SEA LEVEL RISE IN SANTA MONICA

PLANNING FOR A WATERY FUTURE

AB 691 Sea Level Rise Assessment
City of Santa Monica
Office of Sustainability and the Environment

City of
Santa Monica®

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

Santa Monica is a vibrant beach community located on the eastern shore of Santa Monica Bay, an estuary which was historically fed by freshwater from Ballona Creek and the Los Angeles River. The majority of the coastline consists of sandy beaches, which have widened over the past few decades due to the addition of the Pier, groins, other man-made structures, and beach nourishment. The Santa Monica coast, particularly Santa Monica State Beach, plays an important role in providing coastal recreation for the greater Los Angeles metropolitan region despite its relatively small size. Santa Monica Pier alone draws approximately eight million visitors each year from the Los Angeles region and beyond.

Climate change-induced sea level rise, if left unabated, may cause erosion and narrowing of Santa Monica's iconic beaches, leading to frequent flooding of public infrastructure and transportation networks, and occasional flooding of private coastal properties, including residences and hotels. The total value of vulnerable public assets exceeds $74 million not including the value of non-market services provided by the beach. An additional $115 million in private property is at risk, and the total annual non-market value of lost beach is over $11 million.

The goals of this study are to assess the impacts of sea level rise (SLR) on the coastal zone of Santa Monica, and to provide an overview of the costs and benefits of potential adaptation measures to cope. Based on previous studies, city data, and ongoing municipal programs, the study evaluates the impacts of climate change and sea level rise on natural resources (e.g. beach erosion, wetlands), infrastructure, residents, and the economy.

This report provides a sea-level rise vulnerability assessment for the State Grant Area in compliance with Assembly Bill (AB) 691 requirements. AB 691 requires trustees to assess sea-level rise impacts to granted lands. The first step was to inventory vulnerable natural and built resources and facilities. The second was to consider the impacts of sea-level rise itself and other dynamic coastal processes and climatic events that are projected to be exacerbated by sea-level rise such as coastal erosion, storms, and high tides on the vulnerable assets identified. This information was used to inform adaptation strategies.

There are three main adaptation pathways that cities can pursue in response to sea level rise: retreat, accommodate, or protect. Retreat is a move landward to higher ground, and requires the demolition and rebuilding of critical structures and properties. The natural coastal ecology is allowed to take over. Accommodation measures allow coastal communities to cope with higher water levels without retreating, and refer to strategies such as elevation of buildings and the addition of water resistant or responsive design measures. Protection involves the fortification of the oceanfront such that water is unable to enter. It can consist of natural protection measures and the creation of living shorelines or manmade protection measures, such as levees and seawalls. This report treats these types of protection separately. Each pathway has benefits and drawbacks that must be taken into consideration, including cost, impacts to beach ecology, impacts to public access, and preservation of existing infrastructure.

This report showcases the results of studies done on the impacts of sea level rise and climate-induced extreme weather events on Santa Monica's coastline. It contains a high-level financial analysis of the potential adaptation pathways that the City is considering, and details the priorities of the City, based on various planning efforts undertaken in the past two years.

Multiple adaptation pathways were analyzed to understand the costs and benefits of the different approaches. All pathways considered the impacts to public infrastructure, private property, the ecosystem and recreational values provided by the beach and the investment required to protect them. The scenarios are summarized in brief here:

- **Baseline (No Action) -** The City takes no proactive action to mitigate or adapt to the impacts of sea level rise, and portions of the beaches are submerged temporarily by coastal events, including key public infrastructure, private buildings, and several acres of beaches. The beach will erode over time, reducing the width for recreation and ecosystem services.
- **Managed Retreat -** The City prioritizes soft measures and manages a retreat of public infrastructure and private property that experience significant or frequent impacts from coastal events. The beach will erode over time, reducing the width for recreation and ecosystem services.
- **Accommodation -** The City prioritizes adaptive measures that work with heightened water levels, but does not abate them; and builds the resilience of facilities to accommodate temporary flooding. Accommodation measures are the most difficult to value, as adaptive redesign can include an array of possible measures, and varies widely from one project to another. The beach will erode over time, reducing the width for recreation and ecosystem services.
- **Natural Protection -** The City prioritizes adaptive measures that would reintroduce a more natural beach environment. Beach erosion and coastal flooding could be mitigated by restoring natural dunes, creating a living shoreline and replenishing beach sand.

- **Hard Protection -** The City prioritizes mitigation of unavoidable impacts to public resources through the construction of a new shoreline protective structure, or the expansion of an existing shoreline protection structure. These devices are a last resort to protect critical public infrastructure. Any loss of beach width would not be replenished.

The total estimated costs of potential pathways are shown below. Investment costs include the cost of implementing adaptation measures. Public damages include loss of infrastructure, and clean-up costs. Private damages include property loss and adaptation costs, depending on the scenario. Non-market losses captures the estimated value of recreational value and ecosystem services as a result lost beach width, which easily comprise the largest component in this matrix.

Table 1: Estimated Costs of 2100 Adaptation Pathways (2019 $)

Adaptation Pathway	Investment	Public Damages	Private Damages	Non Market Loss	Total Costs
Baseline (No Action)	$0	$8,405,337	$22,725,964	$816,388,850	$847,520,151
Managed Retreat	$26,438,979	$2,500,000	$0	$816,388,850	$845,327,829
Accommodation	$66,000,000	$0	$918,502	$816,388,850	$883,307,352
Natural Protection	$178,507,566	$0	$0	$0	$178,506,866
Hard Protection	$204,500,000	$0	$0	$0	$204,500,000

Through careful planning and community engagement, the City has made a preference for natural, or soft, adaptation measures and managed retreat that would allow the ocean to reclaim some land, and limit development in areas that become increasingly affected by onshore flooding. The report includes specific strategies, an outline of timeframes and the partnerships needed to advance these efforts.

INTRODUCTION

Climate change threatens both natural and manufactured resources, and will cause long-lasting and cascading impacts to populations across the globe. Sea level rise (SLR) in particular poses a serious threat to coastal communities in California. The two primary causes of sea level rise are increased melting of glaciers and ice sheets, and thermal expansion of water as the ocean temperatures increase.

The main impacts are coastal flooding and permanent inundation. Coastal flooding is a temporary condition caused by storms and high tides, while inundation is a permanent condition during which land is submerged under higher water levels and the coastline gradually erodes away.

Table 2: Sea Level Rise Projections for Southern California and Santa Monica[1]

SLR Scenario	Southern California SLR (inches)[2]	City of Santa Monica SLR (inches)[3]
Early-Century (Now - 2030)	2 - 12”	5.3 - 12”
Mid-Century (2030-2050)	5 - 24”	11.6 - 23.8”
Late-Century (2050-2100)	17 - 66”	36.6 - 113”

Global sea levels began to increase between the late 19th and early 20th century. Sea levels rose about 0.66 feet between 1700 and 1975, with the majority of that increase occurring during the 20th century. The rate of global SLR began to rapidly increase in the 1990s, when global SLR rates reached almost twice the heights that they had been over the previous century.[4] Models indicate that Southern

1 Environmental Science Associates. “Los Angeles County Coastal Hazard Modeling and Vulnerability Assessment: Technical Methods Report.” University of Southern California Sea Grant Program, 2016.
2 Southern California SLR ranges are based on the NRC 2012 results for California coastal areas located south of Pt. Conception, as presented in the 2015 CCC SLR Policy Guidance Document.
3 Santa Monica SLR Ranges are based on the NRC medium and high scenarios for Los Angeles region and used in the ESA/Terra Costa Group modeling and the Cayan et al 2016 Extreme scenario (RCP 8.5 and the 99.9% probability that the SLR will be at or below this level).
4 US Department of Commerce, and National Oceanic and Atmospheric Administration. “Is Sea Level Rising?” NOAA's National Ocean Service, 27 Oct. 2008. https://oceanservice.noaa.gov/facts/sealevel.html

California may see between 17 and 66 inches of SLR by the end of this century (Table 2). SLR in the Los Angeles region is expected to match global projections, and even exceed the averages.

The California coastline is home to a broad range of flora and fauna, including the Western Snowy Plover, a small, threatened shorebird with a critical habitat that falls within Santa Monica's Coastal Zone boundaries. The coastline is also home to highly frequented public spaces for tourism, recreation and gathering. Sea level rise poses a threat to this valued amenity, and it is vital that the City and communities of Santa Monica create a plan to respond and mitigate potential harm.

In an effort to prepare for the anticipated impacts of SLR and associated coastal hazards, the City of Santa Monica with assistance from a grant from the Ocean Protection Council, commissioned a technical study projecting shoreline changes, coastal hazard impacts, and vulnerability assessments for the Los Angeles metro region. In addition, the City utilized the Coastal Storm Modeling System (CoSMoS), developed by the US Geological Survey, which also provides data that can be used at the local level to project future impacts of sea level rise.

Using these analyses, Santa Monica updated its Local Coastal Program Land Use Plan (LUP) in 2018, in accordance with the Coastal Act of 1976. The Local Coastal Program Land Use Plan establishes policies and adaptation strategies to be implemented once a certain amount of sea level rise has occurred. Policies are triggered by readings on tidal gauges, and are based on predicted observable impacts of changing shorelines. One set of policies was triggered with the adoption of the plan, and is currently being implemented. A second set of policies will apply when the "Mid-Term" scenario has occurred (defined as 12.1 inches, or 30.7 cm, of SLR). The final set of policies will apply when the "Long-Term" scenario has occurred (24.1 inches, or 61.2 cm, of SLR).

Adaptation policies outlined within the LUP include:

- **Sufficient setbacks**, building criteria and technical hazard analysis to ensure stability and structural integrity and prevent disruption of natural habitat through new development.
- **Minimize development**, only building where necessary, if removal or relocation is impossible.
- **Remove** repeatedly damaged structures.
- **Limit use** of "hard" adaptation strategies, such as shoreline protection devices.
- **Levy impact fees** for new developments.
- **Relocate or elevate** public facilities, including bicycle pathway.
- **Purchase vulnerable private properties** and restrict them for public use.

Santa Monica also commissioned a Vulnerability Assessment for the impacts of climate change on the city, with a focus on vulnerable inhabitants and visitors. The Vulnerability Assessment was a screening to better understand the potential impacts of and vulnerabilities to climate change hazards and to begin defining future adaptation responses.

