the HAZUS Earthquake Model, HAZUS Flood Model does not estimate debris generated from building contents or damage to non-building facilities (such as bridges or lifelines) (FEMA, 2011b). Table 20 summarizes the results of debris generation for different scenarios.

Table 20. Debris Generation

Category	Base Case		0.5 m Sea Level Rise		1.4 m Sea Level Rise	
	10-Yr Flood	100-Yr Flood	10-Yr Flood	100-Yr Flood	10-Yr Flood	100-Yr Flood
Finishes	68%	49%	53%	47%	48%	40%
Structure	20%	32%	29%	34%	33%	36%
Foundations	12%	19%	18%	19%	19%	24%
Total (tons)	19,575	62,725	40,549	96,007	78,420	204,579

E. Shelter Requirements

HAZUS also estimates the number of households that are expected to be displaced due to the flood (based on the location of the inundation areas and the demographic data) and the number of individuals that would seek public shelters in the short-term. Adjustment factors such as income and age are used as well to determine the need for government-provided shelters. For example, lower income people are more likely to use shelter. In addition, younger and less established families as well as elderly families are more likely to use shelter (FEMA, 2011b). The shelter requirement results are shown in Table 21.

Table 21. Shelter Requirements

Category	Base Case		0.5 m Sea Level Rise		1.4 m Sea Level Rise	
	10-Yr Flood	100-Yr Flood	10-Yr Flood	100-Yr Flood	10-Yr Flood	100-Yr Flood
Households Displaced	1,796	3,162	2,680	3,997	3,556	6,868
People Seeking Temporary Shelter	4,114	8,080	6,695	10,399	9,241	18,296

VIII. Conclusion

Sea level rise is among the most profound impacts of climate change. It can be caused by the melting of glacier and massive ice sheets around the world and the thermal expansion of the ocean when the average global temperature goes up. Since early 1990s, the annual average rate of global sea level rise was about 3 mm. Most modeling work has indicated that we will be experiencing more expedited sea level rise in the coming decades. A recent study by National Research Council (NRC) estimated that sea level rise for California coast can reach 0.12 to 0.61 m by 2050 and 0.42 to 1.67 m by 2100 (NRC, 2012).

This study analyzes the potential economic impacts of coastal floods, whose impacts can be greatly amplified by sea level rises. Two sea level rise scenarios are evaluated: 1) 0.5 meters sea level rise by 2050; and 2) 1.4 meter sea level rise by 2100. These two scenarios are consistent with those used in the California Energy Commission's Public Interest Energy Research (PIER) Climate Change Research Program and the ones used in a recent USGS study focusing on the sea level rise impacts to the Southern California coast.

Two advanced modeling tools are applied in this study. Hazards-United States Multihazard (HAZUS-MH) 2.1, the FEMA standardized modeling tool for estimating potential losses from hazards, is used to evaluate the direct losses to building stock and the direct output (business interruption) losses in the flooding affected region. Other impacts such as damage to essential facilities, transportation system, and utility system are also evaluated by HAZUS. The Input-Output (I-O) model, one of the most widely used tool of regional impact analysis, is then applied to calculate the total business interruption losses based on the direct building-related output loss estimates from the HAZUS model.

The results show that with a 0.5 m sea level rise, $2.7 to $3.4 billion of building stock in the City will be at risk to coastal flood events. With a 1.4 m sea level rise, $3.3 billion to $4.5 billion of building stock will be at risk. For a 10-yr flood event, the direct building losses are expected to be $410.3 million with 0.5 m sea level rise, and nearly doubled with 1.4 m sea level rise. For a 100-yr flood event, the building losses increase from $820.2 million to $1,441 million when sea level rises from 0.5 m to 1.4 m. Losses to residential buildings comprise about 50% of the total losses. The other 50% losses are split evenly between the commercial buildings and industrial buildings in most simulated scenarios.

The business interruption losses are relatively small compared with the building stock losses. For a 10-yr flood event, the total output losses in the City are expected to be $5.8 million to $9.1 million under the two simulated sea level rise scenarios. For a 100-yr flood event, the total output losses are expected to be $10.5 to $21.9 million. The major reason of the relatively low business interruption losses caused by the coastal flood events is that over 95% of the damaged buildings are residential buildings, rather than the buildings of producing sectors.

Our simulation shows that the transportation system and the utility system in the City would suffer very limited damages from the flooding in the scenarios evaluated in this study.

Our estimates on the potential economic impacts of sea level rise to the City should be considered on the conservative side. The analysis only focuses on the potential impacts from the temporary flooding in the coastal area due to extreme coastal storms, and how those impacts can be amplified by sea level rise. Any impacts caused by long-term and permanent coastal erosion and beach area losses of sea level rise are not covered in this study.

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Appendix A. Coastal Flood Modeling using HAZUS-MH Flood Tool

Hazards-United States Multihazard (HAZUS-MH) is a Geographic Information Systems (GIS)-based modeling platform to estimate physical, economic, and social impacts of natural disasters. HAZUS-MH Flood 2.1, Federal Emergency Management Agency (FEMA)'s standardized methodology and modeling tool for estimating potential losses from floods, is utilized to estimate potential building stock damages in the event of 10- and 100-yr coastal flood scenarios impacting the County and City of Los Angeles. The modeling tool is also useful for analyzing the effects of sea-level rise (0.5 and 1.4 meter) to the County and City of Los Angeles communities.

The first step in the modeling process is the creation of the study region, the County of Los Angeles, using the aggregation level of census block. The entire County results are needed because when we calculate the indirect business interruption losses, we not only take into account the multiplier (ripple) effects of the direct business interruption losses taking place within the City, but also the indirect effects to the City stemming from the losses to the coastal communities that are outside of the City but within the boundary of the LA County. Flood hazard is chosen as the hazard of concern. In this step, HAZUS-MH assembles data about the chosen built environment. The default inventory using HAZUS-MH default data was utilized in this study. The study region is opened thereafter in an ArcGIS Editor that contains the HAZUS-MH tool set including inventory, hazard, analysis, and results tabs.

A coastal flood hazard type is chosen next within the hazard tab. The terrain is created using a Digital Elevation Model (DEM) which is a 3D representation of a terrain's surface. The geographical extent of the DEM is computed using the extent calculator tool within HAZUS-MH. The default National Elevation Dataset (NED) with spatial resolution of 1 arc-second or 30 meters from the United States Geological Survey (USGS) was used for this analysis. HAZUS then creates the DEM grid and the hillshade from the user data.

A new scenario is created thereafter, where shoreline extent selection and still water elevation data were needed. The default shoreline for the County region was used. FEMA's 2008 Flood Insurance Study (FIS) for Los Angeles County was used to identify the 100-year (or 1-percent annual chance) still water elevation of 10 feet, without wave setup information, for flooding from the Pacific Ocean at the San Pedro Bay. 100-year still water elevations of 11.64 feet and 14.59 feet were used to represent the 0.5 and 1.4 meter sea-level rise scenarios. The still water levels for floods with other return periods (10-, 50-, and 500-year) are computed by HAZUS based on the 100-year still water level.

The next step in the analysis is to delineate the floodplain. Return period of 10 and 100 year floods were chosen for raster processing. The result of this step is a delineated flood plain boundary and a raster grid of the flood elevation.

The analysis tab allows the user to select potential loss modules including building stock, essential facilities, and transportation and utility systems. For building-related losses, the results tab contains information pertaining to the building stock losses and direct output losses by specific occupancy classes.

These direct output losses, from the six user-defined scenarios, for 33 different occupancy classes were extracted from HAZUS-MH and utilized further within the Input-Output (I-O) analysis.

