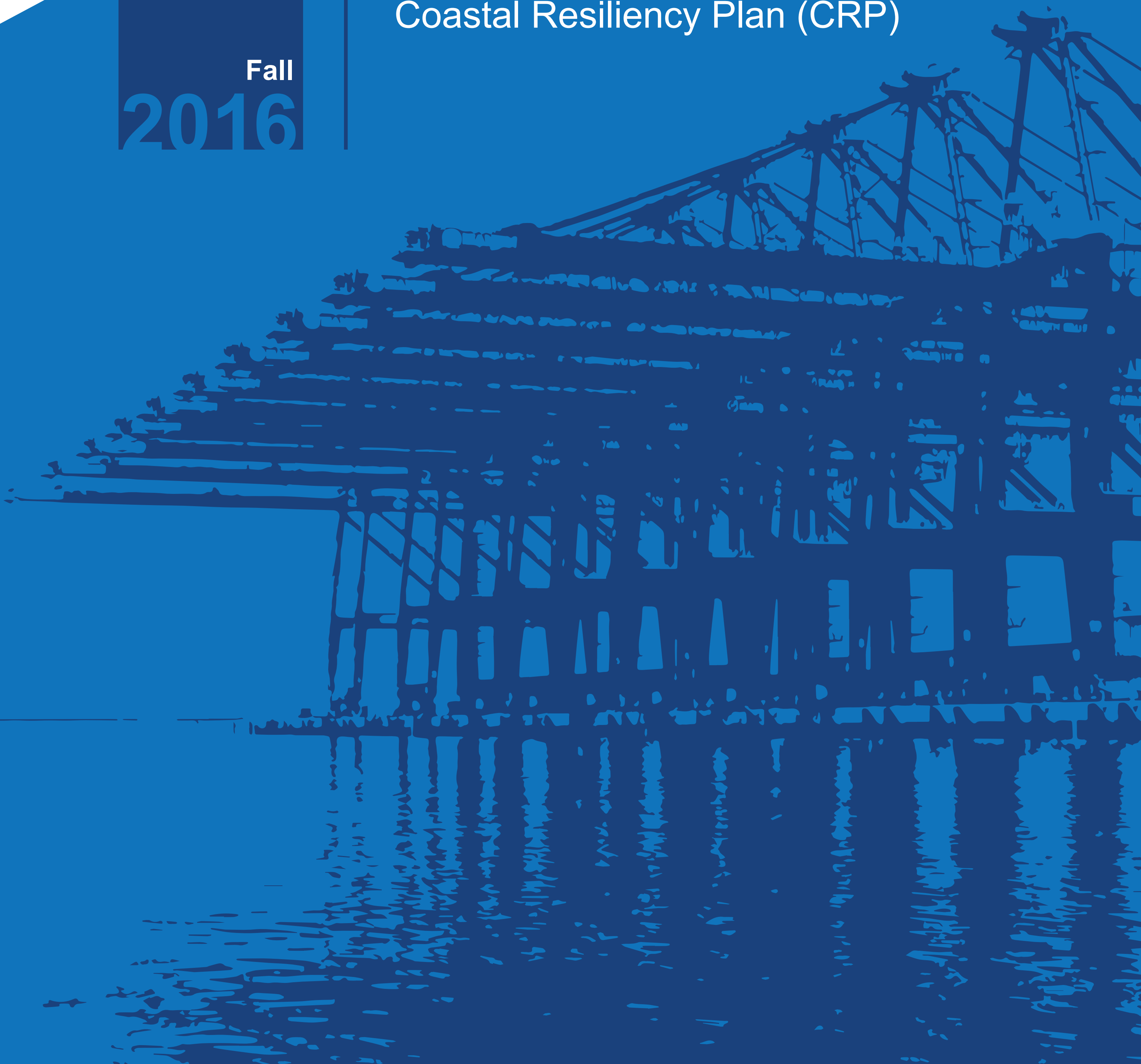
Port of
LONG BEACH
The Green Port

Port of Long Beach

Climate Adaptation and Coastal Resiliency Plan (CRP)

Fall

2016



Executive Summary

The Port of Long Beach (Port) developed a Climate Adaptation and Coastal Resiliency Plan (CRP) to manage the direct and indirect risks associated with climate change and coastal hazards. The CRP provides a framework for the Port to incorporate adaptive measures related to projected climate change into its policymaking and planning processes, construction practices, infrastructure design, and environmental documents.

The Port is an important economic engine for Southern California and the nation and a critical gateway to global trade. The CRP recommends near-term solutions for protecting the Port's most vulnerable areas and long-term strategies that can assist the Port in maintaining business continuity across its infrastructure and operations into the next century.

The CRP includes a review of the best available climate science, an inventory of Port assets, and detailed sea level and storm surge inundation mapping. Together, these data sets informed the development of vulnerability profiles for the Port's infrastructure, transportation networks, critical buildings, and utilities. A broad suite of potential adaptation strategies was developed to reduce the Port's vulnerabilities. A collaborative process was used to select a subset of these strategies for further refinement.

Background

Climate change and extreme storm events are already impacting the Southern California coast. Sea levels will continue to rise, and the frequency and magnitude of extreme storm events are likely to increase. The Port and its tenants will experience storm events with a greater potential to impact Port operations. Consideration of these impacts will allow the Port and its tenants to make sound, science-based decisions as they invest in their maritime infrastructure, and to prioritize their resource allocations in a way that considers near-term and long-term climate change vulnerabilities and risks.

Figure ES-1. Hurricane Marie damage to Nimitz Road

The Port's vulnerabilities were highlighted in August 2014 when storm surge and wave hazards resulting from Hurricane Marie ravaged the Southern California coast (Figure ES-1). The Port suffered damage at the Navy Mole (Nimitz Road) and Pier F, and shipping operations were halted for multiple days. Access to the surrounding roads and facilities was impacted for several months. Although Hurricane Marie was considered a unique storm event due to its direction of attack relative to the coastline, the changing climate and ocean conditions may increase the likelihood of storm events that are outside observations of historical events.

Project Goals

- Manage risks associated with climate change
- Identify Port assets that are most vulnerable
- Identify potential adaptation strategies to protect the Port

Project Benefits

- A more resilient Port able to continue operations with reduced impact
- A Port prepared and ready to adapt
- More future-looking risk assessment process

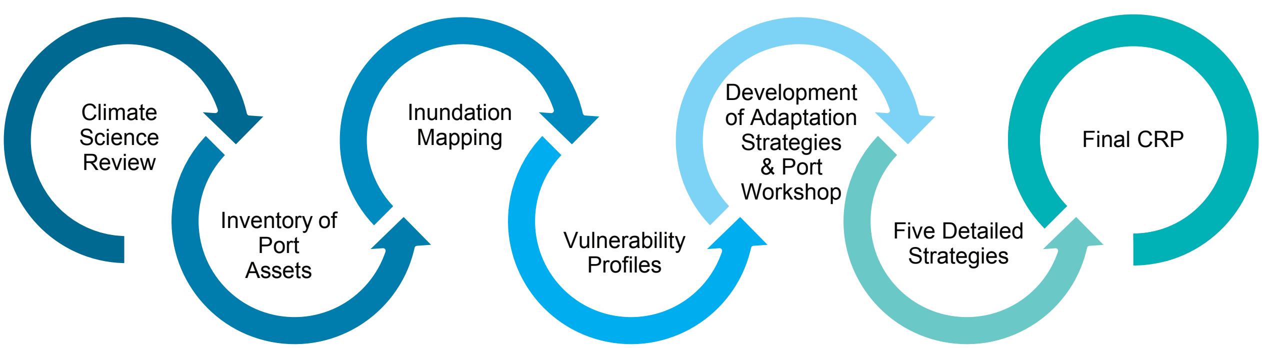


Figure ES-2. Steps to Developing the CRP

Climate Change Stressors and Impacts

The science related to understanding the impacts of climate change is continually evolving and advancing over time. The best available climate science information relating to Sea Level Rise (SLR) and storm surge, temperature, wind, precipitation, and ocean acidity change was reviewed at the global, national, and local levels.

While the exact timing of future climate events is uncertain, there is strong consensus that the global mean temperature is rising. This causes a rise in sea level due to thermal expansion and the melting of land ice (glaciers). Sea levels at the Los Angeles tide station adjacent to the Port are currently projected to rise 5 to 24 inches by mid-century and 17 to 66 inches by end-of-century, based on projections by the Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT 2013) and the National Research Council (2012).

Climate change will affect the intensity, frequency, and paths of coastal storms and wave events. As oceanic temperatures increase, the potential for Pacific Coast hurricanes (i.e., tropical cyclones) with high wind speeds and large waves may also increase. These changes, although not fully understood, can damage the Port's infrastructure, disrupt operations, and impact worker safety.

Climate change may also change the acidity of the ocean and increase the number of extreme heat events. Although the Port area itself is not expected to be directly impacted by extreme temperatures, it may experience indirect effects. For instance, Southern California as a whole may experience electrical outages caused by increased electrical use from elevated demand for summertime cooling as well as transmission efficiency decreasing due to hot temperatures. Such outages could stress the regional electrical grid that is vital to Port operation.

Port Asset Inventory

A comprehensive inventory was developed to identify and organize Port assets and operations that are important for maintaining business continuity. The inventory catalogs assets at the piers, wharves, and backlands, and includes utilities, roadways, rail assets, and critical buildings such as those housing security, administration, fire, and life safety functions. The assets most critical to the Port's business continuity were highlighted.

Sea Level Rise and Storm Surge Maps

Detailed inundation maps were created for the Port study area. The maps considered SLR inundation and extreme tide (storm surge) flooding of the Port property, as well as an overtopping assessment along the existing shoreline structures and the Port's breakwater. Each SLR scenario—16, 36, and 55 inches—was evaluated under two tide conditions, (1) daily high tide and (2) extreme tide[1] without consideration of waves, resulting in six mapped scenarios that highlight both inundation depth and extent.

Increased precipitation may result in increased riverine flows that could also impact Port property and subject areas to temporary flooding. Potential future increases in precipitation of 20 percent and 30 percent and the impact of these increases on riverine flooding were evaluated and mapped. An overtopping assessment highlighted locations along the shoreline where riverine floodwaters were most likely to overtop existing channel banks and shoreline infrastructure.

The asset inventory and inundation maps were used to identify vulnerable areas of the Port. The largest impacts are due to a combination of SLR and storm surge. While SLR is a gradual and long-term stressor, storm surge related to an extreme event can be sudden, unpredictable, and temporary. The impacts associated with storm surge are expected to become more pronounced as sea levels increase.

The two maps in Figure ES-3 and Figure ES-4 identify the least (16-inch SLR without storm surge) and most extreme (55-inch SLR + 100-year storm surge) scenarios that were evaluated. The darker blue colors indicate areas with deeper inundation. The areas in green are below the mapped water surface elevation, but are without a direct hydraulic flow path for floodwaters to reach the area area ('Disconnected Areas'). Figure ES-3 highlights that Piers S and D will be the first areas of the Port to be impacted as sea levels increase. When higher levels of SLR are coupled with an extreme storm surge event, more widespread impacts will occur, and Piers S, D, A, B, and C may be temporarily inundated during an extreme event. Although Piers T, F, and J are not inundated under any scenario evaluated, their access to the transportation network will be impaired, so they may become isolated and potentially inaccessible during flooding events.