Both of these documents informed the Climate Action & Adaptation Plan (CAAP), adopted in 2019, which outlines broad goals and strategies that should inform how the city responds to climate-induced sea level rise. The Climate Action & Adaptation Plan is the first step in a pathway toward carbon neutrality, with a goal of reducing carbon emissions 80% below 1990 levels by 2030 while simultaneously preparing the community for the predicted impacts of climate change. The strategies and actions outlined in each of these documents are incorporated into the adaptation pathways later in this report.

Sea Level Rise Adaptation Planning Workshop (June 2019)

After an evaluation of the LUP and CAAP, and a careful financial analysis of potential adaptation pathways, the City held an interdepartmental workshop to prioritize vulnerabilities and select adaptation pathways. In order to facilitate the evaluation of strategies and their alignment with City goals, actions were placed along spectra corresponding to (1) "softness", or the amount of land the ocean would be allowed to reclaim; (2) maintenance of existing structures; and (3) financial cost. One such matrix is shown on the right.

Figure 1: Adaptation Planning Matrix[5]

Suggestions from city staff were integrated into the adaptation strategies described in the above sections. Managed retreat and accommodation, with a focus on transformative redesign, were chosen as priority pathways. Critical infrastructure was cited as a priority for adaptive redesign to withstand flooding. It was also suggested that the City explore the

[5] Cost is represented by the relative size of the text.

possibility of integrating sea level rise resilience planning into the Capital Improvements planning process. This might allow adaptive redesign, replacement and protection of coastal infrastructure to occur at lower costs and on shorter timelines.

BACKGROUND

HISTORICAL BACKGROUND

Santa Monica was long inhabited by the indigenous Tongva people. Santa Monica was called Kecheek in the Tongva language. The first non-indigenous group to set foot in the area was the party of explorer Gaspar de Portolà in 1769.

The Spanish colonization that followed saw the forced relocation and exposure to Old World diseases, leading to the rapid collapse of the Tongva population because of high mortality from the diseases.

In 1821, Mexico gained its independence from Spain, which included California as a Mexican territory. In 1822, the land, that is Santa Monica today, passed from Spanish rule to the Mexican Republic and came under private ownership. Californios, primarily descendants of the Spanish, ruled the Californian territory until the Mexican–American War. US government sovereignty in California began in 1848.

The potential for developing recreational amenities along Santa Monica's naturally beautiful coast and bluffs was evident to its early founders when the City began to take shape in 1875. Starting with camping facilities and small concessions, early entrepreneurs created a lively beach atmosphere with hotels, a boardwalk full of attractions and multiple piers. The environment of the Santa Monica State Beach inspired technological innovations such as a rollercoaster people-mover from hotel to shore; the Camera Obscura and an electric trolley that shuttled people along the boardwalk to Venice.

Figure 2: State Lands Commission Grant Map

Streetcar connections from Downtown Los Angeles played a pivotal role in the popularity of the Santa Monica State Beach, providing reliable access for many in the region. An extensive roadway system developed to accommodate growing automobile use, and the opening of the Santa Monica Freeway, connecting with PCH through the McClure Tunnel, opened up new avenues for the increasing carowning population to enjoy a day at the beach.

In 1917, the State of California granted the City of Santa Monica the tidelands and submerged lands, situated below the line of mean high tide of the Pacific ocean. By then, Santa Monica was well established as a cultural destination, with lively beachside businesses and pier attractions.

Figure 3: Marina Del Rey North Jetty, Pelican Rock

While piers, hotels and activities have come, gone and returned again, Santa Monica's place as a destination to enjoy the beach and ocean has endured for nearly 150 years, with a focus on welcoming the public. From its early days, decisions to maintain the beach for public use, provide a park along the blufftop (Palisades Park), and construct a municipal pier for fishing and strolling set the course for the beach experience of today and for a future that ensures that the beach is shared and enjoyed by all.

What began as a relatively narrow strip of sand was engineered to become the wide beach we know today through receiving sand from the dredging of Marina del Rey, the construction of jetties and breakwaters, and other sand nourishment projects, growing over a century of human activity. The publicly-owned shoreline and sandy beach comprises approximately 175 acres.[6]

RECREATION & PUBLIC ACCESS

The Santa Monica coast, particularly Santa Monica State Beach, plays an important role in providing coastal recreation for the greater Los Angeles metropolitan region despite its relatively small size. Santa Monica Pier alone draws approximately eight million visitors each year from the Los Angeles region and beyond.

[6] City of Santa Monica. "Santa Monica Local Coastal Program Land Use Plan Update". 2018.

Alongside the sandy beaches, Santa Monica offers many attractions that draw locals and visitors alike. Santa Monica Pier and Annenberg Community Beach House are publicly owned facilities that offer a variety of free and low-cost recreational facilities as well as concessions, retail uses, public parking and beach safety facilities.

There are several transportation options to reach the Santa Monica coast, including the Interstate 10 Freeway, which connects with the Pacific Coast Highway (PCH or Highway 1) just northeast of the Santa Monica Pier. Several bus lines operated by Metro and the Big Blue Bus offer access to visitors from all over Los Angeles. In 2016, the Metro Expo light rail line was completed, connecting Downtown Los Angeles to Downtown Santa Monica, with the terminus ending just 1,200 feet from the famous Santa Monica Pier sign. The Expo line also features a bicycle path runs alongside the line through West Los Angeles.

Santa Monica sits on the northernmost end of the Marvin Braude Beach Trail, which is used by cyclists to traverse the coast all the way from the southernmost LA County beaches. Pedestrian pathways run along the beach, and hiking trails that allow pedestrians to access viewsheds along the shore.

ENVIRONMENTAL QUALITY

According to the U.S. Fish and Wildlife Service (FWS), there are six threatened or endangered plant and animal species that may occur in Santa Monica's coastal area. These species may exist within sensitive habitats, known as Environmentally Sensitive Habitat Areas, or ESHAs. Of the species listed by FWS as potential resources, only the Western Snowy Plover has a critical habitat that falls within Santa Monica's Coastal Zone boundaries. Therefore, special attention should be paid to preserving the habitat of this species.

The Coastal Zone in Santa Monica is largely urbanized, with little undisturbed natural habitat remaining. Although the city is mostly urban, two natural resource areas remain that provide value to the biological inventory of Santa Monica. These two areas are the Palisades Bluff that lines the eastern edge of PCH north of the Santa Monica Pier, and the wide, sandy beach that stretches the entire length of the City. Additionally, there are pockets of estuarine habitat associated with the storm drain outlets near the ocean.

COASTAL CHARACTERISTICS

The Santa Monica coastline can be broadly divided into two areas: Malibu to Will Rogers, and Santa Monica Bay. The characteristics of these two areas are distinct, and therefore should be treated separately:

Malibu to Will Rogers Beach: The coast from the Malibu border to Will Rogers State Beach is south-facing, backed with steep hillsides, and sand transport from west to east. The coastline is dominated by oceanfront homes and the Pacific Coast Highway (PCH), fronting the mountainous coast, and beaches are narrow to non-existent, especially during high tides. The PCH is the essential coastal transportation and utility corridor; the only alternate route is Highway 101 located north of the Santa Monica Mountain coastal range. Much of the Pacific Palisades consists of narrow pocket beaches backed by various shore protection revetments protecting PCH. The extent of existing revetments shows that this reach has in the past and continues to experience episodic erosion that threatens to undermine PCH.

Santa Monica Bay (Will Rogers State Beach to Redondo Beach): Wider beaches emerge at Will Rogers State Beach and south along the Santa Monica Bay shoreline. Will Rogers State Beach is moderately wide owing to a beach groin stabilization system dating back to the 1960s. The Santa Monica breakwater located just offshore of Santa Monica pier was built in the 1930s as an unsuccessful attempt to create a small craft harbor. However, it did result in a significant increase in beach width and stability, and protected the Santa Monica pier from the worst impacts of sea level rise until recently. It is now mostly submerged under water, and has lost most of its impact. These beaches are very wide, largely due to sand supplied as by-products of coastal construction, including Los Angeles International Airport (LAX), Marina Del Rey, and the Hyperion sewage treatment plant. Inland from the Santa Monica Bay beaches, the backshore is comprised of a mix of developed dunes and short cliffs.[7]

Figure 4: Will Rogers State Beach groins[8]

[7] Terracosta Consulting Group, Inc. and Environmental Science Associates. "Coastal Impacts Planning for the Los Angeles Region: Results from the Local Coastal Program Sea Level Rise Grant Program". University of Southern California Sea Grant Program, 2017.
[8] Google Earth, Accessed 2019.

SEA LEVEL RISE PROJECTIONS

Global sea levels began to increase between the late 19th and early 20th century. Sea levels rose about 0.66 feet between 1700 and 1975, with the majority of that increase occurring during the 20th century. The rate of global SLR began to rapidly increase in the 1990s, when global SLR rates reached almost twice the heights that they had been over the previous century.[9]

Models indicate that Southern California may see between 17 and 66 inches of SLR by the end of this century (Table 2 is replicated below for reference). SLR in the Los Angeles region is expected to match global projections, and even exceed the averages seen in the state of California.

Table 2: Sea Level Rise Projections for Southern California and Santa Monica[10]

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Sea level rise projections for the City of Santa Monica conclude that, owing to the relatively wide and stable existing beaches, troublesome levels of beach retreat are unlikely to occur before 2050 in Santa Monica, even when the high 1.67 meter rise by 2100 trajectory is combined with maximum plausible levels of temporary storm erosion.[11, 12] However, by late this century, and assuming the high SLR scenario of 1.67 m, provided by NRC (2012), beach retreat will be obvious everywhere.