Appendix B. I-O Model Sectors and Correspondence to HAZUS Occupancy Classes

Table B1. I-O Model Sectoring Scheme

	Sea Level Rise I-O Model Sector	IMPLAN Sector	HAZUS Occupancy Class
1	Agriculture, Forestry and Fishing	1-19	AGR1
2	Mining, Quarrying, and Oil and Gas Extraction	20-30	IND4
3	Electric Utilities	31; 428; 431	COM4
4	Gas Utilities	32	COM4
5	Water and Wastewater Utilities	33	COM4
6	Construction	34-40	IND6
7	Food Manufacturing	41-69	IND3
8	Beverage and Tobacco Product Manufacturing	70-74	IND3
9	Chemical Manufacturing	115-141	IND3
10	Nonmetallic Mineral/Metals Processing & Manufacturing	153-180	IND4
11	High Technology	192; 209; 211; 234-256; 284-288; 305-308; 345; 350; 352-353	IND5
12	Other Heavy Industry	181-191; 193-208; 210; 212-215; 217-233; 276-283; 289-294	IND1
13	Other Light Industry	75-114; 142-152; 216; 257-275; 295-304; 309-318; 341-344	IND2
14	Air Transportation	332	COM4
15	Rail Transportation	333	COM4
16	Water Transportation	334	COM4
17	Truck Transportation	335	COM4
18	Transit and ground passenger transportation	336	COM4
19	Other Transportation and Warehousing	337-340	COM4
20	Wholesale Trade	319	COM2
21	Retail Trade	320-331	COM1
22	Banks & Financial Institutions	354-359	COM5
23	Telecommunications	351	IND2
24	Professional & Technical Services	362-390	COM4
25	Education Services	391-393	EDU1 & EDU2
26	Medical Office/Clinic	394-396	COM7
27	Hospitals	397	COM6
28	Nursing and Residential Care Facilities	398	RES6
29	Hotels	411-412	RES4
30	Entertainment & Recreation	346-349; 402-410; 413	COM8 & COM9
31	Other Services	399-401; 414-426	COM3, COM10, REL1
32	Gov't & Non-NAICS	427; 429-430; 432-440	GOV1 & GOV2
33	Real Estate	360	RES3
34	Owner-occupied dwellings	361	RES1, RES2, RES5

Table B2. Description of HAZUS Occupancy Classes

No.	Label	Occupancy Class	Description
		Residential	
1	RES1	Single Family Dwelling	Detached House
2	RES2	Mobile Home	Mobile Home
3-8	RES3a-f	Multi Family Dwelling	Apartment/Condominium
9	RES4	Temporary Lodging	Hotel/Motel
10	RES5	Institutional Dormitory	Group Housing (military, college), Jails
11	RES6	Nursing Home	
		Commercial	
12	COM1	Retail Trade	Store
13	COM2	Wholesale Trade	Warehouse
14	COM3	Personal and Repair Services	Service Station/Shop
15	COM4	Professional/Technical Services	Offices
16	COM5	Banks/Financial Institutions	
17	COM6	Hospital	
18	COM7	Medical Office/Clinic	Offices
19	COM8	Entertainment & Recreation	Restaurants/Bars
20	COM9	Theaters	Theaters
21	COM10	Parking	Garages
		Industrial	
22	IND1	Heavy	Factory
23	IND2	Light	Factory
24	IND3	Food/Drugs/Chemicals	Factory
25	IND4	Metals/Minerals Processing	Factory
26	IND5	High Technology	Factory
27	IND6	Construction	Office
		Agriculture	
28	AGR1	Agriculture	
		Religion/Non-Profit	
29	REL1	Church	
		Government	
30	GOV1	General Services	Office
31	GOV2	Emergency Response	Police/Fire Station
		Education	
32	EDU1	Schools	
33	EDU2	Colleges/Universities	Does not include group housing

Source: FEMA (2011b)

Appendix C. Los Angeles City 2010 Input-Output Table

(in million 2010$)