1 Extreme tides are represented by the 1-percent-annual-chance stillwater elevation (SWEL).

Figure ES-3. 16-inch SLR scenario

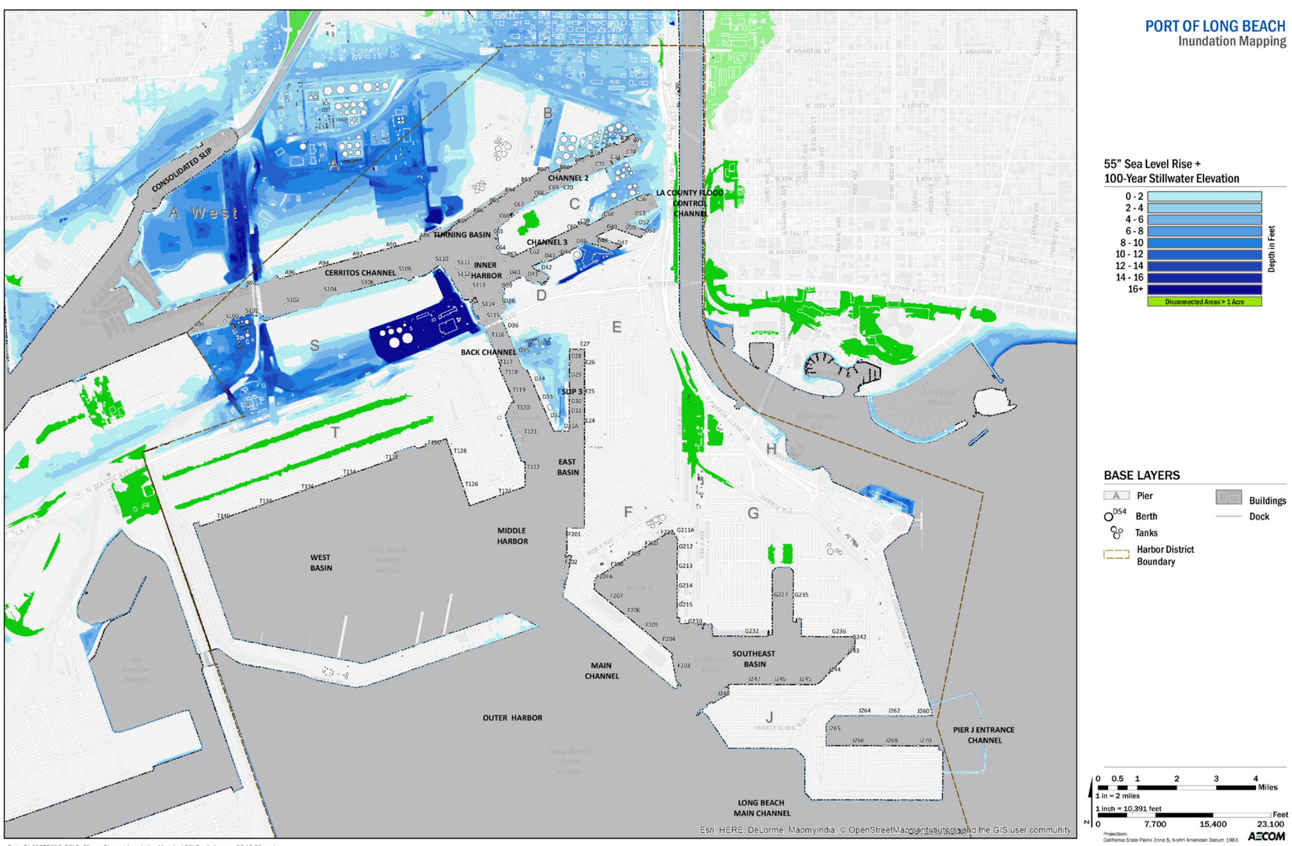


Figure ES-4. 55-inch SLR + 100-year Storm Surge

The impacts during a flood event will vary. Some assets, such as paved roads, may be temporarily closed when flooded but may regain their normal function once floodwaters recede. Some assets may remain fully functional if the inundation is limited to a few inches or less. Other assets, such as the railway system, may completely shut down if any amount of inundation occurs. The actual rails may suffer structural damage if the foundations under the tracks are inundated, especially for an extended period of time, as ballast is likely to settle. As flooding becomes more frequent or more severe, the potential for structural damage will increase. Other assets and cargo, especially those involving electric or mechanical components, may be permanently damaged by even a brief period of flooding.

The inundation maps indicate that the north shoreline of Pier S, immediately west of the Commodore Schurler F. Heim Bridge, is a main pathway to Pier S inland inundation. It is important to clarify that there is an existing sheet pile seawall at this site, which is constructed to approximately 15 feet NAVD88. This is theoretically tall enough to protect against inundation at some SLR scenarios, although at higher SLR scenarios, the shoreline immediately west of the seawall is too low to prevent flooding and inundation. Currently, the wharf does not experience inundation at tide elevations equivalent to the lowest SLR scenario (16-inch SLR without storm surge). The condition and structural integrity of the seawall are not known at this time and it is not an accredited flood protection structure by USACE or FEMA. AECOM was informed by Port staff that the wall might not be in good condition and a structural evaluation of the wall was beyond the scope of this project. Therefore, the exact SLR inundation scenarios that this seawall can protect against, if at all, in its current condition are not known. Finally, the wall is narrow enough that the wall dimensions were not captured in the bathymetric and topographic survey data used in this project. For these reasons, the inundation maps were created under the assumption that the seawall does not provide any flood protection in its current condition. A engineered retrofit was conceptually designed for this seawall as part of this project and is discussed in Chapter 10.

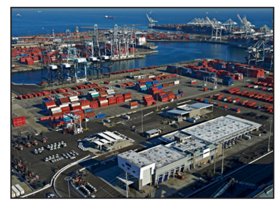
Vulnerability Profiles

Vulnerability is defined as the level to which an asset is exposed to a climate impact combined with its sensitivity to that impact. Understanding the level of vulnerability of an asset to climate impacts is an essential part of decision making and policy development for future adaptation, as it provides a basis for establishing priorities.

Vulnerability profiles were developed for these Port asset types: pier infrastructure, transportation network, critical facilities, utilities, and the breakwater. The impacts of climate change on the Port will likely fall into three broad areas of concern: asset damage, cargo damage, and lost revenue due to facility closure.

Key findings from the asset vulnerability profiles include the following:

Pier Infrastructure:



» Portions of Piers S and D would be inundated first by SLR. Under the most extreme projections, the backlands of Piers A, B, and C would also be inundated, as well the tip of Pier E.

» Overtopping would first occur at Piers S (berth S101) and D (berth D46). Under the most extreme projections, overtopping would also occur along the Pier A West and Pier A backland area (along the river and rail track), as well as along the perimeter of Piers B, C, D, and E.

» Piers F, G, J, and T would not be exposed to SLR or periodic flooding, but they may be isolated due to inundation on adjacent piers.

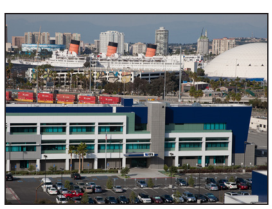
» The riverine floodplain is projected to expand along the wharfs of Pier A West and Pier B, as well significantly at the backlands of Piers A and B if there is a 20 percent increase in precipitation.

» Many portions of the pier structures themselves are not sensitive to damage from short-term flooding. If a portion of the pier is submerged, operations will stop, but they are expected to resume quickly post-flood. However, any wharf or backland infrastructure that has electrical components, such as conveyors, communications, security systems, lighting, and shore-to-ship power systems, may be at risk from damage if not waterproofed or otherwise protected.

Transportation Network:

- Railways on Piers S and D will be the first to be directly impacted due to inundation from SLR, which may prevent cargo from leaving these piers. The Pier T railway would be indirectly impacted because it connects to the inundated rail on Pier S. Under the most extreme conditions, Piers A, B, C, and D would also be inundated, which would indirectly impact Piers F, G, and J, since they connect to the inundated railways.
- Rail infrastructure materials are not sensitive to damage as a result of short-term flooding. If rails are submerged, train movement will stop, but would be expected to resume quickly post-flood.
- Roadways on Piers S and D are most vulnerable and directly inundated. Inundation will prevent cargo leaving these piers. Under the most extreme conditions, roadways within Piers A, B, C, and tip of E would also be directly inundated, as well as the freeway, State Route 47, that connects to Terminal Island.
- Road materials are not very sensitive to damage from temporary inundation. If roads are submerged, vehicle movement will stop during flood depths over a few inches, but would be expected to resume post-flood unless the water is fast moving and causes scouring. Repeated inundation is more likely to cause deterioration. There is an efficient system in place for repairing the roadway network, including traffic signals, so any disruption is not expected to be lengthy.
- Rail speeds are slowed when temperatures reach around 90 degrees Fahrenheit to avoid buckling and derailment, which will occur more often as the frequency of hot days (over 95 degrees) increases.

Critical Facilities:

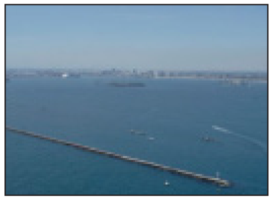


- The majority of critical building structures are located at a high elevation and will not be impacted by the modeled levels of SLR and storm surge.
- The most vulnerable building is Fire Station #24 (Pier S) the access to which will be inundated under the 16-inch SLR scenario. Under storm conditions, the Foss Maritime mooring of tugboats and barges will be indirectly impacted because the access road will be inundated.
- Extreme heat may cause electrical outages and area-wide brown-outs. Building heating and cooling equipment will be disrupted, including all computers and other mechanical and electrical systems, unless the building has backup generators. Employee comfort, health, and productivity may be impacted.

Utilities:

- In most cases, water distribution lines are underground and are currently inundated by groundwater. Apart from valve vaults, water distribution lines are not anticipated to be sensitive to SLR inundation. The valve vaults are located throughout the water distribution lines and are either above or below ground. Generally, the vaults are not waterproof, and during inundation it is possible that valves will be inoperable. However, flooding of a vault is not expected to cause equipment damage.
- In general, sewer lines will not be susceptible to SLR inundation. Lift/pump stations could be inundated with ground or surface water from SLR, affecting the efficiency of these units or causing spills outside of the system.
- Stormwater systems are susceptible to SLR inundation. If the outfall area is inundated, the water cannot drain and will contribute to further flooding in the area. Rising groundwater due to SLR will exacerbate this impact. Further, if the pump station locations are inundated, they will no longer operate.
- Electrical systems that are vulnerable to SLR will no longer be operable if they are subjected to even minimal flooding. These include those located in Piers A, C, F, and S. Electrical system components that will be impacted by flooding include switchgear, substations, transformers, switchboards, panel boards, and building/facility lighting. Other electrical system components such as conduits, manholes and pull boxes are not expected to experience flood impacts because all cable joints and splices are waterproof and all cables used in underground distribution are rated to operate under flooded conditions.
- One telecommunications tower on Pier D is not inundated under any scenario. If communication cable joints and splices are waterproof (most likely the case) and if cables used in underground distribution are rated to operate under flooded conditions, there will be no impact to the cabling system.