Without strategic planning, this may lead to economic losses due to reduced recreational visitors, and also to occasional flooding of public coastal facilities and related damages. Private shoreline residential and commercial properties are also anticipated to become

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9 US Department of Commerce, and National Oceanic and Atmospheric Administration. "Is Sea Level Rising?" NOAA's National Ocean Service, 27 Oct. 2008. https://oceanservice.noaa.gov/facts/sealevel.html
10 Environmental Science Associates. "Los Angeles County Coastal Hazard Modeling and Vulnerability Assessment: Technical Methods Report." University of Southern California Sea Grant Program, 2016.
11 National Research Council (NRC). "Sea Level Rise for the Coasts of California, Oregon and Washington." 2012.
12 California Coastal Commission (CCC). "Sea Level Rise Policy Guidance." 2015.

vulnerable to the impacts of SLR and the associated coastal hazards. Specific impacts from sea level rise detailed in the Local Coastal Program Land Use Plan Update are summarized below.

COASTAL INUNDATION

In its natural condition, the shoreline of Santa Monica would be quite narrow due to the lack of significant sand sources, high rates of longshore or littoral sand transport, and the natural loss of sand into Dume and Redondo submarine canyons. However, for the past 65 years, the beaches in the central and southern portion of Santa Monica Bay have been artificially nourished with sand to provide wide, stable beaches for residents and visitors and also to create a natural buffer from wave attack. As such, Santa Monica's beaches today are typically 150 to 500 feet wider than what the beach width would be under naturally occurring conditions. Shoreline engineering structures have also been built along various sections of the Santa Monica Bay shoreline in an attempt to retain sand on the beaches, especially where the beaches were artificially nourished.

These structures combined with historic large scale sand nourishment projects have resulted in the popular wide and stable sandy beaches along the shoreline.

Figure 5: Heidi-Renee dredge scooping sand at the mouth of Marina del Rey's main channel[13]

As the level of the Pacific Ocean continues to rise, areas that would have formerly only been temporarily flooded or submerged, such as during very high 'King' tides or El Niño conditions, will gradually begin to be submerged or inundated permanently. Over the mid-term (i.e., SLR of 6 inches to 24 inches or 15 to 61 cm), the Santa Monica sandy beach area towards PCH is expected to see moderate inundation levels. Some areas have been flooded in the past during severe storms or El Niño events, and research indicates that this will become an occurrence of increasing frequency. Monthly tidal flooding will reach many of the areas previously exposed only to short-term inundation.

Over the long term (i.e., SLR of 16 inches to 66 inches or 41 to 167 cm, with a possibility of a 113 inch or 287 cm extreme scenario), the coastal inundation hazard area is expected to expand further inland, and the mean high tide line would move closer to its location at the turn of the 20th century.

[13] Jamieson, Darrell and JE McAmis. Los Angeles Times, 2017.

Figure 6: Long-Term Coastal Erosion

Figure 7: Long-Term Tidal Flooding

EXTREME WEATHER EVENTS

Extreme events, such as storms and flooding are exacerbated by climate change, and can combine with sea level rise, creating temporarily elevated sea levels beyond the baseline projections. Extreme events combined with SLR may result in exacerbated coastal flooding. Examples of extreme events that might occur along the coast include:

- An individual storm with an intensity at or above the 100-year event;
- A series of large, long-duration storms during high tides;
- A local storm that coincides with the arrival of distant swell and high tides;
- An ARkStorm (Atmospheric River 1000 Storm), a hypothetical but scientifically realistic "megastorm" scenario developed and published by the United States Geological Survey, Multi Hazards Demonstration Project (MHDP).

Some beach areas and parking lots have been flooded in the past during severe storms or El Niño event. Research indicates that this will increase in frequency. Over the long-term, the coastal inundation hazard area is expected to expand further inland, and the mean high tide line would move closer to its location at the turn of the 20th century. If SLR, by the end of the twenty-first century, reaches the high projections of about 55 inches (1.4 m), "coastal managers can anticipate that coastal flooding events of much greater magnitude than those during the 1982-83 El Niño will occur annually".[14]

[14] Bromirski, Peter D., et al. "Dynamical Suppression of Sea Level Rise along the Pacific Coast of North America: Indications for Imminent Acceleration." *Journal of Geophysical Research*, vol. 116, no. C7, 2011.

Figure 8: Storm Event Erosion

Figure 9: 100-Year Storm Flooding

El Niño and La Niña are opposite phases of what is known as the El Niño-Southern Oscillation (ENSO) cycle. The ENSO cycle describes the fluctuations in wind patterns, sea-surface temperatures, and ocean-atmosphere interactions across the Equatorial Pacific. El Niño events are characterized by higher than normal sea surface temperatures in the eastern and central tropical Pacific Ocean, and can result in higher rainfall for the California coast (Wang et al., 1999). La Niña is the opposite of El Niño, and represents periods of below-average sea surface temperatures across the east-central Equatorial Pacific. During El Niño winters, storm tracks often dip further south than their normal track and directly impact Southern California with more frequent storms, increased chances of heavy rainfall and higher wave heights with accompanying floods, landslides, and coastal erosion. Strong El Niño winters with enhanced storm conditions occurred in 1982−1983, 1997−1998, and 2015−2016.

SALTWATER INTRUSION & GROUNDWATER INUNDATION

In areas already exposed to some form of saltwater intrusion, sea level rise is likely to exacerbate existing problems and pose new management challenges. Notably, under the 2014 Sustainable Groundwater Management Act (SGMA), management agencies are explicitly required to regulate groundwater pumping in order to avoid future saltwater intrusion and associated water quality degradation in freshwater aquifers. As sea levels rises, the minimum freshwater elevation required to resist saltwater intrusion will also increase, which could require agencies to impose new limitations on pumping and may impose other constraints in the Coastal Zone. Saltwater intrusion also has the potential to act as a corrosive force on underground utility lines or other coastal utility infrastructure.

Groundwater or subsurface inundation is an emerging area of concern in coastal hazard assessments. In many coastal areas, freshwater occurs in a lens which floats on the denser saltwater within the aquifer. Rising sea levels will cause the saltwater-freshwater contact to rise, pushing the freshwater table upwards. This phenomenon could cause increased inundation in some low-lying coastal regions.

Given Santa Monica's proximity to the coast, saltwater intrusion is an ongoing concern. If the City were to over-pump from wells, it is possible to reverse the natural water flow and actually pull seawater from the ocean into the local groundwater supply. Seawater intrusion can also occur due to climate change or well-drilling near salt water sources. Experts have concluded that Lincoln Boulevard is the boundary for any potential saltwater intrusion and therefore the western edge of the City's underground water supply. As the level of the Pacific Ocean rises, the City should reevaluate this boundary and the potential impacts of saltwater intrusion.

To address these concerns, Santa Monica launched the Sustainable Water Infrastructure Project (SWIP)[15] in the summer of 2018, an innovative water infrastructure project that will capture rainwater flowing from downtown and divert it to a 1.6-million-gallon cistern adjacent to the Pier. Salty groundwater near the cistern is mixed with the rainwater, treated at the existing Santa Monica Urban Runoff Recycling Facility (SMURRF), and distributed for irrigation and toilet flushing in a purple pipe system for non-potable uses. This project will allow the city to harvest up to 4.5 million gallons of stormwater from any single storm event for treatment and permitted reuse, building resilience toward climate change-induced extreme weather events. It will also help the city work toward water self-sufficiency and prevent water pollution.

EVALUATION OF IMPACTS

The TerraCosta Consulting Group (TCG) and the Environmental Science Associates (ESA) produced models of shoreline change, coastal erosion and coastal retreat under projected future climate scenarios for the Los Angeles County coast. These projects were synthesized and mapped onto the coastline, using the California Coastal Commission sea level rise policy guidance for "projection" and "high" trajectories, and supplemented with an "extreme" scenario from Cayan et al. (2016). This assessment utilizes the 1.67 m by 2100 projections to evaluate the vulnerability of infrastructure and coastal damages.

Table 3: Sea Level Rise Relative to 2000

	Sea Level Rise Relative to 2000 (in meters)		
Year	**0.930 m (3 ft)**	**1.67 m (5.5 ft)**	**2.88 m (9.4 ft)**
2030	0.150	0.300	0.178
2050	0.290	0.610	0.519
2100	0.930	1.67	2.88

15 City of Santa Monica Department of Planning and Community Development. "Sustainable Water Infrastructure Project," 2017. https://www.smgov.net/Departments/PCD/Environmental-Reports/Sustainable-Water-Infrastructure-Project/

ESA developed a suite of products that provide coastal hazard assessments for a 65-mile stretch of the Los Angeles coastline. The ESA analysis included hazard zone components defined below:[16]

1. **Sandy Shoreline Erosion Hazard Zones:** These zones represent future long-term and storm-induced sandy "dune" and beach shoreline erosion hazard zones. Model results incorporate site-specific historic trends in erosion, additional erosion caused by accelerating sea level rise, and (in the case of the "storm erosion hazard zones") the potential erosion impact of a large storm wave event.
2. **Coastal Storm Flood Hazard Zones:** These hazard zones depict flooding that may be caused by a coastal storm and considers a suite of coastal processes, with these processes exacerbated by future sea level rise.
3. **Extreme Monthly Tidal Flooding Hazard Zones:** These zones show the area and depth of flooding caused by the effect of rising sea level on the astronomic tides (not considering storms, erosion, or river discharge). The water level mapped in these flooding areas is the Extreme Monthly High Water (EMHW) level, which is a high water level that is occurs approximately once a month.

The study detailed the impacts of long-term coastal erosion, tidal flooding, and storms and extreme events. These scenarios were modeled for this report for the years 2030, 2050 and 2100, in order to create an inventory of resources and facilities vulnerable under each. These four hazards, in order of decreasing severity:

1. Long-term erosion: Areas subject to long-term shoreline erosion would be lost entirely.
2. Tidal flooding: This comes from the extreme monthly high water analysis. Areas experiencing long-term tidal flooding would be regularly flooded by monthly high tides.
3. Storm event: This combines shoreline erosion with standard deviations and wave run-up areas to account for a single storm event's erosion. Areas experiencing storm or event erosion are likely damaged but could be recoverable.
4. 100-year storm event: This combines the 100-year tide, wave run-up areas, bar built estuaries, and long-term erosion of shorelines and cliffs. Areas experiencing storm or event flooding are likely to return to service when floodwaters recede.

Predictions for long-term coastal retreat are 10 m, 30 m, and 90 m respectively for 2030, 2050 and 2100. Projected beach retreat is largest for both scenarios in the southern part of the study area, peaking below Santa Monica. When combined with wave-driven storm erosion, the maximum beach retreat during storm episodes reaches about 125 m. The maximum wave heights, combining the high scenario for SLR in 2100 with storm surges, could reach up to 3.5 m, while corresponding shoreline retreat would reach 35 - 40 m.