	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21
01. Agriculture, Forestry and Fishing	0.3	0.0	0.0	0.0	0.0	0.2	14.0	0.9	0.2	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
02. Mining, Quarrying, and Oil and Gas Extraction	0.1	4.0	20.2	164.6	0.0	11.7	1.3	0.2	582.4	10.5	2.4	1.4	6.9	1.4	0.1	0.0	0.4	0.0	3.4	0.5	0.4
03. Electric Utilities	0.5	1.2	0.2	0.2	0.0	9.7	20.9	3.9	52.8	10.6	18.8	7.9	40.3	0.5	0.0	0.4	0.8	0.3	7.4	14.4	44.4
04. Gas Utilities	0.7	3.7	0.4	4.3	0.0	13.7	81.7	8.5	317.9	33.4	22.0	17.5	102.4	0.2	0.0	0.7	1.3	0.1	12.1	18.6	23.5
05. Water and Wastewater Utilities	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
06. Construction	1.0	14.1	35.0	3.4	1.0	14.3	34.3	5.0	108.8	16.1	45.3	20.1	78.5	1.3	20.6		2.0	0.3	45.0	26.4	73.6
07. Food Manufacturing	6.3	0.0	0.5	0.0	0.0	2.2	878.2	235.3	47.9	1.0	1.8	0.4	29.1	2.2	0.1	0.2	0.5	0.0	0.6	5.3	3.7
08. Beverage and Tobacco Product Mft	0.0	0.0	0.0	0.0	0.0	0.0	3.4	7.9	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09. Chemical Manufacturing	15.2	9.4	19.7	6.4	0.1	556.9	94.8	25.2	5,420.4	37.9	316.9	97.2	1,593.4	465.0	16.0	0.1	138.8	11.8	150.5	105.5	49.2
10. Nonmetallic Mineral/Metals Processing & Mft	0.0	0.6	0.1	1.3	0.0	50.1	1.8	17.5	10.2	41.4	37.5	55.8	44.9	0.3	0.4	0.0	0.1	0.0	0.3	1.8	1.3
11. High Technology	0.1	0.8	1.3	3.7	0.0	61.2	10.6	38.8	127.2	24.2	3,003.6	116.9	252.2	68.5	0.6	0.6	3.3	0.5	16.7	71.6	51.0
12. Other Heavy Industry	0.7	7.4	4.0	17.3	0.0	327.0	39.5	50.3	73.8	21.4	173.5	568.2	159.2	9.6	6.1	16.7	24.6	9.3	21.9	36.7	53.4
13. Other Light Industry	0.8	3.1	1.8	11.6	0.0	465.6	158.9	85.3	201.4	19.8	263.8	139.3	1,081.9	7.7	3.4	1.3	12.4	1.4	24.2	118.4	120.6
14. Air Transportation	0.1	0.2	0.4	1.1	0.0	8.1	7.6	1.2	11.6	1.7	20.8	5.0	18.6	0.1	0.1	0.4	2.6	0.0	3.0	12.3	3.8
15. Rail Transportation	0.5	1.2	14.2	1.7	0.0	12.2	49.9	6.3	51.8	17.4	7.8	7.6	50.5	1.0	1.0	0.1	12.9	0.1	0.6	1.7	1.5
16. Water Transportation	0.1	0.1	0.3	0.0	0.0	2.5	10.7	0.6	4.8	1.2	0.6	0.4	1.0	1.6	0.1	0.0	0.4	0.0	0.6	0.3	0.1
17. Truck Transportation	1.4	2.0	2.2	2.6	0.0	95.3	122.7	22.9	104.3	32.0	57.1	31.6	122.3	5.2	1.2	1.5	53.1	0.8	11.1	29.3	64.4
18. Transit and Ground Passenger Transportation	0.0	0.0	0.1	0.7	0.0	2.1	1.3	0.2	1.7	0.4	6.2	1.4	4.7	0.0	1.3	0.0	0.0		0.1	1.7	0.8
19. Other Transportation and Warehousing	0.6	1.1	14.9	234.0	0.0	15.6	30.8	5.8	134.0	10.0	58.2	14.4	103.7	228.1	3.1	40.8	103.9	1.4	168.9	296.2	267.2
20. Wholesale Trade	3.8	3.6	3.1	7.2	0.0	258.9	330.0	75.9	644.7	71.3	606.3	200.5	527.9	23.9	3.4	1.0	19.9	1.8	22.1	333.1	135.3
21. Retail Trade	0.1	0.5	0.1	0.2	0.0	338.0	3.4	6.5	51.0	0.3	14.4	14.0	13.9	0.2	0.1		9.0	0.4	4.9	10.2	30.3
22. Banks & Financial Institutions	4.2	7.0	12.3	48.7	0.1	144.9	47.7	7.0	75.3	16.7	177.4	49.9	148.8	60.3	25.7	13.8	70.0	10.0	56.8	286.1	447.0
23. Telecommunications	0.1	0.7	1.6	1.9	0.0	71.3	15.3	3.8	28.7	5.5	149.7	19.2	67.9	27.9	0.4	1.2	9.6	1.2	16.2	79.1	98.2
24. Professional & Technical Services	2.2	47.9	33.7	59.3	0.7	1,031.5	447.4	127.6	1,695.6	96.8	1,927.0	313.5	1,031.8	197.8	32.2	21.2	110.7	16.2	224.0	1,189.4	1,136.3
25. Education Services	0.6	0.0	0.5	2.5		0.4	0.0	0.0	0.2	0.0	0.1	0.0	0.7	0.3	0.2				0.2	6.3	30.4
26. Medical Office/Clinic																					
27. Hospitals																					
28. Nursing and Residential Care Facilities																					
29. Hotels	0.0	0.2	0.7	1.8	0.0	11.1	6.6	0.9	8.4	1.9	31.1	6.8	23.8	0.2	0.1	0.1	0.1	0.2	2.9	7.6	3.6
30. Entertainment & Recreation	0.2	3.2	10.6	8.1	0.0	84.0	44.6	9.6	126.5	10.9	193.8	33.8	117.6	104.2	3.6	1.4	8.0	1.3	20.4	122.8	144.4
31. Other Services	0.4	0.7	1.4	7.7	0.1	159.8	29.1	4.1	72.0	13.1	49.9	18.5	76.3	2.6	1.1	0.2	13.6	2.9	27.2	86.0	91.9
32. Gov't & Non-NAICS	0.8	2.4	3.8	15.6	0.0	16.0	35.2	10.2	270.8	110.3	113.1	32.0	156.6	255.6	1.8	51.3	44.9	1.8	70.8	201.7	106.3
33. Real Estate	7.3	1.5	3.3	8.4	0.1	56.1	33.1	6.8	33.4	5.0	107.4	21.5	99.6	41.4	0.6	12.2	16.2	0.1	66.9	181.3	592.4
34. Owner-occupied Dwellings																					
Employee Compensation	50.5	312.1	343.1	456.2	2.2	3,308.0	935.8	236.5	1,225.1	300.6	5,426.0	1,600.9	4,319.8	1,157.6	144.0	66.8	520.2	214.4	2,251.0	6,862.3	6,285.4
Proprietary Income	64.5	140.9	3.5	90.8	1.0	1,510.0	117.9	62.8	228.4	20.3	281.3	20.6	151.9	-6.8	-0.1	2.2	437.2	74.2	360.3	1,230.5	970.5
Other Property Income	3.8	216.0	295.6	962.9	5.2	1,103.2	639.6	151.5	3,413.3	156.9	3,831.9	808.5	1,685.9	422.8	73.4	95.8	157.4	93.7	602.7	3,524.8	767.6
Indirect Business Taxes	3.4	57.0	16.6	372.3	0.9	85.2	25.4	177.6	88.5	15.8	207.4	48.7	159.7	387.9	6.3	14.8	25.0	15.9	147.7	3,130.2	2,421.7
Other	0.2	0.6	0.5	2.8	0.0	25.7	16.2	7.2	58.0	16.4	68.7	19.2	69.5	37.0	0.5	7.1	6.9	0.3	10.6	33.4	21.4
Foreign Trade	6.7	27.1	111.3	900.0	0.0	528.9	429.8	148.5	3,249.8	173.8	643.7	446.4	765.7	23.1	5.0	8.5	18.5	4.6	40.1	80.9	86.9
Domestic Trade	47.0	56.6	130.1	889.0	0.4	2,019.5	2,877.5	841.3	4,452.6	525.0	3,214.9	1,580.5	3,065.3	380.6	38.9	66.4	218.6	27.5	328.6	990.7	1,354.7
Gross Output	223.8	927.0	1,087.3	4,288.7	12.0	12,400.7	7,597.1	2,393.6	22,973.8	1,819.8	21,080.5	6,319.6	16,174.4	3,909.3	390.8	426.9	2,042.9	492.6	4,719.7	19,097.3	15,483.5

Los Angeles City 2010 Input-Output Table (continued)