Breakwater:



- The existing breakwater protects the Port of Long Beach and the Port of Los Angeles (Middle Breakwater) as well as a portion of the city of Long Beach shoreline (Long Beach breakwater). As sea levels rise, larger waves will impact the breakwater, resulting in increased transmission of waves into the protected harbor.
- Based on historical storm conditions, the Long Beach breakwater is most vulnerable to wave damage from wave runup and overtopping. As the effectiveness of the Long Beach breakwater decreases, Port operations along the eastern edge of the Port (Pier J basin) will be impacted.
- The second most vulnerable area is the eastern portion of the Middle Breakwater; however, the overall impact is projected to be minimal if future storms track well with historical events.
- The breakwater was evaluated based on historical wind directions and wave conditions. However, future storm events may occur that are outside the range of historical observations. Hurricane Marie in August 2014 is an example of such a storm event. The wind and wave direction of Hurricane Marie were unusual and were likely outside the original design parameters for the breakwater. The vulnerability assessment based on historical observations did not find the Middle Breakwater to be highly vulnerable. However, the Middle Breakwater was breached in three locations during Hurricane Marie, leading to infrastructure damage and an impact to Port operations.

Adaptation Strategies – Selection and Methodology

Drawing on best management practices and input from technical experts (coastal and electrical engineers, port and transportation planners, and environmental policy specialists), a preliminary list of potential adaptation strategies was established. Over 20 strategies were identified and categorized into one of three types:

- **Governance** (address Port-wide planning and design documents): By adding language to overarching policies/plans and in technical guidelines, both planners and designers start thinking about climate change from the start of a project.
- **Initiatives** (address informational gaps): By introducing initiatives, stakeholders and Port staff can continue to evaluate impacts on operations and physical damage that are associated specifically with climate change.
- **Infrastructure** (address physical vulnerabilities): By modifying existing infrastructure, such as strengthening sea walls or raising electrical equipment, the Port can be more prepared for future climate-related events.

A workshop was held with staff from Divisions across the Port to review the strategies and select a subset of strategies for further development. Five strategies were prioritized and developed into detailed studies or concept designs (each one is summarized below and described in the pages that follow):

- Strategy #1 (Governance): Addressing climate change impacts through Port policies, plans, and guidelines
- Strategy #2 (Governance): Adding sea level rise analysis to the Harbor Development Permit
- Strategy #3 (Initiative): Piers A & B Study – Combined Impacts of Riverine and Coastal Flooding
- Strategy #4 (Infrastructure): Pier S shoreline protection
- Strategy #5 (Infrastructure): Pier S substation protection – evaluation of multiple strategies

Additionally, several strategies were considered relevant and in the future will be developed further by Port staff:

- Develop a Port climate change policy.
- Add climate change considerations to terminal/tenant leases.
- Share climate change knowledge that could impact Port development plans.
- Modify additional design criteria guidelines to include climate change.
- Modify existing stormwater drainage model design parameters to include climate change.
- Track weather event impacts.
- Include climate change considerations in the Energy Island Initiative.
- Share climate change knowledge with relevant stakeholders.
- Develop Dominguez Channel shoreline protection concept design (follow-up to Strategy #3)
- Understand potential climate change impacts and protect critical security systems.

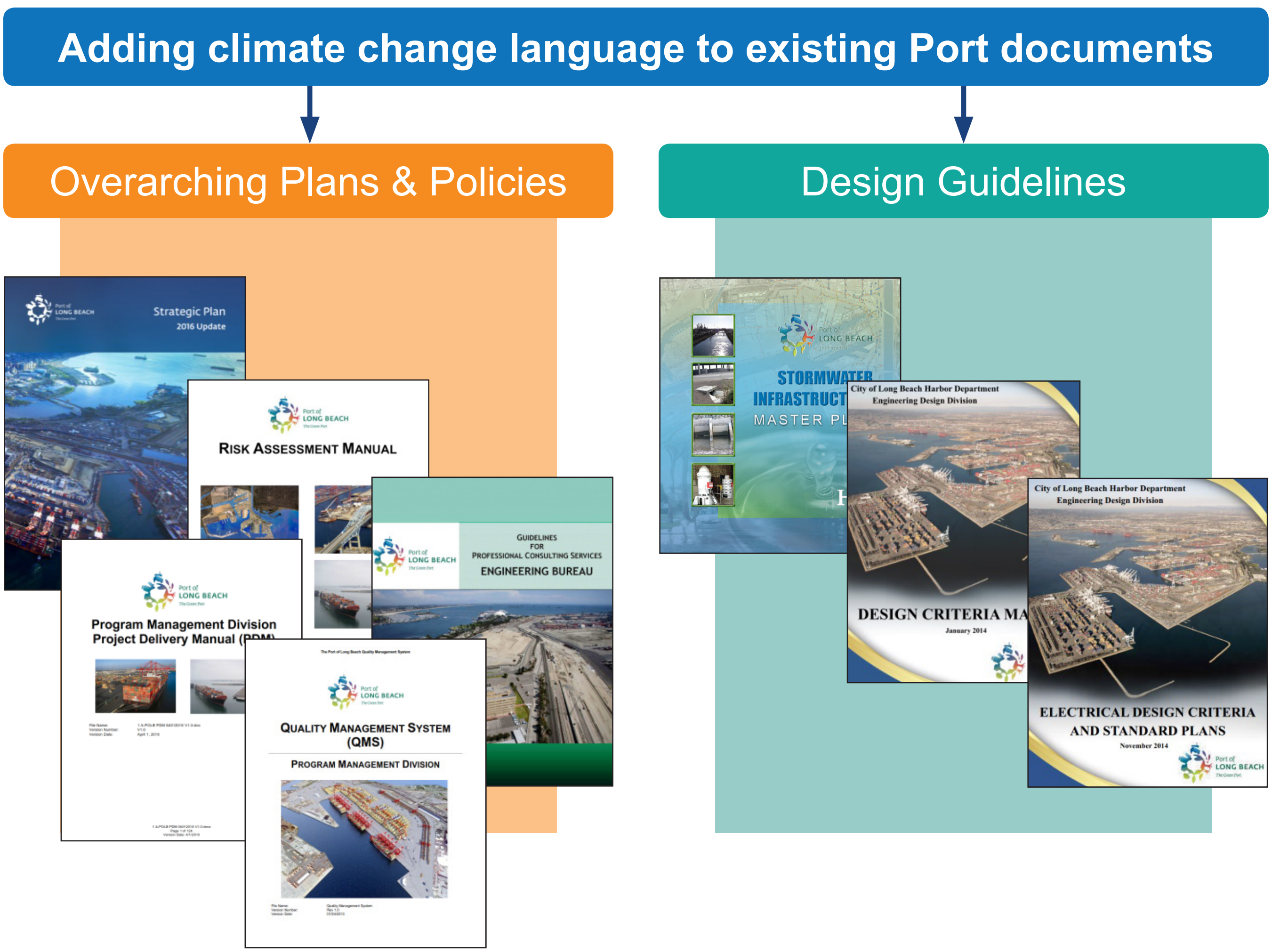
Strategy #1 – Addressing climate change impacts through Port policies, plans, and guidelines

This strategy provides recommended language that can be added to key Port policies, plans, and guidelines to ensure climate change impacts are considered at the most appropriate time during planning and development projects.

Port documents fall into two general categories: overarching planning documents and design guidelines. Overarching documents, such as the Strategic Plan, are high-level and focus on the Port's priorities. Design guidelines, such as the Wharf Design Criteria, are detailed and provide guidance to technical practitioners. Language addressing climate change impacts should be incorporated into both types of documents.

Several Port documents were reviewed for applicability. For the purposes of this study, eight documents were prioritized (by Port staff): Strategic Plan, Risk Assessment Manual, Guidelines for Professional Consulting Services, Project Delivery Manual, Quality Management System, Stormwater Infrastructure Master Plan, Design Criteria Manual, and Electrical Design Criteria and Standard Plans. For each document, recommended text insertions, point of intervention, partners, implementation considerations, and next steps were drafted.

The integration of climate change language into these key planning and design documents will ensure that future investments by the Port are safeguarded through consideration of climate impacts and incorporation of adaptation strategies.



Strategy #2 – Adding sea level rise analysis to the Harbor Development Permit

This strategy recommends updating the Harbor Development Permit (HDP) process to include climate change considerations.

Because Port facilities will face enhanced flood hazards with increasing sea levels, it is important for the applicant to consider adaptation strategies to increase their flood resilience to both ensure business continuity and a good investment by the leaseholder.

A new section in the HDP short/long form will heighten awareness and consideration of SLR impacts on any development as well as on the proposed location of construction projects, utility/pipeline installations, and storm drains within the Port. A Port Coastal Vulnerability Zone map was created to clarify whether an applicant’s project is located in an area that is vulnerable to either permanent or temporary inundation. The 36-inch SLR scenario was used for the zone because it is representative of the high-end projection for 2070 and the most-likely projection for 2100. The Port Coastal Vulnerability Zone Map is shown in Figure ES-5.

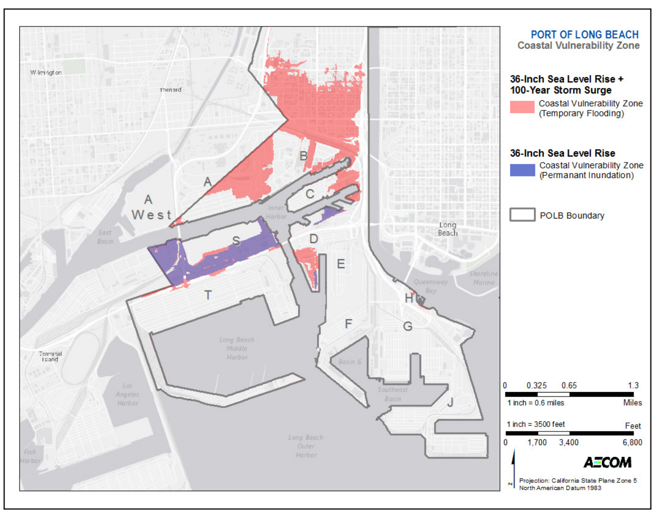


Figure ES-5. Port Coastal Vulnerability Zone Map

A guidance manual was developed for Port staff to provide additional support to ensure that the HDP checklist is properly completed and reviewed. This internal document also includes definitions, the Port Coastal Vulnerability Zone Map, example projects, and an internal form/checklist to assist Port staff in reviewing projects that fall within the Port Coastal Vulnerability Zone.

Strategy #3 – Piers A & B Study – Combined impacts of riverine and coastal flooding

This study investigated whether increased precipitation-based flooding along the Dominguez Channel, in addition to SLR, could have an impact on Piers A and B. The study relied on an existing hydraulic model for the channel and evaluated a range of future conditions (SLR, storm surge, and precipitation) to identify water-level thresholds when the Dominguez Channel bank and levee are first overtopped.

The results of this study provide insight into the existing level of flood protection afforded by the Dominguez Channel levee system. Although the Dominguez Channel is outside of the Port Harbor District Boundary, this analysis demonstrates that, under extreme conditions, future, more intensive riverine storm events coupled with SLR could cause the Dominquez Channel to overtop its banks, resulting in extensive flooding on the Port’s Piers A and B (Figure ES-6). Flooding or inundation at these piers could potentially damage a major rail network and oil refinery.