[16] Terracosta Consulting Group, Inc. and Environmental Science Associates. "Coastal Impacts Planning for the Los Angeles Region: Results from the Local Coastal Program Sea Level Rise Grant Program". University of Southern California Sea Grant Program, 2017.

The main findings were as follows:

- Owing to the relatively wide and stable existing beaches, model results suggest that troublesome levels of beach retreat are unlikely to occur before 2050 in Santa Monica, even when the 1.67 m rise by 2100 trajectory is combined with maximum plausible levels of temporary storm erosion.
- By late this century, and assuming the 1.67 m sea level rise scenario, beach retreat will be obvious everywhere in the modelled region. This will lead to economic losses due to reduced beach width for recreation, but also to more frequent and more severe coastal facilities flooding and related damages that will vary by geographic region.
- Even if flood management addresses coastal flood hazards in these low-lying areas, they will also be subject to greater flood risk from the impaired capacity of stormwater and groundwater to drain to the ocean.
- Beach erosion, described above, will enable both monthly high tides and wave runup to progress further inland.

INVENTORY OF VULNERABLE RESOURCES

Santa Monica's beaches are highly valuable as a local economic engine and cultural hub, providing access to recreation for tourists, visitors and residents. Santa Monica's beaches are equipped with several public amenities, including restrooms, bicycle and pedestrian pathways, and the Annenberg Community Beach House.

The beaches also serve as a natural habitat within a larger regional ecosystem, including sandy beaches and salty wetlands. These ecosystem services are the many benefits that humans gain from the natural environment and from properly-functioning ecosystems. Beaches and wetlands provide a natural buffer against increased wave heights and water volume, and act as barriers against stormwater intrusion. They also provide a habitat for coastal flora and fauna, preserving the biodiversity of the coastline. To assist in decision making, ecosystem services are often given economic values. Without any adaptation measures, sea level rise and consequent erosion will reduce the value of services provided by various natural ecosystems.

Understanding the cost of the various manmade and natural assets, resources and values, requires determining their vulnerability under the multiple sea level rise scenarios and coastal hazards. This report will assign values to the ecosystem services provided by sandy beaches and salty wetlands in order to quantify their loss and compare across adaptation scenarios. However, it should be noted that these values are challenging to assess, with no established industry standard or methodology.

An inventory of vulnerable properties and assets was created by intersecting the analysis from the vulnerability assessment with Citywide GIS data and the LA County Tax Assessor database. Using this approach, total area of the beach and coastal ecosystems vulnerable could also be assessed under each scenario. Beach sand impacts were not measured for 100-year storm events, as beach vulnerability to these events is not of concern.

Table 3 below estimates the extent of area and infrastructure that would be vulnerable under the various scenarios and coastal events.

Table 4: Inventory of Vulnerable Resources[17]

	Long Term Erosion			Storm Event			Tidal Flooding			100 Year Storm Event		
Resource	**2030**	**2050**	**2100**	**2030**	**2050**	**2100**	**2030**	**2050**	**2100**	**2030**	**2050**	**2100**
Sandy beach area (acres)	59	78	128	154	194	231	13	30	93	--	--	--
Salty wetlands (acres)	1	1	1	1	1	1	1	1	1	--	--	--
Roadways (feet)	0	0	0	0	0	0	0	0	0	0	0	1150
Bikeways (feet)	0	0	123	0	0	710	0	80	2,758	1,857	10,927	16,540
Streetlights (count)	0	0	0	0	0	0	0	0	0	15	88	179
Storm Main (feet)	0	0	85	0	45	480	230	273	1,870	700	2,446	5,040
Storm Drains (count)	0	0	0	0	0	0	0	0	5	2	5	9
Sewage Main (feet)	0	0	0	0	0	0	0	0	0	0	115	2,270
Parking Lots (area in ft^2)	0	0	0	0	0	0	0	0	145,687	15,438	316,547	979,278
Water Main (feet)	0	0	0	0	0	120	0	0	38	157	312	6,360
Wifi Terminals (count)	0	0	0	0	0	0	0	0	0	0	0	1
Public Restrooms (count)	0	0	0	0	0	0	0	0	0	2	3	5
Public Buildings (count)	0	0	0	0	0	0	0	0	0	0	0	1
Parcels (count)	0	0	7	1	5	13	1	1	14	33	40	144

17 Mank, Justin. City of Santa Monica GIS Analysis, 2019.

The analysis yielded the following conclusions:

- Starting in 2050 (0.61 meters SLR), there will be frequent flooding of public facilities along the coastline, primarily transportation infrastructure, including bicycle paths and the northern portion of the Pacific Coast Highway.
- Erosion will threaten stormwater and wastewater lines starting in 2030 (0.30 meters SLR), creating a potential for saltwater intrusion and exacerbating precipitation-induced flooding.
- 100-year storm events, which will occur with increasing frequency due to climate change, could already threaten private residential and commercial infrastructure, pier facilities and historic buildings along the coastline.

FINANCIAL COSTS OF VULNERABLE INFRASTRUCTURE

In order to conduct a cost-benefit analysis of various adaptation pathways, it was necessary to determine the costs associated with the loss of infrastructure and services under each scenario. The financial costs associated with the loss or damage of vulnerable infrastructure were calculated based on replacement cost and/or the value of services provided.

The Local Coastal Program Land Use Plan determined the anticipated lifespan of developments in the coastal zone for the purpose of identifying the appropriate sea level rise scenarios to evaluate. These lifespans can inform strategies used to protect these structures. Developments fall into the following categories:

a. Temporary structures, movable or expendable construction (e.g., California coastal trail, bike racks, paved areas, shoreline playgrounds): up to 5 years
b. Ancillary development or amenity structures (e.g. parking structures, shoreline restrooms): 25 years
c. Residential or commercial structures: 75-100 years
d. Critical infrastructure:
    - Asphalt roadways – 25-50 years
    - Concrete pavement – 50-75 years
    - Bridges – 75 years
    - Water mains – 100 years
    - Storm drains – 100 years
    - Electrical and gas – 100 years

The vulnerable infrastructure within each of these categories, risks associated with the impacts of sea level rise, and the financial costs due to those risks are detailed below. Temporary structures were not included in the analysis, as the costs to relocate, demolish or replace these structures was considered negligible. We also added a category for ecological and recreational non-market amenities, including beach tourism and environmental services.

ANCILLARY DEVELOPMENT:

Although there are several structures vulnerable to flooding, few will be impacted by long-term erosion. Because most ancillary structures are either resilient to flooding or easy to relocate, they are not a high priority for protection from and adaptation against sea level rise.

- **Beach parking lots** are vulnerable to 100-year storm events, and will be vulnerable to long-term tidal flooding in 2100. These lots are entirely constructed with asphalt and concrete and contain drainage systems, therefore flooding is not a major concern. However, added clean-up costs from monthly flooding may need to be taken into consideration.
- Coastal **bicycle pathways** are vulnerable to erosion and monthly flooding starting in 2050. Bicycle pathways are concrete structures with drainage pathways, and will therefore require little attention during flooding. The portions of the pathway vulnerable to erosion will need consideration. These portions can be rerouted eastward, or adaptively redesign can be utilized to block sea level rise, create more permeable pathways, or create channels to drain water into alongside pathways.
- **Public restrooms** on the beach are vulnerable to 100-year-storm flooding starting in 2030. Restrooms have built-in drainage and are constructed from concrete, therefore they are at low risk from flooding.
- The **Annenberg Beach House and Community Center** is vulnerable to 100-year-storm flooding starting in 2100. This structure is important to the residential and tourist community in Santa Monica, and hosts events throughout the year. A more detailed vulnerability assessment of this historic building is recommended to determine how best to protect it from flood damage and breaks in operations.
- One **wifi terminal** is vulnerable to a 100-year storm event in 2100. This terminal should be relatively easy to relocate, and is therefore not a major concern.
- Several **streetlights** are vulnerable to 100-year storm events. However, these will likely endure little to no damage from short-term inundation.

RESIDENTIAL AND COMMERCIAL STRUCTURES:

There are very few residential and commercial structures vulnerable to sea level rise, and most of those are only in the path of extreme weather events and flooding several decades in the future. Additionally, due to high property values along the Santa Monica coast, there are few socially vulnerable populations represented in this group. Therefore, these properties were cited as low priorities for public protection and adaptation measures. Educational campaigns, outreach and land use policies to limit development are suggested as priority adaptation strategies for these structures.

- **Pier businesses** on the pier are at risk from onshore flooding from 100-year storms, as well as potential damages to the pier structure. The lowest-lying portion of the pier is elevated to 4.9 m (more than the maximum predicted wave heights of 3.5 m), and is therefore not vulnerable to increased wave heights. However, a winter storm surge could still do considerable damage to the structural integrity of the pier itself.
- Some **residential homes** are vulnerable to flooding from extreme storms and monthly tidal events under high SLR. Private homes should be a priority for educational campaigns on flood-proofing, elevation and flood insurance. These measures can prevent the worst costs of future flood damage, which can cost up to half of a building's market value, though the average homeowner pays significantly less.[18]
- Some **coastal businesses**, including hotels, are vulnerable to flooding from extreme storms and monthly tidal events. These can also be flood-proofed or elevated, though both measures would be significantly costlier. Limitations on coastal development of private properties and awareness campaigns regarding options for private homes and businesses along the coast could be a component of long-term adaptation programming.

Values for residential and commercial properties were taken from the Los Angeles County Property Tax Assessor database. These values are likely to be large underestimates of the current values of coastal properties. Due to Prop 13, properties are reassessed only when they change ownership (barring sale, annual value increase capped at 2% to adjust for inflation). Coastal properties, due to higher market values and demand in Santa Monica, have appreciated at significantly higher rates. However, the estimate was deemed acceptable for this analysis, as outright purchase of coastal property was cited as a low-priority option by city staff, and therefore a detailed cost-benefit analysis of this option was not needed.