	22	23	24	25	26	27	28	29	30	31	32	33	34	Household	Government	Other	Foreign Trade	Domestic Trade	Gross Output
01. Agriculture, Forestry and Fishing	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.1	0.0	7.6	0.1	0.0	34.9	161.2	223.8
02. Mining, Quarrying, and Oil and Gas Extraction	0.2	0.4	4.4	0.3	2.0	0.8	0.2	0.2	4.5	1.7	16.8	0.5	0.6	21.2	1.6	24.6	33.8	1.1	927.0
03. Electric Utilities	12.9	5.6	50.9	22.3	9.4	16.2	5.0	13.9	160.5	26.3	12.7	51.1	0.0	429.3	14.3	0.0	0.2	21.3	1,087.3
04. Gas Utilities	12.2	23.2	51.8	83.0	7.3	5.0	6.2	13.8	149.0	29.2	85.1	22.1	0.0	741.8	46.2	0.0	2.4	2,347.8	4,288.7
05. Water and Wastewater Utilities	0.1	0.1	0.2	0.7	0.0	0.1	0.0	0.1	0.5	0.2	0.5	0.2		7.3	1.4	0.0	0.1	0.0	12.0
06. Construction	284.3	115.2	195.9	8.8	27.9	16.6	8.8	29.4	193.9	110.4	371.6	169.3	281.9	0.0	1,403.4	8,331.8	0.7	304.8	12,400.7
07. Food Manufacturing	0.2	0.1	19.3	64.3	1.8	76.3	24.7	10.1	1,568.4	37.1	19.2	0.1	0.1	3,451.2	36.7	22.2	404.9	645.2	7,597.1
08. Beverage and Tobacco Product Mft	0.0	0.0	0.1	0.6	0.0	0.8	0.2	0.1	26.2	0.3	0.2	0.0		104.2	0.2	0.3	59.2	2,189.6	2,393.6
09. Chemical Manufacturing	40.9	27.5	602.9	23.6	467.8	262.0	21.9	12.5	224.7	130.6	211.6	15.6	23.6	7,164.5	329.4	1,709.4	2,514.1	60.7	22,973.8
10. Nonmetallic Mineral/Metals Processing & Mft	0.3	1.6	6.1	0.4	2.4	0.8	0.2	0.1	17.0	4.3	7.6	0.5	1.7	19.6	3.8	3.4	224.7	1,259.8	1,819.8
11. High Technology	138.6	151.9	378.1	65.7	148.4	67.3	8.8	6.6	154.0	118.8	31.8	16.5	4.9	2,191.6	464.8	4,034.5	2,295.3	6,949.1	21,080.5
12. Other Heavy Industry	5.3	23.5	100.4	11.7	5.5	2.3	0.4	2.7	147.3	177.9	69.7	2.4	11.4	1,010.8	118.9	594.4	863.3	1,551.1	6,319.6
13. Other Light Industry	140.0	55.5	350.6	39.0	90.3	56.5	13.1	26.4	580.0	223.0	109.4	26.0	55.9	2,402.0	163.1	528.9	1,596.4	6,995.5	16,174.4
14. Air Transportation	60.6	8.3	82.5	5.0	10.7	1.2	0.7	1.6	45.4	18.5	8.6	4.8	0.1	647.4	20.7	7.9	987.6	1,898.9	3,909.3
15. Rail Transportation	0.7	2.3	9.4	0.6	2.4	2.2	0.2	0.2	20.9	3.2	7.2	0.8	1.0	38.2	5.9	3.9	52.0	0.0	390.8
16. Water Transportation	0.1	0.1	28.6	0.0	0.1	0.2	0.0	0.0	1.3	0.1	1.7	0.0	0.1	48.7	6.9	0.3	297.2	16.2	426.9
17. Truck Transportation	8.3	6.4	56.7	7.2	22.0	13.9	2.6	2.3	146.4	45.8	29.9	1.8	8.1	536.3	28.0	137.7	226.4	0.0	2,042.9
18. Transit and Ground Passenger Transportation	30.8	4.3	42.0	3.0	5.9	1.5	1.1	1.0	41.3	7.5	4.8	3.8		207.3	7.0	0.0	0.0	108.7	492.6
19. Other Transportation and Warehousing	72.4	15.5	184.9	10.6	27.6	14.1	2.3	4.7	123.7	94.4	38.0	1.7	0.9	149.8	26.8	13.7	874.5	1,331.5	4,719.7
20. Wholesale Trade	38.5	32.4	245.7	40.2	137.5	78.3	15.3	6.0	695.8	136.1	70.3	5.8	18.0	5,404.7	194.5	2,009.6	3,056.1	3,638.9	19,097.3
21. Retail Trade	13.5	0.7	18.6	0.4	15.3	14.1	1.3	0.7	89.3	49.9	0.6	2.3	33.0	14,394.3	0.5	351.6	0.0	0.0	15,483.5
22. Banks & Financial Institutions	8,158.2	103.7	1,376.5	53.2	394.2	157.9	49.4	47.9	974.6	1,119.0	227.0	458.6	1,382.9	10,516.3	130.6	51.1	1,325.8	12,037.1	40,273.6
23. Telecommunications	549.1	735.7	679.8	33.4	87.8	30.9	7.9	15.1	259.7	141.0	38.2	36.2	0.4	1,077.0	127.6	103.9	207.9	4,794.0	9,525.1
24. Professional & Technical Services	3,166.7	738.8	5,533.7	284.2	1,009.4	421.9	113.0	254.1	3,936.4	1,148.6	473.1	664.9	236.3	3,016.6	1,349.7	2,185.3	4,504.7	26,965.3	65,745.3
25. Education Services	1.9	6.5	4.6	14.2	0.8	1.6			14.3	40.9	0.4	0.0		3,975.3	108.8	0.0	16.3	441.9	4,670.0
26. Medical Office/Clinic			4.1		219.7	118.4	0.2		3.4	2.3				11,883.7	11.8	0.0	0.0	77.9	12,321.5
27. Hospitals			0.0		1.3	6.5	0.0		0.0	0.0				6,948.1	4.1	0.0	1.9	0.5	6,962.4
28. Nursing and Residential Care Facilities														1,817.5	4.2	0.0	0.0	0.0	1,821.7
29. Hotels	151.8	19.9	167.8	9.7	21.5	2.7	1.2	3.4	86.0	33.8	7.7	14.0	1.6	938.4	30.9	0.0	0.2	444.6	2,043.4
30. Entertainment & Recreation	614.4	500.8	1,038.6	69.8	171.1	53.0	32.6	62.3	3,668.3	281.3	59.3	89.6	14.0	8,685.9	196.0	127.3	5,291.5	38,772.9	60,777.7
31. Other Services	398.6	73.0	455.8	39.7	90.4	60.4	9.8	24.1	386.1	162.5	34.8	22.8	135.7	8,588.3	135.7	0.0	3.6	4,485.5	15,765.4
32. Gov't & Non-NAICS	910.1	141.0	387.3	102.2	54.3	37.7	7.5	31.7	450.2	135.0	159.5	31.2	5.5	3,473.8	18,217.6	25.4	2,123.4	582.1	28,376.4
33. Real Estate	652.9	94.8	1,038.7	322.3	327.5	478.9	65.2	24.9	1,377.1	588.5	129.4	518.2	354.8	3,962.1	137.5	0.0	33.7	15,733.6	27,134.5
34. Owner-occupied Dwellings														18,948.3	0.0	0.0	0.0	0.0	18,948.3
Employee Compensation	10,659.0	1,558.5	24,837.3	2,811.6	5,583.9	3,766.5	1,023.3	621.2	20,156.7	5,659.6	22,421.4	1,899.4	0.0						
Proprietary Income	719.2	37.5	8,172.3	116.8	1,697.2	73.9	72.3	50.6	2,120.8	2,387.9	0.0	1,262.0	0.0						
Other Property Income	6,812.0	3,216.5	13,357.0	-277.4	462.9	264.4	78.9	371.1	13,641.4	148.3	3,283.3	18,206.9	13,489.6						
Indirect Business Taxes	739.5	598.3	1,714.6	123.4	146.7	109.2	85.1	174.3	2,122.2	457.7	-568.5	2,746.2	1,896.2						
Other	133.1	23.9	72.5	7.7	16.7	10.5	1.4	4.7	89.4	32.2	20.9	2.6	2.6						
Foreign Trade	118.9	56.8	263.4	36.0	70.5	40.8	9.1	15.0	531.8	211.1	190.5	19.3	42.7						
Domestic Trade	5,628.4	1,144.8	4,212.0	535.8	981.1	696.9	152.2	210.7	6,567.2	2,000.5	802.2	837.4	944.6						
Gross Output	40,273.6	9,525.1	65,745.3	4,670.0	12,321.5	6,962.4	1,821.7	2,043.4	60,777.7	15,765.4	28,376.4	27,134.5	18,948.3						438,226.8

Appendix D. Calculation Steps in Input-Output Analysis

In this study, we use Input-Output model to analyze the total business interruption losses of two flood events, 10-year and 100-year floods, for two sea level rise scenarios -- 0.5 m by 2050 and 1.4 m by 2100. The following calculation steps are undertaken to perform the analysis for each scenario:

1. The direct output losses (direct business interruption loss) of the City for each of the 33 occupancy classes are obtained from the HAZUS simulation. These results are then translated to sectoral direct output loss for each of the 34 sectors in the I-O Model using the occupancy to sector mapping scheme shown in Table B2 in Appendix B.

2. The sectoral direct output losses are converted to final demand losses and value added losses using the diagonal element of the corresponding sector in the Leontief inverse matrix and Ghoshian inverse matrix, respectively.

3. The multiplier (total) impacts on both demand-side and supply-side stemming from the direct business interruption (BI) loss are computed by applying the demand-side I-O Model and supply-side I-O Model of the City to the final demand losses and value added losses, respectively.

4. The total multiplier impacts for the City stemming from the direct BI losses incurred in the City are calculated as the sum of the demand-side and supply-side impacts calculated in Step 3, net the double-counting of the direct impacts (the direct impacts are included in both the demand-side total losses and supply-side total losses calculations).

5. The direct BI losses in Rest of the County would also generate indirect impacts to the City. The total impacts (including both demand-side and supply-side) of the direct BI losses in Rest of the County are first computed using the I-O Model of the County.

6. The direct BI losses for Rest of the County are subtracted from the total impacts to get the indirect impacts stemming from the direct BI losses for Rest of the County.