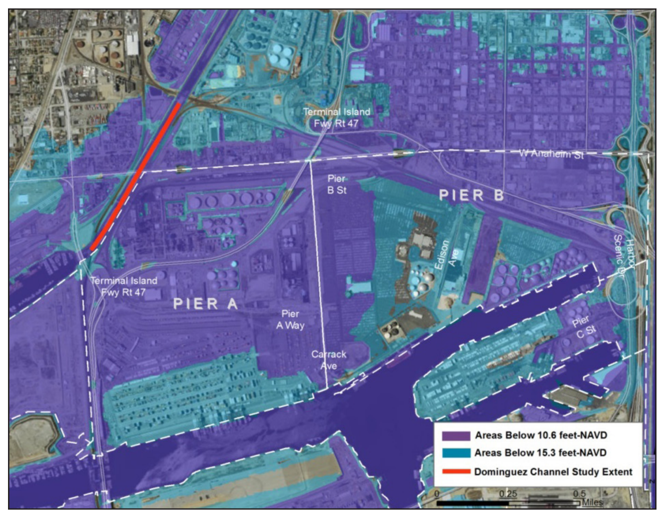


Figure ES-6. Piers A & B Potential Extent of Impact

At a minimum, flood protection improvements should consider providing protection through 2070 (i.e., including expected SLR through 2070). This assumes construction in 2020 and a design life span of 50 years. The design should provide protection for the 100-year peak riverine discharge coupled with the 100-year storm surge, with a minimum of 3 feet of freeboard. In the future, the Port may want to consider completing a concept design adaptation strategy to further evaluate the site.

Strategy #4 – Pier S shoreline protection

This concept design provides an option for strengthening the Pier S shoreline, located along the Cerritos Channel (see Figure ES-7). Based on the inundation mapping and shoreline overtopping assessment, this is an area where floodwaters may first overtop and inundate Port assets.

Flooding at this site would be a critical issue for the Port, as the site includes several chemical storage tanks that could cause environmental and human safety problems if compromised. The site also functions as a pathway for floodwaters to reach adjacent low-lying areas that contain important assets such as Fire Station #24 and the Pier S Southern California Edison (SCE) electrical substation.

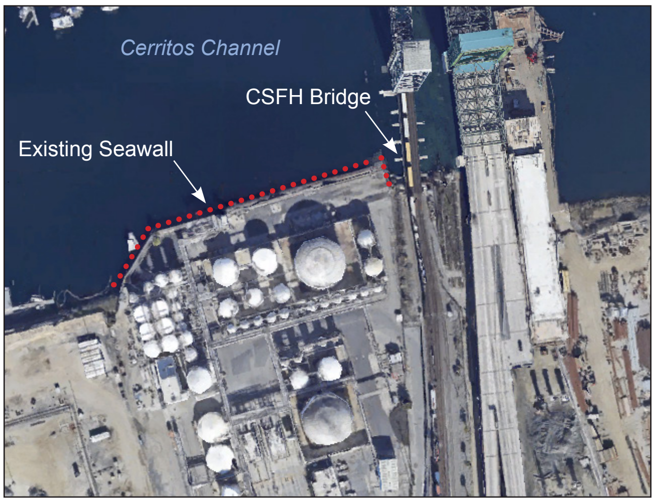


Figure ES-7. Pier S Strategy Location

Initially, a replacement seawall was proposed at this location. However, after a detailed review of the condition and functionality of the existing sheet-pile seawall, a retrofit of the existing seawall was considered a more technically feasible and cost-effective adaptation strategy.

The proposed retrofit design is focused on strengthening the current seawall to protect the low-lying areas south of the Cerritos Channel from the 36-inch SLR scenario (representative of the high-end projection for 2070 and most-likely projection for 2100) coupled with a 100-year storm surge. The design includes sufficient freeboard to meet the Federal Emergency Management Agency's requirements for coastal protection structure accreditation and to protect against potentially greater SLR magnitudes. A preliminary concept design-level cost estimate for this project is estimated at $1.1 million. The existing fuel and facilities are privately owned and will require coordination throughout the implementation of the strategy.

Strategy #5 – Pier S substation protection – Evaluation of multiple strategies

This strategy proposes several adaptation options for the SCE Dock Substation on Pier S. The SCE site is vulnerable to permanent inundation and temporary flooding under multiple SLR scenarios. The substation is considered a critical asset and, if compromised, would affect the power supply to Total Terminals International's Container Terminal, which is located on Pier T, and any additional future port operations added to the SCE grid.

Several near-term and long-term adaptation strategies were evaluated to increase the resilience of the SCE Dock Substation:

» Near-term solutions for periodic flooding focused on the installation of a temporary/semi-permanent barrier (sandbags, self-expanding sandless bags, Water-Gate, AquaFence, portable cylinders, Tiger Dam, or Metalith).

» Long-term solutions for permanent inundation focused on installing a permanent barrier (earthen berm, rubber dam, steel sheet pile wall, or reinforced-concrete cantilevered wall), raising the substation ground level at the present location, or building a new substation at a location that is not subject to inundation.

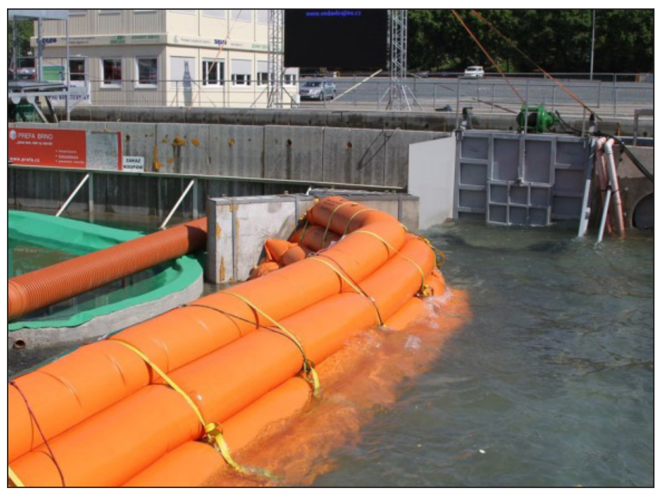


Figure ES-8. Tiger Dam Installation Example

Based on this study, the recommended design option for near-term flood protection is the 3-foot-high Tiger Dam (Figure ES-8). This is a temporary barrier that would include a water evacuation system and water level monitor. When compared with other temporary alternatives, this option can be used for multiple years, has the lowest planning-level cost, and minimizes labor and complexity for installation. A preliminary concept design-level cost for this project is estimated at $250,000.

The recommended design option for long-term flood protection is the reinforced-concrete cantilever wall. This was determined to be the most feasible and affordable option for permanent protection (Figure ES-9). It is recommended the wall be designed to a height of 10 feet. This height considers the 36-inch SLR plus 100-year storm surge scenario, which is relevant for the life span of the substation. A preliminary concept design-level cost for this project is estimated at $1.1M.

It is worth noting that the cost to protect the substation in the long-term is approximately the same as the cost to protect the Pier S shoreline. Based on the inundation mapping, protecting the Pier S shoreline would protect all assets on Pier S, including the SCE Dock Substation.

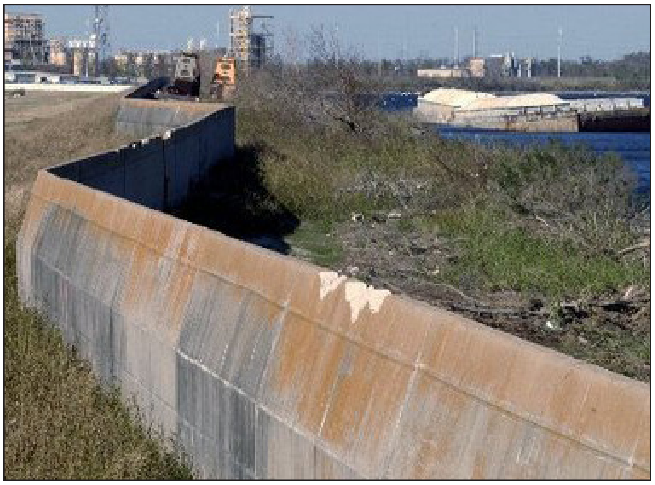


Figure ES-9. Permanent Cantilever Wall

The efforts of this strategy can be applied across the Port to other vulnerable critical assets. The adaptation examples listed for both near- and long-term protection introduce the range of protection types and highlight site-specific implementation considerations (such as storage of equipment, labor, training, and cost).

California Assembly Bill 691

This plan addresses all of the requirements outlined in the California State lands Commission Assembly Bill 691 (2014). More specifically, the Plan includes the following:

- Inundation maps with future planning timeframes (Chapter 4)
- Assessment of SLR impacts (Chapter 5)
- Proposed adaptation strategies (Chapters 6-11)
- Estimate of the financial costs of SLR (Appendix B)

Next Steps:

Near-term Recommendations Next 5 Years

☑ Finalize CRP

☑ Implement governance Strategy #1 – Addressing climate change impacts through Port policies, plans, and guidelines

☑ Implement governance Strategy #2 – Adding sea level rise analysis to the Harbor Development Permit

☑ Continue to assess the potential for a near-term solution for Strategy #5 – Pier S substation protection - evaluation of multiple strategies to address temporary inundation. Alternatively, Strategy #4 – Protection of Pier S shoreline, could be implemented instead, which would then protect all assets on Pier S.

☑ Continue to review “future consideration” strategies and implement as appropriate:

- Develop a Port climate change policy.
- Add climate change considerations to terminal/tenant leases.
- Share climate change knowledge that could impact Port development plans.
- Modify additional design criteria guidelines to include climate change.
- Include climate change considerations in the Energy Island Initiative.
- Share climate change knowledge with relevant stakeholders.
- Modify existing stormwater drainage model design parameters to include climate change.
- Track weather event impacts.

Long-term Recommendations 5 to 20 Years

☑ Review latest climate science and, if necessary, update the CRP (including inundation maps).

☑ Implement Strategy #4 – Pier S shoreline protection (if not already implemented).

☑ Review future consideration strategies and implement as appropriate:

- Dominguez Channel shoreline protection concept design (follow-up to Strategy #3).
- Understand potential climate change impacts and protect critical security systems.

Climate Science Review

Introduction

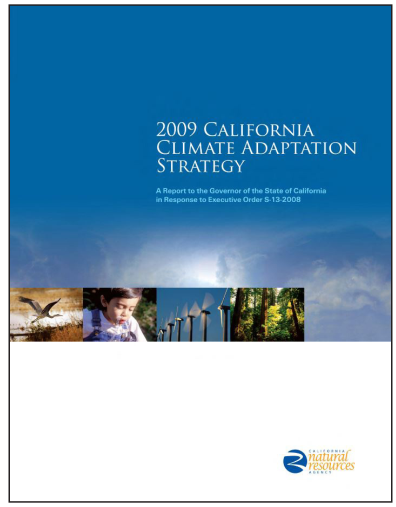
The science related to understanding the impacts of climate change is continually evolving and advancing over time. A detailed climate science review was completed for this project. This chapter highlights climate science information that was reviewed in support of the Climate Adaptation and Coastal Resiliency Plan (CRP), with a focus on the most relevant climate stressors (i.e., air temperature, precipitation, Sea Level Rise (SLR), storm surge, and oceanic acidity and temperature). This chapter also discusses the potential impact of the climate stressors on the Port of Long Beach (Port) (coastal infrastructure, transportation, energy, water, and water quality). The climate projections and associated impacts are summarized by mid-century and/or end-of-century, as appropriate.