CRITICAL INFRASTRUCTURE:

Roadways, pipelines, catch basins and existing coastal protection are critical to the City. It is recommended that these are prioritized for protection from and adaptation to the impacts of sea level rise. Damage to critical infrastructure could have severe impacts on the public health, safety, and livelihood of residents, employees and visitors in Santa Monica.

- **Roadways:** Low-lying stretches of the PCH are vulnerable to long-term tidal flooding and storm events. Although roads have drainage systems built in, road damages and clean-up costs can be substantial. Additionally, the northern portion of the PCH

[18] Federal Emergency Management Association. "Policy & Claim Statistics for Flood Insurance." United States Department of Homeland Security, 2019.

bordering Malibu is vulnerable to cliff erosion. Even temporary loss of this roadway could cause cross-cutting impacts to commuter traffic and emergency routes into and out of Santa Monica.

- **Buried pipelines** are vulnerable to several sea level rise scenarios. These lines can be impacted by flooding, saltwater intrusion, and rising groundwater levels. If not properly protected, pipelines can corrode from exposure to salt water. Prolonged inundation could even cause unweighted lines to float. Rising groundwater can increase the susceptibility of soils around the pipeline to liquefaction, potentially leading to damage and deformation. All of these factors can cause service disruptions, and is a cause for concern for public health and safety.[19]
- **Water lines** are vulnerable only to 100-year storm events until 2100, but in 2100 become vulnerable to all sea level rise-induced events. **Catch basins** are vulnerable to 100-year storm events, and **stormwater lines** are vulnerable to tidal flooding by 2030 and storms starting in 2050. **Wastewater lines** are vulnerable only to 100-year storm events starting in 2050. Water, stormwater and wastewater lines are critical to the functioning of the City, and should be carefully evaluated for vulnerability. Protection, weighing and relocation of these lines are potential measures to combat the impacts of sea level rise.[20]
- Installed in the 1930s, the **Santa Monica breakwater** today is almost completely submerged, and no longer provides much protection against the impacts of sea level rise. Repair and replacement of the breakwater would be costly, but would provide added protection to all critical infrastructure listed here.

Figure 10: Santa Monica breakwater, 1936

[19] San Francisco Bay Conservation and Development Commission. "Adapting to Rising Tides: Energy, Pipelines and Telecommunications," 2019. Accessed 2019. http://www.adaptingtorisingtides.org/portfolio/energy-infrastructure-and-pipelines/

[20] San Francisco Bay Conservation and Development Commission. "Adapting to Rising Tides: Energy, Pipelines and Telecommunications," 2019. Accessed 2019. http://www.adaptingtorisingtides.org/portfolio/energy-infrastructure-and-pipelines/

ECOLOGICAL AND RECREATIONAL AMENITIES:

There is a high level of uncertainty in the changes to visitation levels from beach visitation due to sea level rise. According to a study on the economic impacts of climate change on Southern California beaches, one result of sea level rise and beach erosion is that visitors will tend to substitute already small beaches that have eroded further for beaches that remain large. For example, Newport, Huntington City, and Manhattan beaches will have even higher levels of attendance with sea level rise, while visits to other popular beaches like Huntington State, Venice, and Santa Monica beaches are not expected to differ substantially. Other, relatively small beaches show lower levels of attendance with sea level rise.[21]

The uncertainty in the changes to beach attendance makes it difficult to evaluate potential impacts to tourism revenue and the market value of beach recreation. Therefore, this study calculates a total value for ecosystem services and beach recreation (using non-market valuations), but does not attempt to theorize the impact of narrowing beaches on market values.

- Several acres of beach ecosystems could be impacted due to sea level rise, threatening flora and fauna that live along the coast. Migration patterns could be disrupted by sea level rise. **Ecosystem services from sandy beaches** include biodiversity and habitats provided by beaches. **Ecosystem services from salty wetlands** include flood protection benefits, habitat and refugia provision, primary production and water cycling.[22]
- **Non-market recreational value** from beaches was estimated based on impacts to public access and recreation from lost beach acreage. The costs of impacts to these are much greater than the cost of replacement of the infrastructure alone, and this should be taken into consideration when deciding on adaptation strategies and pathways. All recreational and ecosystem service values were calculated on an annual basis, and were later aggregated based on the number of years for which financial costs were being evaluated.

The total value of vulnerable public assets was estimated as $74,306,737, and the total estimated annual non-market value of lost beach width was $11,112,314. A table showcasing the per-unit value for each asset evaluated within this report is below. Other costs, such as revenue from tourism and/or beach concessions, was not included in the analysis, as beach tourism is not expected to change due to sea level rise.

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21 Pendleton, Linwood, et al. "Estimating the Potential Economic Impacts of Climate Change on Southern California Beaches." *Climatic Change*, vol. 109, no. S1, 2011.

22 Costanza, R., Wilson, M., Troy, A., Voinov, A., Liu, S., and D'Agostino, J. "The Value of New Jersey's Ecosystem Services and Natural Capital". Gund Institute for Ecological Economics, 2006.

Table 5: Per-unit Values for Estimating Vulnerable Assets (2019 $)

VULNERABLE ASSET	UNIT	VALUE	SOURCE
Beach recreational value[23]	acre/yr	$16,946	Journal of Marine Policy
Sandy beach ecosystem services[24]	acre/yr	$31,131	Journal of Marine Policy
Salty wetlands ecosystem services	acre/yr	$6,527	Nature Journal
Roadway	ft	$280	Santa Clara County Climate Adaptation Guidebook
Bikeway	ft	$123	Santa Clara County Climate Adaptation Guidebook
Streetlights	unit	$6,250	City of Santa Monica Department of Public Works
Water main	ft	$610	City of Santa Cruz AB 691 Sea Level Rise Assessment
Sewage main	ft	$400	City of Santa Cruz AB 691 Sea Level Rise Assessment
Storm main	ft	$600	City of Santa Cruz AB 691 Sea Level Rise Assessment
Storm drains	unit	$3,240	City of Goleta Coastal Hazards Vulnerability and Fiscal Impacts
Private Buildings	total	$115,111,607	Los Angeles County Property Tax Assessor
Public Buildings	total	$28,827,883	City of Santa Monica Department of Public Works
Parking lots	ft^2	$30	California Department of Boating and Waterways
Public restrooms	unit	$956,566	City of Santa Monica Department of Public Works

23 Beach recreational valuation methodologies and values differ substantially across studies, though most valuate beach days. Because tourism numbers are not expected to change dramatically in Santa Monica, this report referenced only studies which valued beach width. Values were fairly similar across the few papers that exist using beach width as a metric, so this report used the most recent available.

24 Beach ecosystem valuation methodologies also differ, from $1,619 (King et. al., California Department of Boating and Waterways) to $31,131 (Raheem et. al., Journal of Marine Policy). This report used a measure from the Raheem et. al. paper, so as to be consistent with the recreational valuation.

OTHER COSTS

The economic value of beaches from tourism and market revenue was also not included in the total cost of any adaptation pathway, as beach visitation is not predicted to decrease significantly. The total value of tourism within the City is shown below.

Table 6: Coastal Revenue (2017)[25]

Category	Total Revenue
Business Revenue	
Tourism revenue (total)[26]	$1,963,046,718
City Revenue	
Beach expenditure[27,28]	($751,636)
Visitor retail sales tax revenue	$12,176,830
Hotel tax revenue to city	$54,353,740
Total Public Revenue	**$65,778,934**

25 City of Santa Monica. "Santa Monica 2017 Summary Tourism Economic & Fiscal Impacts, Visitor Profile".
26 This number includes money spent on lodging, meals and beverages, shopping, activities, transportation, groceries, etc.
27 This represents the total revenue over expenditures from beach operations, maintenance, permits, concessions, parking fees, etc. It is negative, as expenditures exceeded revenues in 2018.
28 City of Santa Monica. Granted Public Trust Lands: Annual Financial Statement, 2018. State Lands Commission.

ADAPTATION PATHWAYS & COSTS

There are three main adaptation pathways that cities can pursue in response to sea level rise: retreat, accommodation, or protection.

1. **Managed Retreat** allows the ocean to reclaim land. It involves the demolition and relocation of vulnerable infrastructure and buildings. New development along the coast would be limited to necessary public good. Private property could also be purchased and converted to public uses.
2. **Accommodation** refers to the transformation of infrastructure in its current place to be able to withstand increased sea levels. Design guidelines would be revised and vulnerable infrastructure would be made resilient through elevation, floating, and/or flood-proofing to withstand flooding.
3. **Protection** refers to sea level rise being stopped, so that vulnerable buildings and infrastructure can remain in their current state. Protection can be "soft" or "hard". "Soft" protection includes living shorelines. "Hard" protection involves levees and other man-made devices to halt SLR.

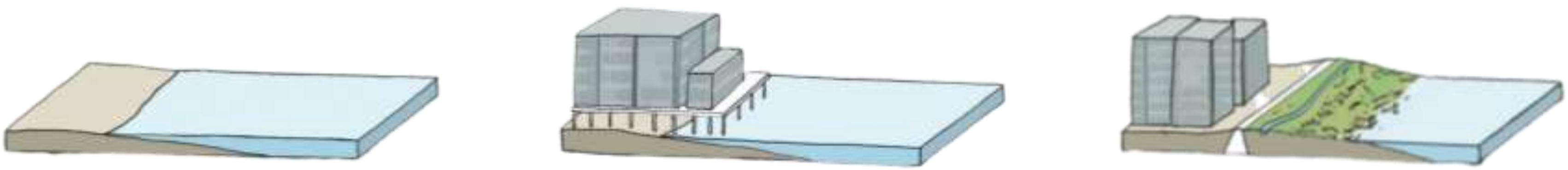

Figure 11: Adaptation Pathways[29]

In order to fully evaluate each adaptation pathway, we conducted a financial analysis of five possible adaptation scenarios: the four mentioned above (retreat, accommodation, soft protection and hard protection) and a baseline measure of doing nothing. Ultimately, the City may need to combine multiple strategies in order to combat sea level rise, as there is no one pathway that will suffice on its own. The pathways outlined here are intended as guidance in order to prioritize strategies. Most strategies outlined and analyzed in this report were pulled from either the Local Coastal Program Land Use Plan or the Climate Action and Adaptation Plan. Strategies that were taken from other studies and reports are cited as such. Per unit costs for each adaptation strategy used in the analysis are shown below.