7. The indirect impacts (calculated in Step 6) on the City economy stemming from the direct BI losses for Rest of the County are computed by multiplying the total indirect impacts to the County as a whole by the percentage economy size of the City with respect to the County.

The total BI losses for the City is the sum of the total multiplier impacts for the City stemming from the direct BI losses incurred in the City (Step 4) and the indirect impacts to the City stemming from the direct BI losses incurred in Rest of the County (Step 7).

Appendix E. Sectoral Business Interruption Losses

Table E1. Total Business Interruption Losses by Sector for City of Los Angeles, 10-Year Flood Event for the Base Case

Sector		City Direct BI Losses			City Total Impacts from City Direct BI Losses			Indirect Impacts to the City from Direct BI Losses in Rest of County			City Total BI Losses		
		Output ($M)	Income ($M)	Employment (Jobs)	Output ($M)	Income ($M)	Employment (Jobs)	Output ($M)	Income ($M)	Employment (Jobs)	Output ($M)	Income ($M)	Employment (Jobs)
1	Agriculture, Forestry and Fishing	0.001	0.001	0	0.001	0.001	0	0.001	0.001	0	0.002	0.001	0
2	Mining, Quarrying, and Oil and Gas Extraction	0.000	0.000	0	0.004	0.002	0	0.003	0.003	0	0.007	0.005	0
3	Electric Utilities	0.002	0.001	0	0.006	0.002	0	0.006	0.007	0	0.012	0.009	0
4	Gas Utilities	0.006	0.001	0	0.015	0.002	0	0.010	0.010	0	0.024	0.011	0
5	Water and Wastewater Utilities	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0
6	Construction	0.002	0.001	0	0.026	0.010	0	0.036	0.036	0	0.062	0.046	0
7	Food Manufacturing	0.014	0.002	0	0.038	0.005	0	0.025	0.025	0	0.063	0.030	0
8	Beverage and Tobacco Product Manufacturing	0.004	0.001	0	0.007	0.001	0	0.008	0.008	0	0.015	0.009	0
9	Chemical Manufacturing	0.043	0.003	0	0.100	0.006	0	0.053	0.052	0	0.152	0.058	0
10	Nonmetallic Mineral/Metals Processing & Mfg	0.000	0.000	0	0.003	0.000	0	0.004	0.004	0	0.007	0.004	0
11	High Technology	0.000	0.000	0	0.038	0.010	0	0.040	0.044	0	0.078	0.054	0
12	Other Heavy Industry	0.002	0.001	0	0.016	0.004	0	0.012	0.012	0	0.028	0.016	0
13	Other Light Industry	0.001	0.000	0	0.039	0.011	0	0.044	0.047	0	0.083	0.058	0
14	Air Transportation	0.006	0.002	0	0.014	0.004	0	0.018	0.018	0	0.031	0.022	0
15	Rail Transportation	0.001	0.000	0	0.002	0.001	0	0.002	0.002	0	0.004	0.002	0
16	Water Transportation	0.001	0.000	0	0.001	0.000	0	0.001	0.001	0	0.002	0.001	0
17	Truck Transportation	0.003	0.001	0	0.010	0.005	0	0.010	0.010	0	0.021	0.015	0
18	Transit and Ground Passenger Transportation	0.001	0.000	0	0.002	0.001	0	0.003	0.003	0	0.005	0.004	0
19	Other Transportation and Warehousing	0.007	0.004	0	0.021	0.011	0	0.022	0.022	0	0.043	0.033	0
20	Wholesale Trade	0.060	0.026	0	0.102	0.043	1	0.055	0.055	0	0.157	0.098	1
21	Retail Trade	0.008	0.004	0	0.060	0.028	1	0.079	0.079	1	0.139	0.107	2
22	Banks & Financial Institutions	0.004	0.001	0	0.121	0.034	1	0.250	0.235	1	0.371	0.269	2
23	Telecommunications	0.000	0.000	0	0.021	0.003	0	0.060	0.060	0	0.081	0.064	0
24	Professional & Technical Services	0.098	0.049	1	0.249	0.125	2	0.303	0.301	2	0.553	0.426	4
25	Education Services	0.069	0.043	1	0.083	0.052	1	0.026	0.026	0	0.109	0.078	1
26	Medical Office/Clinic	0.045	0.027	0	0.088	0.052	1	0.066	0.066	1	0.153	0.117	1
27	Hospitals	0.003	0.002	0	0.029	0.016	0	0.041	0.041	0	0.070	0.057	0
28	Nursing and Residential Care Facilities	0.000	0.000	0	0.007	0.004	0	0.011	0.011	0	0.017	0.015	0
29	Hotels	0.039	0.013	0	0.045	0.015	0	0.005	0.005	0	0.050	0.020	0
30	Entertainment & Recreation	0.131	0.048	1	0.227	0.083	1	0.159	0.161	1	0.386	0.244	2
31	Other Services	0.140	0.071	2	0.179	0.091	3	0.071	0.069	1	0.250	0.160	4
32	Gov't & Non-NAICS	0.039	0.031	0	0.095	0.075	1	0.092	0.092	1	0.187	0.167	2
33	Real Estate	0.000	0.000	0	0.045	0.005	0	0.118	0.118	1	0.163	0.123	1
34	Owner-occupied Dwellings	0.000	0.000	0	0.047	0.000	0	0.077	0.000	0	0.123	0.000	0
Total		**0.729**	**0.330**	**6**	**1.739**	**0.705**	**13**	**1.710**	**1.621**	**11**	**3.449**	**2.325**	**24**

Table E2. Total Business Interruption Losses by Sector for City of Los Angeles, 100-Year Flood Event for Base Case