The Port acknowledges the findings of the 2007 report of the Intergovernmental Panel on Climate Change (IPCC 2007), IPCC's Fifth Assessment Report (IPCC 2013), and the National Research Council's *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future* (NRC 2012) as the best available science. In addition, the State of California supports the findings of these reports and recognizes that climate change is already affecting California (California Natural Resources Agency 2009; California Coastal Commission 2015).

Information Sources

This summary draws on the best available data on climate science and the potential effects in California (as of April 2016). Pursuant to Executive Order S-3-05, enacted in 2005, the California Climate Change Center, a division of the California Energy Commission, prepares periodic reports on the science of climate change and the impacts on California's economy. To date, the California Climate Change Center has conducted three assessments, the latest released in July 2012. Each assessment highlights the major findings and implications of climate change for California based on a collection of scientific studies from academic institutions and state agencies.

This summary relied heavily on California's Third Assessment and the *2009 California Adaptation Strategy* (California Natural Resources Agency 2009) for information on statewide climate stressors and impacts. For more detail on state-level topics (e.g., precipitation, energy), this review relied on scientific studies, most of which were produced by the California Climate Change Center as part of the State's Second and Third Assessment. Where information was not available for California, peer-reviewed publications from the U.S. Global Change Research Program (USGCRP)—a collaborative venture of 13 Federal agencies that directs and integrates climate change research—and other research organizations filled in the gaps.



A variety of resources provided information on climate stressors and impacts specific to Southern California or the Los Angeles Region. In some cases, scientific studies from the California Climate Change Center included this level of detail. The Los Angeles Regional Collaborative (LARC) for Climate Action and Sustainability, a collaborative composed of leading municipal governments, agencies, universities, and organizations, is currently studying the effects of climate change at the neighborhood level, including the neighborhoods of Long Beach. The collaborative released a study of temperature in 2012 (updated in 2015) that provided the most detailed data on the Port (UCLA et al. 2012; Sun et al. 2015). Additionally, the group released a study in 2014 on future precipitation projections for the Los Angeles area (Berg et al. 2015).

Modeling Climate Change

A considerable amount of uncertainty surrounds future climate and the effects of climate change. Global Circulation Models (GCMs) incorporate the physical processes of the atmosphere, ocean, and land surface to simulate the response of the climate system to changing greenhouse gas (GHG) and sulfate aerosol emissions. Because the level of emissions in the future is unknown and will be affected by population, economic development, environmental changes, technology, and policy decisions, the IPCC developed a range of possible future emissions that are used in climate models (IPCC 2000).

In 2000, the IPCC Special Report on Emission Scenarios (SRES) was released and scenarios based on four main "families" (A1, A2, B1, and B2) were constructed to explore future developments in the global environment with reference to the production of GHGs. Each family represents different demographic, social, economic, technological, and environmental developments. Model scenarios in the "A" family generally emphasize economic development over environmental conservation with higher emissions, whereas scenarios in the "B" family predict lower emissions resulting from increased energy conservation and clean energy technologies. Both A and B include increased emissions over current (relative to 2015) levels. Model Scenarios in the "1" family consider a more unified world focus, resulting in lower population, whereas scenarios in the "2" family are more regionally focused and generally have higher population forecasts. Therefore, the higher-emissions scenarios would generally be in the "A" and "2" families. The four model families are subdivided into six scenario groups: one group each in the A2, B1, and B2 families, and three groups in the A1 family, characterizing developments of energy technologies: A1FI (fossil intensive), A1T (predominately non-fossil), and A1B (balanced energy sources).

Each of the six groups contains additional model scenarios that have different driving forces yet similar emissions to their family. Altogether, this structure encompasses 40 individual emission scenarios, developed to cover a wide range of key future characteristics (Figure 2-1). In Figure 2-1, each line represents an individual scenario that is grouped into the six scenario groups (from IPCC 2000).

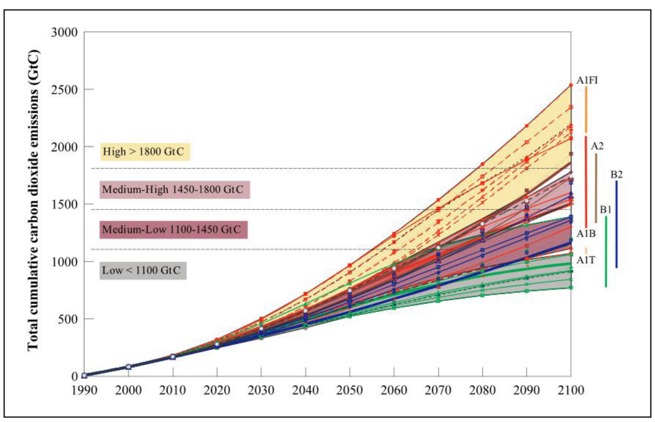


Figure 2-1. SRES Example of Cumulative Carbon Dioxide Emissions (in gigatons [GtC])

A new set of scenarios, Representative Concentration Pathways (RCPs), was released in the IPCC's Fifth Assessment Report on Climate Change (AR5) in 2014. Rather than updating the previous SRES projections, RCPs offer an enhanced representation of climate processes, including updates in data and advances in model development. The RCPs represent the change between incoming and outgoing radiation to the atmosphere caused by differences in atmospheric composition. GHG emission scenarios between IPCC AR4 and AR5 are similar, but the associated climate impacts may diverge due enhancements in the RCP approach. The four RCPs—RCP2.6, RCP4.5, RCP6, and RCP8.5 – are named after a possible range of radiative forcing in the year 2100 (+2.6, +4.5, +6.0, and +8.5 watts per square meter, respectively). Figure 2-3 describes each scenario and the SRES it most resembles.

RCP8.5

Describes a world characterized by rapid economic growth. CO_2e concentrations reach ~1,370 parts per million (ppm) by the end of the century. This is similar to the **A1FI** scenario of the SRES. It is often referred to as the **"business-as-usual"** scenario.

RCP6

Represents a stabilization scenario. CO_2e concentrations reach ~850 ppm by the end of the century, followed by stabilization. This is similar to the **A2** scenario from the SRES.

RCP4.5

Represents a stabilization scenario where CO_2e concentrations reach ~650 ppm by the end of the century, followed by stabilization. This is similar to the **B1** scenario from the SRES.

RCP2.6

Signifies a peak and decline scenario where CO_2e concentrations peak at ~490 ppm by mid-century, followed by rapid greenhouse gas emission reduction. This scenario is not similar to a scenario from the SRES.

Figure 2-2. RCP Characteristics Compared with the 2000 IPCC Special Report on Emissions (SRES)

GCMs provide estimates of climate change at a global level because the resolution—approximately 200 kilometers (km)—is typically too coarse for detailed regional climate projections (UCLA et al. 2012). Therefore, models are often "downscaled" to provide additional regional detail (i.e., a 200 km GCM may be downscaled to a 25 km scale for a specific region). California's Second and Third Assessments on climate change downscaled the outputs of six GCMs using two IPCC emissions scenarios (A2 and B1).

The downscaled GCM model output allows for more place-based projections of climate change at the state and local level. However, increased resolution does not necessarily equate to greater accuracy or reliability, as uncertainties remain in all climate projections.

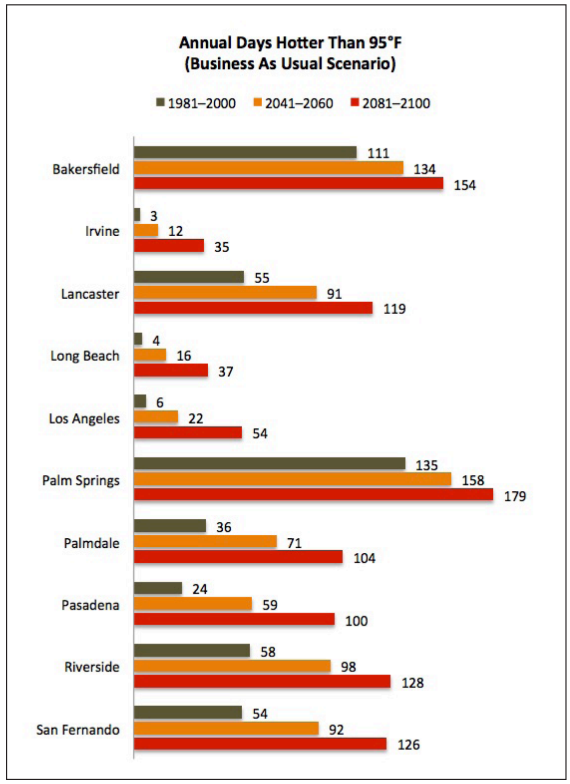
Climate Change Stressors

Temperature

Temperature varies considerably throughout the Los Angeles region. Warming is projected to be lowest along the coast, due to the Pacific Ocean's ability to absorb heat and the cooling effects of evaporation (UCLA et al. 2012). By mid-century (2041–2060), Long Beach temperatures are expected to increase by an average of 3.8°F (ranging from 1.8°F to 6.4°F) under the business-as-usual, RCP8.5) emission scenario, and an average of 3.4°F (ranging from 0.6°F to 6.1°F) under the RCP2.6 emission scenario relative to a baseline of 1981–2000. Warming is also likely to be greatest during the hottest months (summer and fall). The contrast between coastal and inland climates will also be the greatest during these seasons. These projections are consistent with a study of regional climate change impacts, which projected a 3.8°F temperature increase on the Southern California coast by the years 2060–2069 compared to 1985–1994, with greatest warming in the summer and fall months based on a downscaling of 16 GCMs (Pierce et al. 2013). In addition, the number of days with higher minimum temperatures is likely to increase.

The Los Angeles region is also expected to experience longer and more severe heat waves in the future. Figure 2-4 shows the average number of days per year that are projected to exceed 95°F in the baseline period (1981–2000) and the two future periods under the business-as-usual scenario, RCP8.5. This scenario assumes a continued increase in GHGs throughout the 21st century. The number of extremely hot days in Long Beach is likely to increase two- to threefold by the middle of the century (UCLA et al. 2012). By mid-century, extremely hot days (temperatures above 95°F) in Long Beach are projected to increase from a baseline (1981–2000) of 4 days to an average of 11 days per year under the RCP2.6 scenario and an average of 16 days per year under the business-as-usual RCP8.5 scenario. By the end of the century, the number of extremely hot days per year remains at 11 under the RCP2.6 scenario, but the number increases to 37 under the RCP8.5 scenario.

By comparison, inland areas are expected to experience even greater increases in the number of extremely hot days. For example, the inland city of Riverside experiences one of the region's greatest increases in days with temperatures above 95°F, with an average of 98 days per year by mid-century compared to a current average of 58 days per year.



Source: Sun et al. 2015.