[29] Underwood, Emily. "Four Ways to Guard Against Sea Level Rise". San Francisco Public Press, 2015.

Table 7: Per-unit Costs of Adaptation Strategies (2019 $)

ADAPTATION STRATEGY	UNIT	COST	SOURCE
Beach nourishment	yd^3	$15	Annals of the New York Academy of Sciences[30]
Dune restoration	acre	$70,000	Bay Foundation Pilot Study, Santa Monica[31]
Flood damage clean up	total	$2,500,000	City of Goleta Coastal Hazards Vulnerability and Fiscal Impact[32]
Elevate buildings	unit	$140,000	Annals of the New York Academy of Sciences
Dry-proof buildings	unit	$10,320	Annals of the New York Academy of Sciences
Wet-proof buildings	unit	$25,000	Annals of the New York Academy of Sciences
Purchase damaged private property	total	$20,325,986	LA County Property Tax Assessor
Increase stormwater pump capacity	unit	$200,000	Annals of the New York Academy of Sciences
Build SWIP treatment plant[33]	total	$65,000,000	Santa Monica Civil Engineering Division
Remove roadway or bikeway	ft^2	$4	City of Imperial Beach Sea Level Rise Assessment
Remove pipeline	ft^2	$20	City of Imperial Beach Sea Level Rise Assessment
Replace roadway	ft	$280	City of Santa Cruz AB 691 Sea Level Rise Assessment
Replace bikeway	ft	$123	City of Santa Cruz AB 691 Sea Level Rise Assessment
Replace stormwater pipeline	ft	$600	City of Santa Cruz AB 691 Sea Level Rise Assessment
Replace water pipeline	ft	$610	City of Santa Cruz AB 691 Sea Level Rise Assessment
Replace wastewater pipeline	ft	$400	City of Santa Cruz AB 691 Sea Level Rise Assessment

30 Total costs from this study were recalculated using 1.67 m sea level rise projections.
31 This cost is based on the pilot dune restoration project carried out by the Bay Foundation in Santa Monica. It accounts for primarily passive dune restoration techniques, and actual costs may reach as high as $200,000/acre.
32 The City of Goleta estimated that cleanup costs from one storm flood event can cost between $0.5 million and $4.5 million (based on significant flood events in 1998 and 2005), depending on the storm intensity, duration, flood depths, and flood extents. An average of $2.5 million was used here.
33 This is an estimate from the City's Sustainable Groundwater Management effort.

Harden pier[34]	total	$45,000,000	Santa Monica Civil Engineering Division
Install jetties	unit	$800,000	Annals of the New York Academy of Sciences
Install dike under beach	total	$45,000,000	Annals of the New York Academy of Sciences
Replace Santa Monica breakwater	total	$3,000,000	Annals of the New York Academy of Sciences
Install groins	unit	$800,000	Annals of the New York Academy of Sciences

BASELINE: NO ACTION

Total Cost (2100) in damages, property loss and loss of non-market services: $847,520,151

In order to establish a baseline and compare strategies, the social and financial repercussions of doing nothing must be evaluated. In this scenario, the City takes no proactive action to mitigate or adapt to the impacts of sea level rise, and portions of the beaches are submerged temporarily by coastal events, including key public infrastructure, private buildings, and several acres of beaches. The costs were estimated as:

- the value of all infrastructure and land that is submerged;
- the cost to replace needed assets, including water and wastewater pipelines, catch basins, and roadways; and
- flood clean-up costs for public and private infrastructure.
- Non-market values of lost beach, and recreational and tourist revenue are also calculated into the total cost of this scenario.

There are several potential public health and safety dangers from this pathway, including saltwater intrusion into the drinking water supply, blockage of groundwater pipelines, and disruption of service to residents. Unmitigated flooding may also create road blockage and congestion, which would be exacerbated by the flooding of parking lots.

The value of infrastructure was estimated as its total replacement cost. Infrastructure or services that were only vulnerable to short-term inundation from 100-year storms were not considered in the costs for that scenario. The costs from no action are itemized below, with amounts reflecting the unit length, area or number of each asset that is vulnerable to severe damage or loss from erosion or long-term inundation.

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34 In 2014, the City removed and replaced about 13,000 ft^2 of the timber piles on the Pier for about $8 million. The remaining area is about 3 times as large. After adjusting for escalation of about 4%/year over 5 years and adding in leeway for complications due to existing buildings in this area, an estimate of $45 million was reached.

Table 8: No Action Pathway Costs (Damages or Property Loss in 2019 $)

	2030		2050		2100	
Strategy	Amount	Cost	Amount	Cost	Amount	Cost
Public Losses						
Bikeway	0 ft	$0	80 ft	$9,848	2,758 ft	$339,527
Water main	0 ft	$0	0 ft	$0	120 ft	$73,200
Storm main	230 ft	$138,000	273 ft	$163,800	1,870 ft	$1,122,000
Parking lots	0 ft^2	$0	0 ft^2	$0	145,687 ft^2	$4,370,610
Flood clean-up costs	Estimate	$2,500,000	Estimate	$2,500,000	Estimate	$2,500,000
TOTAL COST		**$2,638,000**		**$2,673,648**		**$8,405,337**
Private Losses						
Parcels land value	1 parcel	$0	5 parcels	$0	14 parcels	$15,187,438
Private property	0 buildings	$0	0 buildings	$0	12 buildings	$5,138,548
Clean-up costs	0 buildings	$0	0 buildings	$0	12 buildings	$2,399,978
TOTAL COST		**$0**		**$0**		**$22,725,964**
Non-market Annual Losses						
Recreational value	154 acres	$26,096,840	194 acres	$91,847,320	231 acres	$287,573,620
Ecosystem services	154 acres	$48,007,010	194 acres	$168,925,830	231 acres	$528,815,230
TOTAL COST		**$74,103,850**		**$260,773,150**		**$816,388,850**

The total estimated direct public cost from the "No Action" scenario in 2100 would be $8,405,337, with an additional $22,725,964 in private costs.

There are several additional costs that are not directly borne by the City, including the values of recreational and ecosystem services provided by beaches. The non-market recreational value of lost beach width was calculated to be $3,914,526 annually. This represents the recreational value of lost beach width due to long-term and storm erosion, and far outpaces all other financial impacts of sea level rise. The annual value of ecosystem services from lost sandy beaches was estimated as $7,191,261, and the annual value from lost salty wetlands was estimated as $6,257. This totalled to $816,388,850 over the course of 80 years until 2100.

Private property owners impacted by sea level rise would bear some costs of flood clean up if buildings remain maladapted to inundation. The average flood insurance payout for repair costs to a residential home is $7,500, but costs can run as high as half of the market value of the property. An estimate of $4.50 per square foot is the estimated cost to dry out a home, given that there is no substantial damage from flooding.[35] There are a total of 12 private buildings that might be impacted by tidal flooding and 89 by 100-year storm. The total costs for flood clean-up for private property owners in 2100 is estimated to be $1,732,478, with an additional $667,500 in damages.

MANAGED RETREAT

Total Costs in implementation, damages, property loss and loss of non-market services (2100): $845,327,829

The Local Coastal Program Land Use Plan outlines several measures to adapt to sea level rise, prioritizing soft measures and managed retreat. The plan emphasizes the need to preserve the ecological benefits that the coastal zone provides.

Limit new shoreline development.

- Ensure that new development minimize risks to life and property and assures stability and structural integrity in hazardous areas.
- Do not approve new development in hazardous areas unless such development has been sited and designed to avoid coastal hazards and impacts and take into account adaptive management strategies for sea level rise.
- Permit temporary structures with a specific expiration date by which they must be removed.
- In the mid-term, limit new development on properties that have experienced damage to more than 30% of the existing structures or have been partially or wholly exposed to continuous storm flooding for a tide cycle (6 hours) more than 1 time a year for a 3-year period to small, easily-movable structures (excluding shoreline protective devices) built at low densities.

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[35] HomeAdvisor. "How Much Does It Cost To Repair & Cleanup Water Damage?" Accessed 2019. https://www.homeadvisor.com/cost/disaster-recovery/repair-water-damage/

Regulate vulnerable infrastructure.

- When the structural components of existing, lawfully constructed structures are damaged by more than 30%, due to coastal hazards, or continuously exposed to storm flooding for a tide cycle more than 1 time a year for a 3-year consecutive period, or meets the FEMA definition for repetitive loss, then that existing development becomes legally non-conforming.
- Establish a Rolling Easements Program that would accomplish the following:
  - Require the removal of existing structures once the land they are located upon is flooded on a regular basis at high tide and comes to encroach on public lands due to erosion;
  - Require the removal of existing shoreline protective devices when they are proven to interfere with public access or the biological productivity of marine or shoreline areas, as demonstrated by beach width monitoring data.
- Establish a Development Impact Fee Program for properties located in hazardous areas. Use the sum collected to finance activities and programs that address sea level rise.

Demolish and relocate public buildings and critical infrastructure.

- Demolish and relocate all water, wastewater and stormwater lines vulnerable to long-term coastal erosion, in order to protect them from seawater intrusion.
- To maximize public coastal access, relocate City-owned or maintained visitor-serving facilities further inland. There are no public buildings currently located in the path of long-term erosion or inundation, but the City can re-evaluate with changing shorelines and models.
- Whenever beach parking lots are removed, restore sandy beach area for public use.[36]

Relocate bicycle pathways.

- In the event of damage to the trail, relocate the trail landward.

Purchase vulnerable private property and convert it to public use.

- In the long term, develop and implement a Coastal Property Purchase Program that would facilitate the purchase of vulnerable or continuously damaged private properties to be converted to public uses.

The costs associated with this pathway are shown below.

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[36] It is likely that parking lots will be converted to other uses far earlier, as parking demand is projected to decrease significantly over the next 10 years.