Sector		City Direct BI Losses			City Total Impacts from City Direct BI Losses			Indirect Impacts to the City from Direct BI Losses in Rest of County			City Total BI Losses		
		Output ($M)	Income ($M)	Employment (Jobs)	Output ($M)	Income ($M)	Employment (Jobs)	Output ($M)	Income ($M)	Employment (Jobs)	Output ($M)	Income ($M)	Employment (Jobs)
1	Agriculture, Forestry and Fishing	0.003	0.002	0	0.004	0.002	0	0.001	0.001	0	0.005	0.003	0
2	Mining, Quarrying, and Oil and Gas Extraction	0.000	0.000	0	0.009	0.004	0	0.006	0.006	0	0.015	0.010	0
3	Electric Utilities	0.003	0.001	0	0.013	0.004	0	0.011	0.014	0	0.024	0.018	0
4	Gas Utilities	0.013	0.002	0	0.032	0.004	0	0.020	0.020	0	0.052	0.024	0
5	Water and Wastewater Utilities	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0
6	Construction	0.003	0.001	0	0.057	0.022	0	0.074	0.074	0	0.131	0.096	1
7	Food Manufacturing	0.032	0.004	0	0.085	0.012	0	0.051	0.051	0	0.136	0.062	0
8	Beverage and Tobacco Product Manufacturing	0.010	0.001	0	0.016	0.002	0	0.017	0.017	0	0.033	0.019	0
9	Chemical Manufacturing	0.097	0.006	0	0.225	0.014	0	0.107	0.106	0	0.333	0.121	0
10	Nonmetallic Mineral/Metals Processing & Mfg	0.000	0.000	0	0.006	0.001	0	0.008	0.008	0	0.014	0.009	0
11	High Technology	0.000	0.000	0	0.087	0.023	0	0.084	0.091	0	0.170	0.114	0
12	Other Heavy Industry	0.003	0.001	0	0.034	0.009	0	0.025	0.025	0	0.060	0.034	0
13	Other Light Industry	0.001	0.000	0	0.089	0.024	0	0.091	0.096	0	0.179	0.121	1
14	Air Transportation	0.012	0.004	0	0.030	0.009	0	0.036	0.036	0	0.066	0.045	0
15	Rail Transportation	0.001	0.000	0	0.004	0.002	0	0.004	0.004	0	0.008	0.005	0
16	Water Transportation	0.001	0.000	0	0.003	0.000	0	0.002	0.002	0	0.005	0.002	0
17	Truck Transportation	0.006	0.003	0	0.023	0.011	0	0.021	0.021	0	0.044	0.032	0
18	Transit and Ground Passenger Transportation	0.002	0.001	0	0.005	0.003	0	0.006	0.006	0	0.011	0.009	0
19	Other Transportation and Warehousing	0.014	0.008	0	0.046	0.025	0	0.046	0.046	0	0.092	0.071	1
20	Wholesale Trade	0.156	0.066	1	0.250	0.106	1	0.113	0.113	1	0.362	0.218	2
21	Retail Trade	0.032	0.015	0	0.149	0.070	2	0.162	0.161	2	0.311	0.231	4
22	Banks & Financial Institutions	0.009	0.002	0	0.270	0.076	1	0.511	0.480	2	0.781	0.556	4
23	Telecommunications	0.001	0.000	0	0.046	0.008	0	0.122	0.122	0	0.168	0.129	0
24	Professional & Technical Services	0.202	0.101	1	0.548	0.275	4	0.620	0.615	5	1.168	0.890	9
25	Education Services	0.159	0.100	2	0.192	0.120	3	0.051	0.052	1	0.243	0.173	3
26	Medical Office/Clinic	0.134	0.079	1	0.227	0.134	2	0.136	0.136	1	0.364	0.271	3
27	Hospitals	0.011	0.006	0	0.069	0.038	0	0.085	0.085	1	0.154	0.123	1
28	Nursing and Residential Care Facilities	0.000	0.000	0	0.015	0.009	0	0.022	0.022	0	0.037	0.031	1
29	Hotels	0.066	0.022	1	0.080	0.026	1	0.011	0.011	0	0.091	0.037	1
30	Entertainment & Recreation	0.285	0.104	2	0.502	0.184	3	0.333	0.336	2	0.835	0.520	5
31	Other Services	0.309	0.158	5	0.397	0.203	6	0.144	0.139	2	0.540	0.341	8
32	Gov't & Non-NAICS	0.066	0.052	1	0.196	0.155	2	0.195	0.194	2	0.391	0.349	4
33	Real Estate	0.000	0.000	0	0.103	0.012	1	0.246	0.246	1	0.349	0.258	2
34	Owner-occupied Dwellings	0.000	0.000	0	0.105	0.000	0	0.156	0.000	0	0.261	0.000	0
Total		**1.631**	**0.740**	**15**	**3.915**	**1.588**	**29**	**3.518**	**3.336**	**23**	**7.434**	**4.925**	**52**

Table E3. Total Business Interruption Losses by Sector for City of Los Angeles, 10-Year Flood Event for the 0.5 M Sea Level Rise Scenario

Sector		City Direct BI Losses			City Total Impacts from City Direct BI Losses			Indirect Impacts to the City from Direct BI Losses in Rest of County			City Total BI Losses		
		Output ($M)	Income ($M)	Employment (Jobs)	Output ($M)	Income ($M)	Employment (Jobs)	Output ($M)	Income ($M)	Employment (Jobs)	Output ($M)	Income ($M)	Employment (Jobs)
1	Agriculture, Forestry and Fishing	0.002	0.001	0	0.003	0.001	0	0.001	0.001	0	0.004	0.002	0
2	Mining, Quarrying, and Oil and Gas Extraction	0.000	0.000	0	0.007	0.003	0	0.005	0.004	0	0.011	0.008	0
3	Electric Utilities	0.003	0.001	0	0.010	0.003	0	0.009	0.011	0	0.019	0.014	0
4	Gas Utilities	0.011	0.001	0	0.026	0.003	0	0.015	0.015	0	0.041	0.018	0
5	Water and Wastewater Utilities	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0
6	Construction	0.002	0.001	0	0.046	0.018	0	0.055	0.055	0	0.101	0.073	1
7	Food Manufacturing	0.023	0.003	0	0.067	0.009	0	0.037	0.037	0	0.104	0.046	0
8	Beverage and Tobacco Product Manufacturing	0.007	0.001	0	0.012	0.002	0	0.012	0.012	0	0.024	0.014	0
9	Chemical Manufacturing	0.070	0.004	0	0.175	0.011	0	0.080	0.079	0	0.255	0.090	0
10	Nonmetallic Mineral/Metals Processing & Mfg	0.000	0.000	0	0.005	0.001	0	0.006	0.006	0	0.011	0.007	0
11	High Technology	0.000	0.000	0	0.070	0.019	0	0.061	0.067	0	0.131	0.086	0
12	Other Heavy Industry	0.002	0.001	0	0.028	0.007	0	0.019	0.019	0	0.046	0.026	0
13	Other Light Industry	0.001	0.000	0	0.072	0.020	0	0.067	0.071	0	0.139	0.091	1
14	Air Transportation	0.010	0.003	0	0.024	0.007	0	0.027	0.027	0	0.051	0.034	0
15	Rail Transportation	0.001	0.000	0	0.003	0.001	0	0.003	0.003	0	0.006	0.004	0
16	Water Transportation	0.001	0.000	0	0.002	0.000	0	0.001	0.001	0	0.004	0.002	0
17	Truck Transportation	0.005	0.002	0	0.019	0.009	0	0.016	0.016	0	0.035	0.025	0
18	Transit and Ground Passenger Transportation	0.001	0.001	0	0.004	0.002	0	0.005	0.005	0	0.009	0.007	0
19	Other Transportation and Warehousing	0.012	0.007	0	0.037	0.021	0	0.034	0.034	0	0.071	0.054	1
20	Wholesale Trade	0.103	0.044	1	0.181	0.077	1	0.083	0.083	0	0.264	0.160	2
21	Retail Trade	0.027	0.013	0	0.123	0.058	2	0.121	0.120	2	0.244	0.178	3
22	Banks & Financial Institutions	0.005	0.002	0	0.222	0.063	1	0.383	0.360	2	0.605	0.422	3
23	Telecommunications	0.001	0.000	0	0.038	0.006	0	0.091	0.091	0	0.129	0.097	0
24	Professional & Technical Services	0.166	0.083	1	0.450	0.226	3	0.461	0.457	3	0.911	0.683	7
25	Education Services	0.137	0.086	2	0.163	0.103	2	0.039	0.039	1	0.202	0.142	3
26	Medical Office/Clinic	0.102	0.060	1	0.179	0.106	2	0.101	0.100	1	0.280	0.206	2
27	Hospitals	0.011	0.006	0	0.058	0.032	0	0.063	0.063	0	0.121	0.095	1
28	Nursing and Residential Care Facilities	0.000	0.000	0	0.012	0.007	0	0.016	0.016	0	0.029	0.024	0
29	Hotels	0.051	0.017	0	0.062	0.020	1	0.008	0.008	0	0.070	0.028	1
30	Entertainment & Recreation	0.241	0.088	2	0.417	0.153	3	0.249	0.252	2	0.667	0.405	4
31	Other Services	0.280	0.143	4	0.350	0.179	5	0.104	0.100	2	0.454	0.279	7
32	Gov't & Non-NAICS	0.055	0.043	1	0.162	0.128	2	0.142	0.142	1	0.304	0.270	3
33	Real Estate	0.000	0.000	0	0.086	0.010	0	0.180	0.180	1	0.266	0.190	1
34	Owner-occupied Dwellings	0.000	0.000	0	0.087	0.000	0	0.116	0.000	0	0.203	0.000	0
Total		**1.330**	**0.611**	**12**	**3.202**	**1.306**	**24**	**2.608**	**2.473**	**17**	**5.811**	**3.778**	**41**