Figure 2-3. Annual Number of Days Hotter than 95°F in the Los Angeles Region

Precipitation

Although considerable uncertainty surrounds the effects of climate change on precipitation, research conducted for California's Third Assessment projects substantially drier climates in Southern California by the mid-to-late century (CEC 2012). This results primarily from a decline in the frequency of rain and snowfall. Earlier snowmelt and increased soil moisture evaporation from temperature increases will compound the drying effects of decreased precipitation. Downscaled outputs of 16 GCMs predict that the total amount of precipitation along the Southern California coast will decline by an average of 9 percent by mid-century (2060–2069) compared to 1985–1994 (Pierce et al. 2013)[1] . However, high seasonal variability is expected and the magnitude of individual storm events could increase.

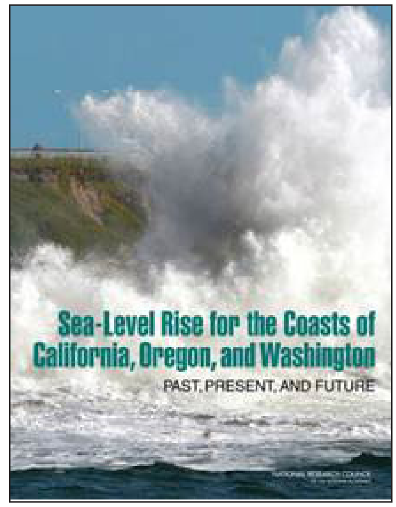
1 Since the climate science review was completed, downscaled precipitation models used in the Pierce et al. 2014 study shows variable results ranging from an increase, decrease, and no change in future annual precipitation over Los Angeles. Although the model results in this study showed an increase, the change is small compared with the region's natural variability. http://research.atmos.ucla.edu/csrl/LA_project_summary.html#Precipitation

Between 1970 and 2000, the average annual precipitation recorded at the Long Beach Airport was 12.94 inches (NCDC 2004). Seasonal averages for this same period ranged from 0.02 inches in July to 3.01 inches in February. Between 1970 and 2000, Long Beach Airport experienced an average of 36.1 days per year with precipitation over 0.01 inches (NCDC 2004). Precipitation in this region has historically been highly variable. The Los Angeles region is an excellent example of this variability, with both the driest (2006–2007) and wettest (2004–2005) water years on record (post-1921) occurring within the past 15 years (DWR 2008).

Storm frequency and intensity in Southern California have increased, which is consistent with statewide and national trends. Between 1948 and 2011, the frequency of extreme downpours increased by 35 percent in the portion of the state south of San Francisco Bay (Madsen and Wilson 2012). As a result, an intense storm that formerly occurred in the region only once per year now occurs every 9 months. During the same period, Southern California experienced a 7-percent increase in the amount of rainfall per storm.

Sea Level Rise

Global and regional climate models can be used to project the range of estimated SLR based on emission scenarios and climate simulations. Using low (B1), medium (A2), and high (A1FI) IPCC emissions scenarios with SLR projections based on Rahmstorf and Vermeer (2009), CO-CAT (2010) developed SLR projections relative to a Year 2000 baseline. Since the release of CO-CAT's Interim Guidance Document, the National Research Council (NRC 2012) published additional research regarding global and regional (West Coast) SLR (Figure 2-5). Table 2-1 presents the NRC (2012) and CO-CAT (2010) global SLR projections. In April 2013, CO-CAT released an update to their guidance document, revising SLR estimates to be consistent with findings of NRC (CO-CAT 2013).



After the release of both NRC (2012) and updated CO-CAT (2013) guidance, the IPCC released AR5, which provided updated consensus estimates of local SLR (IPCC 2014). One of the most notable updates to IPCC AR5 covers the advances in incorporating the influence of dynamic ice sheets and glaciers. However, the NRC (2012) high-end ranges are substantially higher than the upper estimates presented in IPCC AR5. The NRC (2012) high-end range includes significant land ice melt in Antarctica and Greenland, but IPCC AR5 does not include this in its projections, as there was not sufficient scientific consensus on this component of the SLR projections. The NRC (2012) projections are therefore a better comparison to the IPCC AR5 high-end estimates, and both sets of estimates agree well.

In March 2013, the State of California (State) adopted the NRC (2012) Report, as the best available science on SLR for the state and published guidance on incorporating SLR into state planning (CO-CAT 2013). At this time, the use of NRC (2012) projections and ranges as presented are appropriate for the Port's planning because they encompass the best available science, they have been derived considering local and regional processes, and their use is consistent with current State guidance.

Table 2-1. Global Sea Level Rise Projections from NRC (2012) and CO-CAT (2010)

	NRC (2012)		CO-CAT (2010)		
Year	Projection	Range	IPCC Emissions Scenario	Average of Models	Range of Models
2030	5.3 +/- 0.7 in	3.3–9.1 in	-	7 in	5–8 in
2050	11.0 +/- 1.3 in	6.9–19.0 in	-	14 in	10–7 in
2070	-	-	Low (B1)	23 in	17–27 in
			Medium (A2)	24 in	18–29 in
			High (A1FI)	27 in	20–32 in
2100	32.6 +/- 4.2 in	19.8–55.2 in	Low	40 in	31–50 in
			Medium	47 in	37–60 in
			High	55 in	43–69 in

NOTE: Projections provided relative to a Year 2000 baseline

Mean sea level response along the Los Angeles shoreline reflects the relative contributions of global SLR coupled with local and regional processes. Recent estimates of relative SLR at West Coast tide stations are available from the National Oceanic and Atmospheric Administration (NOAA 2012) and NRC (2012). Table 2-2 presents the NRC study findings for relative SLR projections at the Los Angeles tide station, which is immediately adjacent to the Port.

Based on the CO-CAT (2010) and NRC (2012) findings for projected global and regional SLR, the following SLR scenarios were selected for the Port's Climate Change Adaptation and Coastal Resiliency Plan: 16 inches, 36 inches, and 55 inches. These rates of SLR were not selected to correspond with a specific time horizon, but rather to represent the variability and uncertainty of SLR projections for mid-century and end-of-century planning purposes. Sea levels at the Los Angeles tide station adjacent to the Port can be expected to rise 5 to 24 inches by mid-century and 17 to 66 inches by end-of-century, based on both the CO-CAT (2010) and NRC (2012) projections.

Table 2-2. Regional Sea Level Rise Projections at Los Angeles Relative to Year 2000

Year	Projection (NRC)	Range
2030	5.8 in ± 2.0 in	2–11.8 in
2050	11.2 in ± 3.5 in	5.0–23.9 in
2100	36.7 in ± 9.8 in	17.4–65.6 in

Future SLR will elevate the mean sea level baseline upon which daily and extreme tidal variations are measured. Table 2-3 shows existing and projected future daily and extreme tides at the Los Angeles tide station under the three SLR scenarios. As can be seen, even a moderate sea level increase of 16 inches shifts the existing 100-year tide elevation (7.61 feet) to a roughly annual occurrence (1-year tide of 8.05 feet). Based on NOAA Coastal Services Center SLR inundation methods developed for the Sea Level Rise Viewer (Marcy et al. 2011), future SLR is typically mapped using the Mean Higher High Water (MHHW) tidal datum as a baseline; MHHW is the long-term average of the higher of the two high tides each day and represents an elevation which is exposed to daily tidal inundation. Mapping for extreme tide events typically uses the 100-year stillwater elevation (SWEL) as a baseline, which is the sum of the astronomical tide plus storm surge (wave effects are excluded). The 100-year SWEL represents an elevation that is exposed to inundation during an extreme tide and coastal storm surge event. Inundation mapping for the CRP used both MHHW and 100-year SWEL as baselines, as shown in Table 2-3, and described further in Chapter 4, Inundation Mapping.

Table 2-3. Regional Sea Level Rise Projections from NRC (2012) and CO-CAT (2010)

	Tide Level	Water Level in feet: Existing	+ 16 in SLR	+ 36 in SLR	+ 55 in SLR
Extreme Tides	100-year Tide (SWEL)	7.61	8.94	10.61	12.19
	10-year Tide	7.38	8.71	10.38	11.96
	Highest Astronomic Tide	7.14	8.47	10.14	11.72
	2-year Tide	7.11	8.45	10.11	11.70
	1-year Tide	6.72	8.05	9.72	11.30
Daily Tides	MHHW	5.29	6.62	8.29	9.87
	MHW	4.55	5.88	7.55	9.13
	MTL	2.64	3.97	5.64	7.22
	MSL	2.62	3.95	5.62	7.20
	MLW	0.74	2.07	3.74	5.32
	MLLW	-0.20	1.13	2.80	4.38

*NOTE: * Tidal datums are shown for the Los Angeles (#9410660) tide station for the 1983-2001 National Tidal Datum Epoch. Return periods (1-year, 10-year, etc.) shown correspond to the equivalent percent-annual-chance of occurrence. For example, a 100-year tide has a 1% chance of occurrence in any particular year. The bold numbers presented for MHHW and 100-year SWEL are the water surface baseline elevations used for the CRP inundation mapping.*

Acronyms:
MHHW = *Mean Higher High Water*
MHW = *Mean High Water*
MLLW = *Mean Lower Low Water*
MLW = *Mean Low Water*
MSL = *Mean Sea Level*
MTL = *Mean Tide Level*
SLR = *Sea Level Rise*
SWEL = *Stillwater Elevation*

Pacific Ocean Storm Climate

There is a general consensus among scientists that climate change will affect the intensity, frequency, and paths of coastal storms and wave events; however, a clear consensus has not yet emerged on the nature of these changes in the North Pacific Ocean (NRC 2012). The NRC provides a summary of recent research into changes in storminess in the North Pacific Ocean. Various physical processes are typically grouped together under the term "storminess," including frequency and intensity of storms, shifts in storm tracks, magnitude of storm surges, and changes in mean and extreme wind speed and wave heights (NRC 2012). Researchers have found some evidence of changes in storminess in both the 20th-century historical record and in climate model projections of future conditions, but interpretation of these results is somewhat controversial and partly reflects changes due to natural climate variability. One common trend among these studies is a tendency towards increases in wind speed and wave height, especially in the northeast Pacific from Northern California to Washington; however, further research is needed to confirm these findings and determine their relevance for the Southern California shoreline.

Ocean Acidity and Temperature

The California Current System (CCS), which spans the Pacific Coast of North America, is particularly vulnerable to future ocean acidification (Hauri et al. 2009). Regional modeling found that the pH of the CCS declined from 8.14 to 8.05 between 1750 and 2000, due to greater (carbon dioxide (CO2) emissions and ocean absorption of CO2. Such a decline was not anticipated to occur for several decades. Regional modeling shows the surface pH of the CCS to vary highly, both spatially and temporally. Nearshore waters along California's coast tend to have a generally low pH, although large seasonal changes occur. From April to October, offshore winds cause seasonal upwelling of waters high in CO2 (from organic matter respiration) and therefore, low in pH. For example, waters off the coast of Oregon have been found to have a pH as low as 7.75 during seasonal upwelling.[2]

The pH of the CCS may fall to as low as 7.6 by mid-century, depending on future emissions (Hauri et al. 2009). Positive feedback between ocean temperatures and pH is likely to amplify acidification. Declining pH may increase ocean temperatures and low-oxygen conditions, which in turn increases ocean acidification. At the same time, California's shallow coastal waters (e.g., wetlands, lagoons, bays) are expected to warm the fastest with future emissions and consequently are expected to reduce dissolved oxygen levels (California Natural Resources Agency 2009).