Table 9: Managed Retreat Pathway (2019 $)

	2030		2050		2100	
Strategy	**Amount**	**Cost**	**Amount**	**Cost**	**Amount**	**Cost**
Public Costs						
Demolish bike paths[37]	0 ft	$0	80 ft	$2,560	2,758 ft	$88,256
Relocate bike paths	0 ft	$0	80 ft	$9,848	2,758 ft	$339,527
Demolish water lines	0 ft	$0	0 ft	$0	120 ft	$7,200
Relocate water lines	0 ft	$0	0 ft	$0	120 ft	$73,200
Demolish stormwater lines	230 ft	$13,800	273 ft	$18,940	1,870 ft	$112,200
Relocate stormwater lines	230 ft	$138,000	273 ft	$163,800	1,870 ft	$1,122,000
Relocate parking lots	0 ft^2	$0	0 ft^2	$0	145,687 ft^2	$4,370,610
Purchase private property[38]	0 buildings	$0	0 buildings	$0	12 buildings	$20,325,986
Flood clean-up costs	Estimate	$2,500,000	Estimate	$2,500,000	Estimate	$2,500,000
TOTAL COST		**$2,651,800**		**$2,695,148**		**$28,938,979**

Non-market Annual Losses						
Recreational value	154 acres	$26,096,840	194 acres	$91,847,320	231 acres	$287,573,620
Ecosystem services	154 acres	$48,007,010	194 acres	$168,925,830	231 acres	$528,815,230
TOTAL COST		**$74,103,850**		**$260,773,150**		**$816,388,850**

37 Total costs to demolish and replace bicycle, roadway and pipeline infrastructure was estimated based on average width of each good, as noted by the City of Santa Monica Department of Public Works.

38 This reflects the improvement value of private property vulnerable to long-term inundation or erosion, i.e. those properties likely to be heavily or continuously damaged.

The costs of implementing these strategies were calculated with the following assumptions:

- Structures vulnerable to erosion and long-term inundation (tidal flooding) were considered, as these are at risk for damage and loss. Assets would be able to recover after short-term inundation, though post-flood clean-up would be required. The total direct cost associated with demolishing and replacing this infrastructure would be $6,112,993 in 2100.
- The cost associated with purchasing damaged private property was estimated as $20,325,986, and an additional $2.5 million was added to account for flood clean-up costs for public property.
- The non-market value of lost beach should also be considered in this scenario, as beach width would be lost under this strategy as well. This value was estimated as a total of $11,112,314 annually from ecosystem services and recreational services.

ACCOMMODATION

Total Costs in implementation, damages, property loss and loss of non-market services (2100): $883,307,352

The City will prioritize adaptive measures that work with heightened water levels, and build the resilience of facilities to accommodate water flow. Accommodation measures are the most difficult to value, as adaptive redesign can include an array of possible measures, and varies widely from one project to another.

Elevate or flood-proof existing and new buildings in flood zones.

- Reassess FEMA flood zones to reflect the effects of sea level rise, and existing vulnerable buildings and mandate that new construction meet elevated base floor elevation of FEMA BFE plus 3 feet. In the 1/100 (+3 ft) flood zone, dry flood-proofing requirements will likely increase to +4 ft.
- Allow wet or dry-proofing buildings as an alternative to elevation.
    - Wet flood-proofing is a measure that allows floodwater to enter a house, causing minimal damage to the structure and its contents. This minimizes the risk that the walls of the house will collapse because of the hydrostatic pressure from rising floodwaters on the outside. Measures include building utility installations and high-value areas above flood levels; walls built using water-resistant building materials; adding wall openings for the entry and exit of floodwaters; installing pumps; and relocating utility systems.

    - Dry flood-proofing measures aim to seal a building up to a certain height, making it watertight, such that floodwaters cannot enter.[39] Measures include sealing walls with waterproof coatings, impermeable membranes, or supplemental layers of masonry or concrete. Doors and other openings must be protected by permanent or removable flood shields. Backflow valves must be installed in sewer lines and drains to prevent floodwaters from entering the building via the sewer system. Dry flood-proofing is not allowed in areas where waves may impact the building, and it not be effective during high flood depths. In both conditions, pressure on the walls of the building may cause the building to collapse. Dry flood-proofing should only be applied up to a flood depth of 3 ft.[40]

Increase stormwater pumping capacity and number of wells.

- Increase the capacity of stormwater drainage system by building additional pumps to inject freshwater into the ground to combat intrusion of saltwater, and thus mitigate the impacts of prolonged flooding.[41]
- Implement the Sustainable Water Infrastructure Project (SWIP)[42], to capture and treat stormwater and brackish water for distribution through the City's purple pipe system for irrigation and toilet flushing.[43]

Increase setback policy.

- Increase setbacks such that shoreline development is set back a sufficient distance from the shoreline and/or designed to reduce the size of the structure or structure footprint to avoid hazards and coastal resource impacts to the maximum feasible extent and ensure stability and structural integrity for the anticipated lifespan of the development.

Use adaptive redesign to flood-proof critical public infrastructure.[44]

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39 Federal Emergency Management Association (2018). "Best Practices for Minimizing Flood Damage to Existing Structures". Department of Homeland Security.

40 Federal Emergency Management Association. "Best Practices for Minimizing Flood Damage to Existing Structures". Department of Homeland Security, 2018.

41 Aerts, Jeroen C.J.H., Patrick L. Barnard, Wouter Botzen, Phyllis Grifman, Juliette Finzi Hart, Hans De Moel, Alyssa Newton Mann, Lars T. de Ruig, and Nick Sadrpour. "Pathways to resilience: adapting to sea level rise in Los Angeles". Annals of the New York Academy of Sciences, 2018.

42 The Sustainable Water Infrastructure Project (SWIP) will capture rainwater flowing from downtown and divert it to a 1.6-million-gallon cistern adjacent to the Pier. Salty groundwater near the cistern is mixed with the rainwater, treated at the existing Santa Monica Urban Runoff Recycling Facility (SMURRF), and distributed for irrigation and toilet flushing in a purple pipe system for non-potable uses. It will allow the city to harvest up to 4.5 million gallons of stormwater from any single storm event for treatment and permitted reuse.

43 City of Santa Monica Department of Planning and Community Development. "Sustainable Water Infrastructure Project", 2017. https://www.smgov.net/Departments/PCD/Environmental-Reports/Sustainable-Water-Infrastructure-Project/

44 This pathway was not included in the cost estimate, as there are several methods for adaptive redesign, and they are highly variable in cost.

- Redesign bicycle paths and walkways to withstand temporary inundation, and add strategic barriers at key vulnerable points. Ensure that planned pedestrian walkways are designed to withstand flooding through pervious surfaces, barriers, channelization or sufficient drainage.
- Increase drainage at roadways vulnerable to prolonged flooding in order to prevent road damage.
- Conduct a detailed, site-by-site evaluation of public infrastructure vulnerable to flooding, and work with city staff to make this infrastructure resilient. Prioritize the Annenberg Community Beach House for capital improvements to increase its resilience.

Table 10: Accommodation Pathway (2019 $)

	2030		2050		2100	
Strategy	Amount	Cost	Amount	Cost	Amount	Cost
Private Costs						
Elevate buildings	12 buildings	$1,680,000	12 buildings	$1,680,000	89 buildings	$12,460,000
Dry-proof buildings	12 buildings	$123,843	12 buildings	$123,843	89 buildings	$918,502
Wet-proof buildings	12 buildings	$300,000	12 buildings	$300,000	89 buildings	$2,225,000
Public Costs						
Increase stormwater pump capacity	3 pumps	$600,000	4 pumps	$800,000	5 pumps	$1,000,000
SWIP treatment plant	Total	$65,000,000	Total	$65,000,000	Total	$65,000,000
TOTAL COST		**$65,600,000**		**$65,800,000**		**$66,000,000**
Non-market Annual Losses						
Recreational value	154 acres	$26,096,840	194 acres	$91,847,320	231 acres	$287,573,620
Ecosystem services	154 acres	$48,007,010	194 acres	$168,925,830	231 acres	$528,815,230
TOTAL COST		**$74,103,850**		**$260,773,150**		**$816,388,850**

The direct costs calculated above are primarily borne by private property owners, and the total would depend on the property owners chosen pathway. In the total cost, the lowest possible cost to private property owners (dry flood-proofing) was chosen. Costs to the City would be mainly from increased stormwater pumping capacity, the elevation or flood-proofing of one public property, and (if heavily damaged) the costs of purchasing private property.

However, under this scenario, the City would bear the costs of beach width loss, as well as the costs of the adaptive redesign of critical infrastructure, which are high. Total direct costs to the City under this scenario would be $86,325,986 in 2100, not counting these. Santa Monica would still lose beach width in this scenario, and therefore the added values associated with recreational and ecosystem services provided by the beach would still be borne by the City.

NATURAL PROTECTION

Total Costs in implementation, damages, property loss and loss of non-market services (2100): $178,506,866

To improve the biodiversity and resiliency of Santa Monica's beaches, and to address potential impacts of sea level rise, the City considered adaptation measures that would reintroduce a more natural beach environment, including dune restoration and the creation of a living shoreline.

Create a living shoreline through dune restoration.

- Transform seasonal sand berms programs into permanent dune restoration programs.
    - The first pilot studies for such transformation are promising and currently ongoing. Although larger volumes of sand are required, dunes provide a natural buffer against storms and can "naturally" re-nourish beaches impacted by high storm surge. Dunes are most practical when sufficiently wide and high backlands are available; at least 45−60m (150−200 ft) of beach width is required to develop dunes.[45] As with sand berms, artificial dune construction involves the placement of sediment deposits, which are then reshaped into dunes using bulldozers. Experimental dunes have been shown to attract

[45] Aerts, Jeroen C.J.H., Patrick L. Barnard, Wouter Botzen, Phyllis Grifman, Juliette Finzi Hart, Hans De Moel, Alyssa Newton Mann, Lars T. de Ruig, and Nick Sadrpour. "Pathways to resilience: adapting to sea level rise in Los Angeles". Annals of the New York Academy of Sciences, 2018.

endangered least terns, once a common resident of Southern California beaches. New nests have been observed within the first year of new dune projects.[46,47]

- In 2016, the City implemented a pilot project in the North Beach area, suspending beach grooming, erecting a low fence, and seeding foliage to encourage dune growth. Evaluation of the effects of this pilot project will guide future efforts. Small "dunelets" might also benefit the Western Snowy Plover, discussed above, by mimicking natural beach landscapes and providing protection from the wind. While dune fields may cause disturbances to nearby communities from windblown sand or hinder ocean views, adequate vegetation cover should reduce some of these effects.