Table E4. Total Business Interruption Losses by Sector for City of Los Angeles, 100-Year Flood Event for the 0.5 M Sea Level Rise Scenario

Sector		City Direct BI Losses			City Total Impacts from City Direct BI Losses			Indirect Impacts to the City from Direct BI Losses in Rest of County			City Total BI Losses		
		Output ($M)	Income ($M)	Employment (Jobs)	Output ($M)	Income ($M)	Employment (Jobs)	Output ($M)	Income ($M)	Employment (Jobs)	Output ($M)	Income ($M)	Employment (Jobs)
1	Agriculture, Forestry and Fishing	0.004	0.002	0	0.006	0.003	0	0.002	0.001	0	0.007	0.004	0
2	Mining, Quarrying, and Oil and Gas Extraction	0.000	0.000	0	0.012	0.006	0	0.007	0.007	0	0.020	0.013	0
3	Electric Utilities	0.003	0.001	0	0.018	0.006	0	0.014	0.018	0	0.033	0.024	0
4	Gas Utilities	0.014	0.002	0	0.044	0.006	0	0.024	0.024	0	0.068	0.030	0
5	Water and Wastewater Utilities	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0
6	Construction	0.004	0.002	0	0.084	0.033	1	0.094	0.094	1	0.177	0.126	1
7	Food Manufacturing	0.042	0.006	0	0.124	0.017	0	0.064	0.063	0	0.188	0.080	0
8	Beverage and Tobacco Product Manufacturing	0.013	0.002	0	0.021	0.003	0	0.021	0.021	0	0.042	0.023	0
9	Chemical Manufacturing	0.127	0.008	0	0.300	0.019	0	0.122	0.121	0	0.422	0.140	0
10	Nonmetallic Mineral/Metals Processing & Mfg	0.001	0.000	0	0.008	0.001	0	0.010	0.010	0	0.019	0.011	0
11	High Technology	0.001	0.000	0	0.121	0.033	0	0.100	0.109	0	0.221	0.141	1
12	Other Heavy Industry	0.004	0.001	0	0.049	0.012	0	0.031	0.031	0	0.079	0.043	0
13	Other Light Industry	0.002	0.001	0	0.125	0.035	1	0.111	0.118	1	0.236	0.152	1
14	Air Transportation	0.012	0.004	0	0.039	0.011	0	0.046	0.046	0	0.085	0.057	0
15	Rail Transportation	0.001	0.000	0	0.006	0.002	0	0.005	0.005	0	0.010	0.007	0
16	Water Transportation	0.001	0.000	0	0.004	0.001	0	0.002	0.002	0	0.006	0.003	0
17	Truck Transportation	0.006	0.003	0	0.031	0.015	0	0.027	0.027	0	0.059	0.042	0
18	Transit and Ground Passenger Transportation	0.002	0.001	0	0.007	0.004	0	0.008	0.008	0	0.016	0.013	0
19	Other Transportation and Warehousing	0.015	0.008	0	0.058	0.032	1	0.055	0.054	0	0.113	0.087	1
20	Wholesale Trade	0.000	0.000	0	0.152	0.065	1	0.144	0.144	1	0.296	0.208	2
21	Retail Trade	0.049	0.023	1	0.227	0.107	3	0.203	0.202	3	0.431	0.309	6
22	Banks & Financial Institutions	0.396	0.112	2	0.749	0.212	4	0.573	0.538	3	1.322	0.750	6
23	Telecommunications	0.001	0.000	0	0.074	0.012	0	0.159	0.159	0	0.234	0.172	0
24	Professional & Technical Services	0.208	0.104	2	0.769	0.386	6	0.835	0.828	6	1.604	1.214	12
25	Education Services	0.355	0.222	5	0.401	0.251	5	0.065	0.066	1	0.465	0.317	6
26	Medical Office/Clinic	0.023	0.013	0	0.179	0.106	2	0.190	0.190	2	0.369	0.295	3
27	Hospitals	0.015	0.008	0	0.101	0.056	1	0.102	0.102	1	0.204	0.158	1
28	Nursing and Residential Care Facilities	0.000	0.000	0	0.023	0.014	0	0.028	0.028	0	0.050	0.041	1
29	Hotels	0.085	0.028	1	0.108	0.035	1	0.015	0.014	0	0.122	0.050	1
30	Entertainment & Recreation	0.640	0.234	4	0.948	0.347	6	0.399	0.403	2	1.346	0.750	8
31	Other Services	0.490	0.250	8	0.632	0.323	10	0.184	0.177	3	0.816	0.500	13
32	Gov't & Non-NAICS	0.092	0.073	1	0.296	0.234	3	0.249	0.248	3	0.545	0.482	6
33	Real Estate	0.000	0.000	0	0.171	0.020	1	0.311	0.311	2	0.482	0.331	3
34	Owner-occupied Dwellings	0.000	0.000	0	0.172	0.000	0	0.208	0.000	0	0.380	0.000	0
Total		**2.608**	**1.110**	**23**	**6.060**	**2.406**	**45**	**4.406**	**4.168**	**29**	**10.466**	**6.573**	**74**

Table E5. Total Business Interruption Losses by Sector for City of Los Angeles, 10-Year Flood Event for the 1.4 M Sea Level Rise Scenario