Climate Change Impacts

There are impacts that result from the climate stressors described above on a range of sectors in California. Table 2-4 summarizes the climate stressors and highlights potential climate change impacts in coastal infrastructure, transportation, energy, water, water quality, and coastal ecosystems. For impacts more specific to the Port and its operations, see Chapter 5, Vulnerability Profiles.

Coastal Infrastructure

Sea level rise will increase the risk of flooding for a wide range of coastal infrastructure. The combination of SLR, storm surge, and high tides with inland flooding will further increase the risk of coastal flooding. Sea level rise and more intense coastal storms will also increase the rate of coastal erosion and alter sediment transport patterns (California Natural Resources Agency 2009). Flooding and erosion will cause the greatest damage where unprotected coastal areas are subject to SLR and extreme wave conditions. Currently protected coastal areas, such as beaches and bluffs armored by seawalls and revetments, may become more vulnerable in the future as sea level rises, shorelines erode, and structures are exposed to water level and wave conditions that exceed those for which they were designed (NRC 2012). Similarly, protective port and harbor structures, such as breakwaters and wharves, will increasingly be exposed to wave overtopping and structural damage if they are not retrofitted for future conditions. Winter ocean storms (especially those occurring during El Niño conditions) are likely to be the most destructive, particularly as sea levels rise and ocean wave and storm conditions change.

Permanent property loss is a risk where continual inundation and erosion of low-lying areas occurs (California Natural Resources Agency 2009). Ports, and the infrastructure that serve them, are at particular risk for flooding from SLR and storm surge, given their coastal locations (CEC 2012). In addition to roads and railways, other supporting infrastructure along the coast is at risk.

As the focus is primarily on the impacts to marine organisms, there appears to be little research on the effects of ocean acidification and rising ocean temperatures on coastal infrastructure (see Coastal Ecosystems, below). However, a study of the risks of climate change to Australia's coasts states that declining ocean pH when combined with SLR and rising temperature can corrode materials and compromise their stability (Australian Government 2009). For example, acidic seawater can leach calcium from concrete, creating voids that reduce its strength. The corrosion of public utilities located along the coast, to which the Port is particularly vulnerable, is also a potential impact.

Transportation

Increased temperatures and extreme events place California's transportation infrastructure at considerable risk. Hotter and longer heat waves may increase the likelihood that highways and railroad tracks will buckle, deteriorate prematurely, or otherwise fail (California Natural Resources Agency 2009). Changes in precipitation patterns, such as more frequent and intense downpours, earlier snowmelt, and increased runoff, can all cause flooding of coastal highways, tunnels, railways, and runways, and associated interruptions to business operations. Peak flows have increased in many of California's rivers over the last 50 years; a continuation of this trend into the future will further increase the risk of flooding (DWR 2008).

2 Similar data does not appear to be available for Southern California's waters.

Transportation infrastructure located along the coast is especially vulnerable to flooding from SLR and storm surge, particularly when SLR and storm surge coincide with inland flooding. The inundation of key transportation corridors, particularly from SLR coupled with the more frequent occurrence of extreme storms, may result in increased travel times via alternate routes (CEC 2012).

Energy

Climate change is likely to have considerable effects on the availability of energy in the future, increasing the risk of power outages (California Natural Resources Agency 2009). Rising temperatures, notably longer and hotter summers, together with population growth, are likely to increase the demand for summertime cooling in Southern California (CEC 2012; California Natural Resources Agency 2009). The residential sector is the main driver of increased electricity demand, as it is the most sensitive to temperature changes (compared to industrial and other sectors) (Franco et al. 2011). In some parts of the Los Angeles region, residential electricity demand may increase by as much as 50 percent by 2100, depending on warming, energy efficiency upgrades, and rate increases (CEC 2012; Franco et al. 2011; Guegan et al. 2012). Similar electrical demand increases are expected to occur in the state's other major metropolitan areas, and electricity demand in the Central Valley by the end of the century may increase by over 100 percent, placing major strains on California's energy supplies and affecting other users (CEC 2012; Aroonruengsawat and Auffhammer 2009).

The effects of increasing energy demand during heat waves are already apparent in Southern California. During August 2012, temperatures above 100°F caused spikes in demand that affected Long Beach's power provider, Southern California Edison (SCE), and caused outages in Simi Valley, north of Los Angeles (Garcia et al. 2012). Severe storms caused by the extreme heat also knocked down SCE poles in inland areas east of Long Beach, causing power outages (Phillips et al. 2012). During the heat wave, the California Independent System Operation, which operates the majority of the State's high-voltage grid, issued a rare statewide alert to conserve electricity, particularly during afternoons when demand for air conditioning is often the greatest (Carroll 2012).

High temperatures reduce the capacity of transmission lines by 7 to 8 percent, and the number of extremely hot days is expected to dramatically increase in the Los Angeles region by mid-century, as described above (CEC 2012; UCLA et al. 2012). Transmission lines are also vulnerable to extreme events, notably wildfire and flooding, and consequently, to power outages. Transmission lines in the Los Angeles metropolitan area are at particularly high risk for wildfire, some with a 45 percent probability of wildfire by 2100 (CEC 2012). Transmission lines are also at risk of flooding from earlier snowmelt, increased runoff, and winter storms (California Natural Resources Agency 2009).

The combination of increased energy demand and strains on supplies means that California faces up to a 17 percent chance of electricity deficits during high-demand periods (notably summer) by 2070–2099 (California Natural Resources Agency 2009). By 2100, the state will need to increase its energy generation by an estimated 38 percent (17 gigawatts) to account for the effects of rising temperatures alone (CEC 2012).

Water

Climate change has the potential to cause serious water shortages throughout California, exacerbating conflicts among users. The state's growing population will increase the demand for water in the future, by over 10 percent between 2020 and 2050 (CEC 2012; California Natural Resources Agency 2009). Coincidentally, substantial declines in the availability of surface water supplies are expected.

Water Quality

Climate change is likely to adversely affect not only water supplies, but water quality as well. Rising temperatures and changes in precipitation that reduce stream flows will increase pollutant concentrations and water temperature, the latter decreasing dissolved oxygen (California Natural Resources Agency 2009; DWR 2008). Higher peak flows from increased runoff and more severe storms will likely cause erosion, thereby increasing turbidity and higher pollution loads, which pose risks to public health.

Summary

This chapter summarized the results of the climate science review. It also included discussion of information sources used (California's Third Assessment, the 2009 California Adaptation Strategy and Climate Change in the Los Angeles Region project, the 2012 National Research Council's Sea Level Rise Report for the U.S. West Coast, and the International Panel on Climate Change's Fourth and Fifth Assessments), climate stressors (temperature, precipitation, SLR, extreme wind, and ocean acidity), and potential climate impacts to Port operations by mid-century and end-of-century with regards to coastal infrastructure, transportation, energy, water, and water quality.

Table 2-4. Summary of Climate Stressors and Impacts

<table>
<tr><th></th><th>Mid-Century</th><th>End-of-Century</th><th>References</th></tr>
<tr><td colspan="4">Climate Stressors</td></tr>
<tr><td>Temperature</td><td>▪ +0.6°F–6.4°F in Long Beach
▪ +two- to threefold extremely hot days</td><td>▪ +4.1°F–8.6°F in California</td><td>▪ UCLA et al. 2012
▪ CEC 2012</td></tr>
<tr><td>Precipitation</td><td>▪ −9% total rainfall on California Coast
▪ −13% days of rainfall on California coast</td><td>▪ Increased storm frequency/severity (20-year storm becomes 4–15-year storm) in California
▪ +10–25% total rainfall per storm in California</td><td>▪ Pierce et al. 2013
▪ USGCRP 2009</td></tr>
<tr><td>Sea Level Rise (SLR)</td><td>▪ 11–24 in. of SLR in Los Angeles</td><td>▪ 37–66 in. of SLR in Los Angeles</td><td>▪ CO-CAT 2010
▪ NRC 2012</td></tr>
<tr><td>Extreme Wind</td><td>▪ Limited data available</td><td>▪ Limited data available</td><td>▪ N/A</td></tr>
<tr><td>Ocean Acidity + Temperature</td><td>▪ −0.5 units pH in California waters
▪ Warming of coastal waters</td><td>▪ Warming of coastal waters</td><td>▪ Hauri et al. 2009
▪ California Natural Resources Agency 2009</td></tr>
<tr><td colspan="4">Climate Impacts</td></tr>
<tr><td>Coastal Infrastructure</td><td colspan="2">▪ Coastal flooding, erosion and damage from SLR, storm surge and high tides
▪ Altered sediment transport from SLR and changing coastal storm surge conditions
▪ Inland flooding from increased peak flows, runoff, and more frequent/severe rainstorms
▪ Materials corrosion from lower ocean acidity
▪ Corrosion of coastal utilities from lower ocean acidity</td><td>▪ California Natural Resources Agency 2009
▪ NRC 2012
▪ Australian Government 2009</td></tr>
<tr><td>Transportation</td><td colspan="2">▪ Coastal flooding, erosion, and damage from SLR, storm surge and high tides
▪ Inland flooding from increased peak flows, runoff, and more frequent/severe rainstorms
▪ Landslides/mudslides from more frequent/severe wildfires and rainstorms
▪ Materials degradation/failure from heat waves</td><td>▪ CEC 2012
▪ DWR 2008
▪ CEC 2012</td></tr>
<tr><td>Energy</td><td>▪ −7–8% transmission capacity on extremely hot days
▪ Reduced hydropower generation</td><td>▪ +50% residential demand in Los Angeles region
▪ +100% residential demand in Central Valley
▪ +45% probability of wildfire affecting transmission lines in Los Angeles region
▪ 38% energy supply shortfall
▪ −7–8% transmission capacity on extremely hot days
▪ 17% probability of electricity deficit
▪ Reduced hydropower generation</td><td>▪ CEC 2012
▪ UCLA et al. 2012
▪ Franco et al. 2011
▪ Guegan et al. 2012
▪ Aroonruengsawat and Auffhammer 2009</td></tr>
<tr><td>Water Quality</td><td colspan="2">▪ Increased sediment runoff and turbidity
▪ Increased pollutant concentrations
▪ Increased salinity</td><td>▪ California Natural Resources Agency 2009
▪ DWR 2008
▪ Chung et al. 2009</td></tr>
</table>

Acronyms and Abbreviations:

CEC = *California Energy Commission*
CO-CAT = *Coastal and Ocean Working Group of the California Climate Action Team*
DWR = *California Department of Water Resources*
In. = *inches*
N/A = *not available*
NRC = *National Research Council*
SLR = *Sea Level Rise*
UCLA = *University of California, Los Angeles*
USGCRP = *U.S. Global Change Research Program*

Asset Inventory

Introduction

An inventory was developed to identify and organize the assets of the Port of Long Beach (Port) prior to undertaking the vulnerability assessment to climate change stressors. The inventory of assets was developed in a Microsoft Excel format.

The main goal of the inventory is to capture the Port's critical assets, specific components/operations, present an estimate of critical asset value, and then assess vulnerability to climate change impacts. The vulnerability assessment uses the inventory to evaluate an asset's exposure to climate stressors, its sensitivity, and its adaptive capacity.