Figure 12: Dune Restoration Pilot Project[48]

- Lead the development and implementation of a tax incentive program, grant program, or direct cost share assistance program for private landowners along the shoreline to incentivize the creation of new dune habitat areas that function to slow coastal erosion, as an alternative to hard shoreline protective devices such as seawalls and revetments.

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46 Pilot studies in Los Angeles have tested the viability of dune rehabilitation on urban coastlines
47 The Bay Foundation. "Santa Monica Beach Restoration Pilot Project", 2017. Accessed 2019. https://www.santamonicabay.org/explore/beaches-dunes-bluffs/beach-restoration/santa-monica-beach-restoration-pilot/
48 Ibid

Nourish beaches to prevent erosion.

- Add large quantities of sand to Santa Monica beaches to combat erosion and increase beach width.
    - Beach nourishment is a short-term solution that protects people and property by decreasing the energy of waves and limiting how far inland storm surges travel. Beaches must be supplemented with additional quantities of sand every few years, however, for this measure to continue to be effective.
    - Large quantities of sand have been dredged from harbors along the Southern California coastline over the past several decades, and additional study is needed to determine the quantities that remain and can be used for future nourishment projects.
    - Beach nourishment is very effective against water-level increases up to the beach height; for larger events that greatly exceed the beach height, however, beach nourishment will have a minimal effect on mitigating coastal flooding, and the flooding levels will be similar to what they would be without the measure.[49]

The cost of these strategies was calculated based on volumes of sand estimated in the Annals of the New York Academy of Sciences study on the Los Angeles coastline. Pilot projects on dune restoration and the creation of living shorelines are still ongoing, and costs are uncertain. Estimates are based on the Bay Foundation restoration in Santa Monica.

Table 11: Natural Protection Pathway (2019 $)

	2030		2050		2100	
Strategy	**Amount**	**Cost**	**Amount**	**Cost**	**Amount**	**Cost**
Public Costs						
Beach nourishment	7,376,325 yd^3	$110,644,869	9,258,081 yd^3	$138,871,217	11,139,838 yd^3	$167,097,566
Dune restoration[50]	54 acres	$3,803,100	109 acres	$7,606,200	163 acres	$11,409,300
TOTAL COST		**$114,447,969**		**$146,477,417**		**$178,506,866**

HARD PROTECTION

49 National Oceanic and Atmospheric Administration. "What Will Adaptation Cost?" State Lands Commission, 2018. Accessed 2019. https://www.slc.ca.gov/wp-content/uploads/2018/08/NOAA_WhatWillAdaptationCostReport.pdf

50 The Bay Foundation estimated the need for 163 acres to restored, which was broken down into thirds for a cumulative cost of $11,409,300.

Total Costs in implementation, damages, property loss and loss of non-market services (2100): $204,500,000

The Local Coastal Program Land Use Plan emphasizes the need to prioritize soft adaptation measures. The plan outlines a Shoreline Protective Device Impact Fee, in which it states that the City will require mitigation for unavoidable public resource impacts over the life of a new shoreline protective structure, or the expansion of an existing shoreline protection structure as a condition of approval for any Coastal Development Permit authorizing such development. These devices are to be used only as a last resort to protect critical public infrastructure.

Harden pier and stabilize.

- Use capital improvements to strengthen pier resilience to increased wave heights and onshore flooding. Replace existing timber piles with concrete to increase resistance to inundation.

Repair or replace the Santa Monica breakwater.

- The Santa Monica breakwater was poorly engineered and gradually sank into the water and today is almost completely submerged. It could be repaired or replaced entirely in order to protect the pier and public beach access today.

Install dikes and groins to stall SLR.

- As a last resort, hard protection measures can be used to protect public facilities, infrastructure and recreational access to Santa Monica beaches. However, this will decrease the quality of public recreation, viewshed, and ecological services provided by the coast.

Strategies outlined here were taken from suggestions in the Annals of the New York Academy of Sciences study, supplemented by existing plans for capital improvement projects. Additional research would need to be done in order to determine the efficacy of each measure and the need for multiple. It is likely that a combination of natural and hard protective measures would significantly reduce costs, while protecting large portions of the coastline infrastructure and beach width.

The total cost to the City if all strategies were to be implemented would be $204,500,000. However, if combined with other pathways to create a hybrid of protection, accommodation and retreat, the cost would be far less.

Table 12: Hard Protection Pathway (2019 $)

	2030		2050		2100	
Strategy	**Amount**	**Cost**	**Amount**	**Cost**	**Amount**	**Cost**
Public Costs						
Harden pier	total	$45,000,000	total	$45,000,000	total	$45,000,000
Install jetties	6 jetties	$4,800,000	8 jetties	$6,400,000	10 jetties	$8,000,000
Install dike under beach	total	$112,500,000	total	$112,500,000	total	$112,500,000
Replace breakwater	total	$3,000,000	total	$3,000,000	total	$3,000,000
Install groins	27 groins	$21,600,000	36 groins	$28,800,000	45 groins	$36,000,000
TOTAL COST		**$186,900,000**		**$195,700,000**		**$204,500,000**

ONGOING RESEARCH & MONITORING

Sea Level Rise Data Collection and Monitoring. Within the framework of the LUP, the City is required to monitor sea levels using the data collection methods identified below and keep records of all monitoring data and reports.

a. Tidal Gage Data. Sea levels vary based on predictable tides and seasonal cycles and unpredictability based on El Niño and storm events. The mean sea level measurements shall come from the Santa Monica tide gauge (NOAA Station 9410840) maintained by the National Ocean Service. The City's periodic evaluation of the tidal gage data and tidal datum shall occur at least once every 5 years. Given the variability in sea levels, the evaluation shall consider the average sea level based on an entire year of tide data compared with the National Ocean Service mean sea level elevation for the most recent tidal epoch (1983-2001).
b. Pier scour analysis. To support the long-term monitoring and maintenance of the Santa Monica Pier infrastructure, a technical scour analysis and existing conditions report shall be prepared each time the 100-year wave run up elevation (to be extracted from FEMA, technical reports, or CoSMoS) comes within 5 feet of the deck boards or if there is any wave damage to the Pier that requires repair (but no more than once per year).
c. Beach width. The seasonal (winter and summer) beach widths, measured from the back of the sand to the Mean High Water shoreline, shall be monitored annually to compile information about the changes in beach width at the same specified locations

each year. The City will use this baseline beach width monitoring data to inform prioritization of adaptation strategies for vulnerable public infrastructure and important public recreational coastal resources along the City's shoreline.

d. Storm Flooding and Damage. Quantitative storm flooding measurements shall be kept after major storm events that impact assets including but not limited to the Marvin Braude Walkway, the Pier restaurant on the lowest level of sand (currently Bubba Gump), the City-owned beach lease spaces (currently Perry's on the Beach), the Annenberg Community Beach House and other public assets. Flooding and property damage due to storm drain backup shall also be recorded and quantitatively measured after major storm events.

Additional Research and Next Steps. It is recommended that the City conduct site and asset-specific vulnerability assessments for critical public infrastructure to adaptively redesign or relocate key infrastructure. The City's update to their Sustainable Groundwater Management Plan is also in motion, and will include an analysis of the dangers of saltwater intrusion and inundation for pipelines. It is recommended that this plan also explore the length of expected flooding from coastal storms and monthly tidal events based on the drainage capacity of the stormwater system.

Additionally, since most of the natural, less disruptive protection adaptation pathways (including both beach nourishment and dune restoration) depend on nourishment using large quantities of offshore sand, it is important to improve assessments of the volume of available offshore sand reserves. The environmental impacts and economic viability of utilizing these offshore reserves must also be examined.

PARTNERSHIPS & ENGAGEMENT

Regional Partnerships. In 2013, Regional AdaptLA, a coalition of coastal municipalities in Los Angeles County led by Santa Monica and USC, along with a team of support organizations, was established to develop a multisectoral and stakeholder-supported process focused on building capacity for assessing vulnerabilities to coastal change throughout the Los Angeles region. The goals of the coalition were to strengthen the ability of local jurisdictions to evaluate their vulnerable assets and populations and to begin planning to address the impacts of sea level rise. This partnership was essential in gathering the information that the City needed in order to draft the Climate Action and Adaptation Plan, and was integral to this report.

Threats to the portion of the Pacific Coast Highway that is vulnerable to SLR are a concern for multiple jurisdictions, including Caltrans, the City of Los Angeles, the City of Malibu and the City of Santa Monica. Partnerships with these entities will be key to addressing these concerns. Caltrans recently conducted a Vulnerability Assessment for climate change impacts to highways along the coast, and determined that the portions of the Pacific Coast Highway in northern Santa Monica and Malibu are particularly vulnerable to cliff retreat.[51] They announced plans to complete a wave run-up study during the next stages of project development. As Caltrans moves forward with building new shoreline structures and rehabilitating older ones, it will continue to address the effects of future sea level rise and storm surge on each project.

National Flood Insurance Program. Even after incorporating adaptation measures, there will still remain considerable flood risk as SLR continues to accelerate. To cover this "residual risk," and to compensate for the losses households may endure in the aftermath of a flood event, FEMA operates the federally run flood insurance program. This program offers financial relief after flood events and aims to provide incentives for adaptation and flood risk mitigation before an event. The program sets minimum regulations; thus, there is an opportunity for the City of Santa Monica to consider improving current zoning policies in the City beyond FEMA regulations to provide maximum benefits from reducing flood risk for households.

Community Awareness. In 2016, the City installed two telescopic viewers on the Santa Monica Pier. In partnership with the USC Sea Grant, the US Geological Survey (USGS) and Owlized, Inc. "The Owls on the Pier" offered passersby the augmented reality experience into potential future scenarios of sea level rise impacts on Santa Monica's beach. The Owls surveyed participants on their views and concerns about climate change and sea level rise and their preference for climate adaptation approaches. Over 10,000 people visited the Owls, and more than 2,500 of those participated in the survey. Additional community awareness campaigns on sea level rise impacts and flood risks are needed in order to inform the public of potential risks, as well as inform coastal property owners of options that they have.

[51] Caltrans. "Climate Change Vulnerability Assessment Summary Report: District 7", 2019.

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