Sector		City Direct BI Losses			City Total Impacts from City Direct BI Losses			Indirect Impacts to the City from Direct BI Losses in Rest of County			City Total BI Losses		
		Output ($M)	Income ($M)	Employment (Jobs)	Output ($M)	Income ($M)	Employment (Jobs)	Output ($M)	Income ($M)	Employment (Jobs)	Output ($M)	Income ($M)	Employment (Jobs)
1	Agriculture, Forestry and Fishing	0.003	0.002	0	0.004	0.002	0	0.001	0.001	0	0.006	0.004	0
2	Mining, Quarrying, and Oil and Gas Extraction	0.000	0.000	0	0.011	0.006	0	0.007	0.007	0	0.019	0.012	0
3	Electric Utilities	0.004	0.001	0	0.017	0.005	0	0.013	0.016	0	0.029	0.021	0
4	Gas Utilities	0.016	0.002	0	0.042	0.005	0	0.022	0.022	0	0.064	0.027	0
5	Water and Wastewater Utilities	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0	0.000	0.000	0
6	Construction	0.004	0.002	0	0.075	0.029	1	0.084	0.084	1	0.160	0.114	1
7	Food Manufacturing	0.045	0.006	0	0.115	0.016	0	0.057	0.057	0	0.173	0.073	0
8	Beverage and Tobacco Product Manufacturing	0.014	0.002	0	0.022	0.003	0	0.019	0.019	0	0.041	0.022	0
9	Chemical Manufacturing	0.137	0.009	0	0.304	0.019	0	0.123	0.122	0	0.427	0.141	0
10	Nonmetallic Mineral/Metals Processing & Mfg	0.000	0.000	0	0.008	0.001	0	0.010	0.009	0	0.017	0.010	0
11	High Technology	0.001	0.000	0	0.115	0.031	0	0.095	0.104	0	0.211	0.135	1
12	Other Heavy Industry	0.004	0.001	0	0.045	0.012	0	0.029	0.029	0	0.074	0.040	0
13	Other Light Industry	0.002	0.001	0	0.117	0.032	1	0.103	0.110	1	0.220	0.142	1
14	Air Transportation	0.015	0.004	0	0.038	0.011	0	0.041	0.041	0	0.079	0.052	0
15	Rail Transportation	0.001	0.001	0	0.006	0.002	0	0.004	0.004	0	0.010	0.006	0
16	Water Transportation	0.002	0.000	0	0.004	0.001	0	0.002	0.002	0	0.006	0.003	0
17	Truck Transportation	0.008	0.004	0	0.030	0.014	0	0.024	0.024	0	0.054	0.038	0
18	Transit and Ground Passenger Transportation	0.002	0.001	0	0.007	0.004	0	0.007	0.007	0	0.014	0.011	0
19	Other Transportation and Warehousing	0.018	0.010	0	0.059	0.033	1	0.053	0.053	0	0.112	0.085	1
20	Wholesale Trade	0.191	0.081	1	0.316	0.134	2	0.127	0.127	1	0.443	0.261	3
21	Retail Trade	0.041	0.019	1	0.195	0.091	3	0.184	0.183	2	0.379	0.274	5
22	Banks & Financial Institutions	0.009	0.002	0	0.350	0.099	2	0.582	0.547	3	0.933	0.646	4
23	Telecommunications	0.001	0.000	0	0.060	0.010	0	0.138	0.138	0	0.198	0.148	0
24	Professional & Technical Services	0.247	0.124	2	0.708	0.356	5	0.697	0.690	5	1.405	1.046	10
25	Education Services	0.263	0.165	3	0.305	0.191	4	0.059	0.060	1	0.365	0.252	5
26	Medical Office/Clinic	0.175	0.104	1	0.298	0.176	3	0.154	0.154	1	0.452	0.330	4
27	Hospitals	0.013	0.007	0	0.090	0.050	1	0.096	0.096	1	0.186	0.146	1
28	Nursing and Residential Care Facilities	0.000	0.000	0	0.020	0.012	0	0.025	0.025	0	0.045	0.037	1
29	Hotels	0.081	0.027	1	0.099	0.033	1	0.013	0.013	0	0.112	0.045	1
30	Entertainment & Recreation	0.368	0.135	2	0.655	0.240	4	0.380	0.384	2	1.035	0.624	6
31	Other Services	0.397	0.203	6	0.514	0.262	8	0.158	0.153	2	0.672	0.415	11
32	Gov't & Non-NAICS	0.074	0.059	1	0.250	0.197	3	0.219	0.218	2	0.469	0.416	5
33	Real Estate	0.000	0.000	0	0.138	0.016	1	0.275	0.275	1	0.413	0.291	2
34	Owner-occupied Dwellings	0.000	0.000	0	0.138	0.000	0	0.177	0.000	0	0.314	0.000	0
Total		**2.136**	**0.970**	**19**	**5.157**	**2.094**	**38**	**3.980**	**3.773**	**26**	**9.137**	**5.868**	**64**

Table E6. Total Business Interruption Losses by Sector for City of Los Angeles, 100-Year Flood Event for the 1.4 M Sea Level Rise Scenario

Sector		City Direct BI Losses			City Total Impacts from City Direct BI Losses			Indirect Impacts to the City from Direct BI Losses in Rest of County			City Total BI Losses		
		Output ($M)	Income ($M)	Employment (Jobs)	Output ($M)	Income ($M)	Employment (Jobs)	Output ($M)	Income ($M)	Employment (Jobs)	Output ($M)	Income ($M)	Employment (Jobs)
1	Agriculture, Forestry and Fishing	0.005	0.003	0	0.008	0.004	0	0.003	0.003	0	0.011	0.007	0
2	Mining, Quarrying, and Oil and Gas Extraction	0.001	0.001	0	0.027	0.013	0	0.015	0.014	0	0.042	0.027	0
3	Electric Utilities	0.011	0.003	0	0.043	0.014	0	0.027	0.034	0	0.071	0.048	0
4	Gas Utilities	0.042	0.005	0	0.108	0.014	0	0.049	0.049	0	0.158	0.063	0
5	Water and Wastewater Utilities	0.000	0.000	0	0.001	0.000	0	0.000	0.000	0	0.001	0.001	0
6	Construction	0.008	0.003	0	0.191	0.074	1	0.175	0.175	1	0.367	0.249	2
7	Food Manufacturing	0.053	0.007	0	0.237	0.033	1	0.115	0.114	0	0.352	0.147	1
8	Beverage and Tobacco Product Manufacturing	0.017	0.002	0	0.036	0.004	0	0.038	0.038	0	0.073	0.042	0
9	Chemical Manufacturing	0.160	0.010	0	0.617	0.039	0	0.251	0.248	0	0.867	0.287	0
10	Nonmetallic Mineral/Metals Processing & Mfg	0.003	0.001	0	0.022	0.004	0	0.020	0.019	0	0.042	0.023	0
11	High Technology	0.002	0.001	0	0.302	0.082	1	0.197	0.214	0	0.499	0.295	1
12	Other Heavy Industry	0.014	0.004	0	0.121	0.031	0	0.060	0.060	0	0.181	0.091	1
13	Other Light Industry	0.005	0.001	0	0.293	0.081	2	0.213	0.227	1	0.507	0.308	3
14	Air Transportation	0.039	0.011	0	0.097	0.029	0	0.084	0.084	0	0.181	0.113	1
15	Rail Transportation	0.004	0.001	0	0.014	0.005	0	0.008	0.008	0	0.022	0.013	0
16	Water Transportation	0.004	0.001	0	0.010	0.002	0	0.005	0.005	0	0.014	0.006	0
17	Truck Transportation	0.020	0.009	0	0.076	0.036	1	0.050	0.050	0	0.126	0.086	1
18	Transit and Ground Passenger Transportation	0.005	0.003	0	0.017	0.010	0	0.015	0.015	0	0.032	0.025	1
19	Other Transportation and Warehousing	0.047	0.026	0	0.154	0.085	1	0.109	0.108	1	0.263	0.194	2
20	Wholesale Trade	0.501	0.212	3	0.827	0.351	5	0.264	0.264	2	1.092	0.615	6
21	Retail Trade	0.129	0.060	2	0.540	0.253	7	0.390	0.388	5	0.930	0.641	12
22	Banks & Financial Institutions	0.031	0.009	0	0.943	0.267	5	1.202	1.129	6	2.145	1.395	10
23	Telecommunications	0.003	0.001	0	0.159	0.027	0	0.280	0.280	1	0.440	0.307	1
24	Professional & Technical Services	0.648	0.325	5	1.853	0.930	14	1.483	1.470	11	3.336	2.400	24
25	Education Services	0.730	0.458	10	0.841	0.527	11	0.113	0.115	1	0.953	0.642	12
26	Medical Office/Clinic	0.397	0.234	3	0.732	0.433	6	0.322	0.321	3	1.054	0.754	9
27	Hospitals	0.227	0.125	2	0.421	0.232	3	0.202	0.202	1	0.623	0.434	4
28	Nursing and Residential Care Facilities	0.001	0.001	0	0.054	0.032	1	0.052	0.052	1	0.106	0.084	2
29	Hotels	0.128	0.042	1	0.178	0.059	2	0.026	0.025	0	0.204	0.084	2
30	Entertainment & Recreation	0.939	0.344	6	1.689	0.619	11	0.859	0.868	5	2.548	1.487	16
31	Other Services	1.143	0.583	18	1.449	0.740	23	0.333	0.322	5	1.782	1.061	28
32	Gov't & Non-NAICS	0.189	0.150	2	0.657	0.519	7	0.475	0.473	5	1.132	0.992	12
33	Real Estate	0.000	0.000	0	0.384	0.045	2	0.593	0.593	3	0.977	0.638	5
34	Owner-occupied Dwellings	0.000	0.000	0	0.370	0.000	0	0.369	0.000	0	0.739	0.000	0
Total		**5.506**	**2.637**	**52**	**13.472**	**5.593**	**103**	**8.397**	**7.967**	**55**	**21.869**	**13.559**	**158**

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