The Port comprises:

- 3,000 acres of land
- 4,600 acres of water
- 10 piers
- 80 berths
- 66 post-Panamax gantry cranes
- 22 shipping piers
  - 5 break-bulk piers (automobiles, lumber, steel, iron ore)
  - 6 bulk piers (petroleum coke, salt, gypsum, cement)
  - 6 container piers
  - 5 liquid bulk piers (petroleum)

Methodology

The inventory was developed in Microsoft Excel spreadsheet format with worksheets organized by piers, transportation (road and rail), and miscellaneous land use.

The inventory was developed using extensive data provided by the Port as well as review and discussions with AECOM and Port engineers. The remainder of this chapter describes each of the inventory categories in more detail.

All Piers

The Piers category provides detailed information for each berth (see Table 3-1).

Table 3-1. Piers Inventory Data

Criteria and Data Points

Critical Port Asset? Y/N

Private Property Y/N

Cargo Type
- Container (20-foot equivalent units [TEUs])
- Liquid Bulk (barrels)
- Dry Bulk (tons)
- Roll-on/Roll-off (RORO) (units)

Pier Functional Characteristics
- Pier Volume (million units)
- Pier Size (acres)
- Berth Length (ft)
- Wharf Height (ft)
- % Cargo Moved by Truck, Rail, or Pipeline
- Annual Value Moved ($M)
- Annual Value per Acre ($M)

Wharf Assets
- Structure – Wharf on Concrete Piles, Steel Piles, Steel Bulkhead, or Concrete Quay Wall
- Structure – Rock Dike
- Structure – Mooring Dolphin
- Mooring Hardware (Bollards, Cleats, Quick Release Hooks)
- Fender Systems – Timber Piles
- Fender Systems – Rubber Fender Units
- Shore-to-Ship Power Receptacles
- On Dock Rail
- Cranes / Lifting Equipment / Product Loading / Unloading Arms / Traveling Bulk Shiploaders
- Small Vessel Access Dock
- Containment Boom Storage
- Piping Supports & Corridors
- Fire Detection & Suppression Systems
- Conveyor Systems

Backland Assets
- Pavements
- Contaminated Material Storage
- Building Structures
- Buildings – Administration / Operations
- Buildings – Transit Sheds & Warehouses
- Gate Facilities (with Radiation Portal Monitors)
- Yard Gantry Cranes, Reefer (Refrigerator Container) Power Receptacle
- Liquid Bulk Storage and Movement
- Truck Loading / Unloading Facilities
- Conveyor Systems
- Receiving Hopper Systems
- Stockpile & Storage & Processing Facilities

Utilities
- Distribution Systems
- Sewer Conveyance Systems
- Sewer Pump / Lift Stations
- Storm Drain Conveyance
- Storm Drain Pump / Lift Stations
- Electrical Distribution Systems
- Lighting Distribution Systems
- Communication Systems
- Security Infrastructure

Transportation Road and Rail

Table 3-2 provides transportation road and rail information for each pier:

Table 3-2. Transportation Road and Rail Inventory Data

Transportation Road and Rail Inventory Data Included

ROAD

Classification
- Freeway
- Arterial
- Collector
- Private
- Roads / Traffic Signals
- Bridge

Outside Port Boundary: Y/N
Critical Port Asset: Y/N
Pier Location
Pier A, B, C, D, E, F, G, H, J, S, T, Navy Mole

RAIL

Company
List of all rail companies

Classification
- Storage
- Yard

Critical Port Asset: Y/N
Pier Location
Pier A, B, C, D, E, F, G, H, J, S, T, Navy Mole

Miscellaneous Land Uses

Table 3-3 identifies and provides information on the various land uses at the Port.

Table 3-3. Inventory of Miscellaneous Land Uses

Miscellaneous Land Uses Inventory Data

Pier: Address
Operator: Company Name
Current Land Use: Varies based on company
Public Safety Asset: Y/N
Critical Asset: Y/N

Critical Buildings

The inventory identified critical Port facilities, as shown on Figure 3-1, and Table 3-4 provides a key to the critical facilities identified on the map in Figure 3-1.

Value of Cargo

The inventory also estimates the total value by cargo type as a way of identifying which locations are most valuable in terms of cargo moved. The following methodology was used:

- Each pier was put into one of five categories: container, liquid bulk, dry bulk, break bulk, roll-on roll-off (RORO).
- Port staff provided the 2012 cargo volume for each pier.
- Liquid bulk used the current price of approximately $100 per barrel of oil (see www.oil-price.net/).
- Dry bulk based the dry bulk value on the price of coal (see www.eia.gov/coal/news_markets/).
- RORO used $20,000 per vehicle.
- For break-bulk and container units, the values were not known. It was assumed that these units were of similar value on a per-ton basis and that each 20-foot equivalent container unit (TEU) contained 10 tons of cargo on average.
- The value of a TEU was adjusted until the Port-wide total cargo value was approximately $155 billion. These data were then used to develop charts of value moved per pier and to aggregate charts of value moved per cargo type and per acre of facility by cargo type

This exercise demonstrates that container cargo is the dominant cargo type by value, at over 80 percent of the Port's total cargo value. Container terminals are also by far the largest segment of the Port on a per-acre basis. Liquid bulk terminals tend to be quite small, and are able to move a lot of product by value because of low dwell times and high backland capacity. This means that on a per-acre basis, liquid bulk terminals are the most valuable in the Port by a considerable margin. The remaining three categories (dry bulk, break bulk, and RORO) are relatively small in both size and intensity of operations. As a result, these three categories combined make up less than 5 percent of Port cargo by value.

Asset Inventory Spreadsheet

The asset inventory includes sensitive, dated, and confidential information, and it is therefore a separate internal document for Port staff only.

Summary

This chapter summarizes the asset inventory developed to catalogue the Port's assets prior to carrying out the vulnerability assessment. The main goals of the inventory are to capture the Port's critical assets and specific components/ operations, to present an estimate of critical asset value, and to provide a framework to assess vulnerability to climate change impacts.

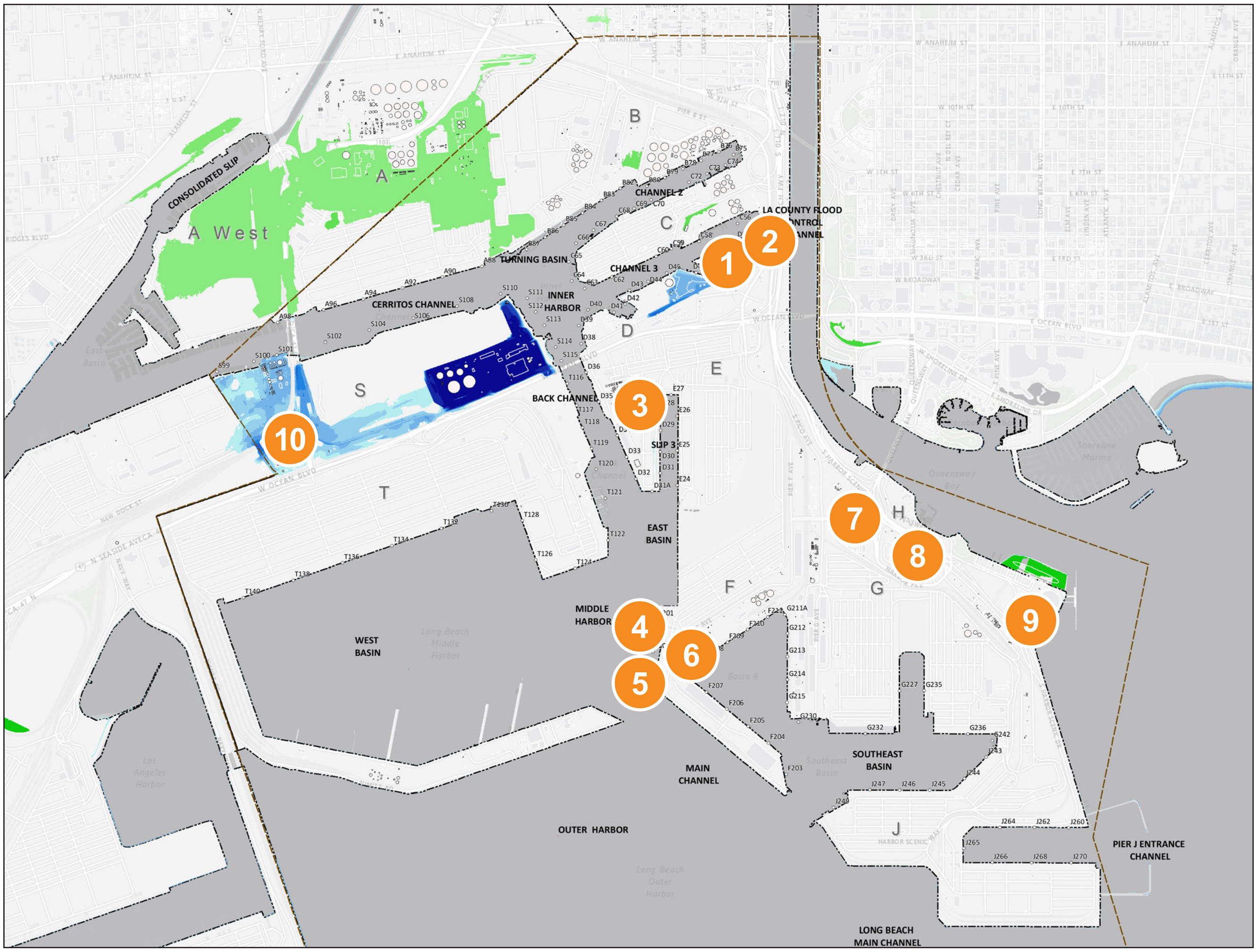


Figure 3-1. Location of Critical Facilities

Table 3-4. Key for Critical Facilities Map

Ref #	Pier	Description	Company/Agency
1	Pier D	Mooring of tug boats and barges	Foss Maritime
2	Pier D	Fireboat Station #20 (Temporary fireboat dock and fire station)	Long Beach Fire Department
3	Pier D	Storage Warehouse (Police department and bridge contractors use area for storage of fire trucks and important equipment.)	Port of Long Beach
4	Pier F	Fireboat Station #15	Long Beach Fire Department
5	Pier F	Operation of pilotage business	Jacobsen Pilot Service, Inc.
6	Pier F	Security Command and Control Center Building	Port of Long Beach Security Command and Control Center
7	Pier G	Port Administration Building (Building is slated for demolition in late 2015 / early 2016.)	Port of Long Beach
8	Pier G	Port Maintenance Facility (Construction and Operation Trailers)	Port of Long Beach
9	Pier H	Fireboat Station #6 (on land)	Long Beach Fire Department
10	Pier S	Fire Station #24	Long Beach Fire Department

PORT OF LONG BEACH
Inundation Mapping

16" Sea Level Rise + 100-Year Stillwater Elevation

Depth in Feet

- 0 - 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- 10 - 12
- 12 - 14
- 14 - 16
- 16+
- Disconnected Areas > 1 Acre

TRANSPORTATION FEATURES

- Road Edge
- Bridges
- Rail

BASE LAYERS

- Pier
- Critical Facility
- Buildings
- Dock
- Berth
- Tanks
- Harbor District Boundary

0 0.1 0.2 0.4 Miles

1 in = 0.4 miles

1 inch = 1,874 feet

0 600 1,200 2,400 3,600 Feet

Projection:
California State Plane Zone 5, North American Datum 1983

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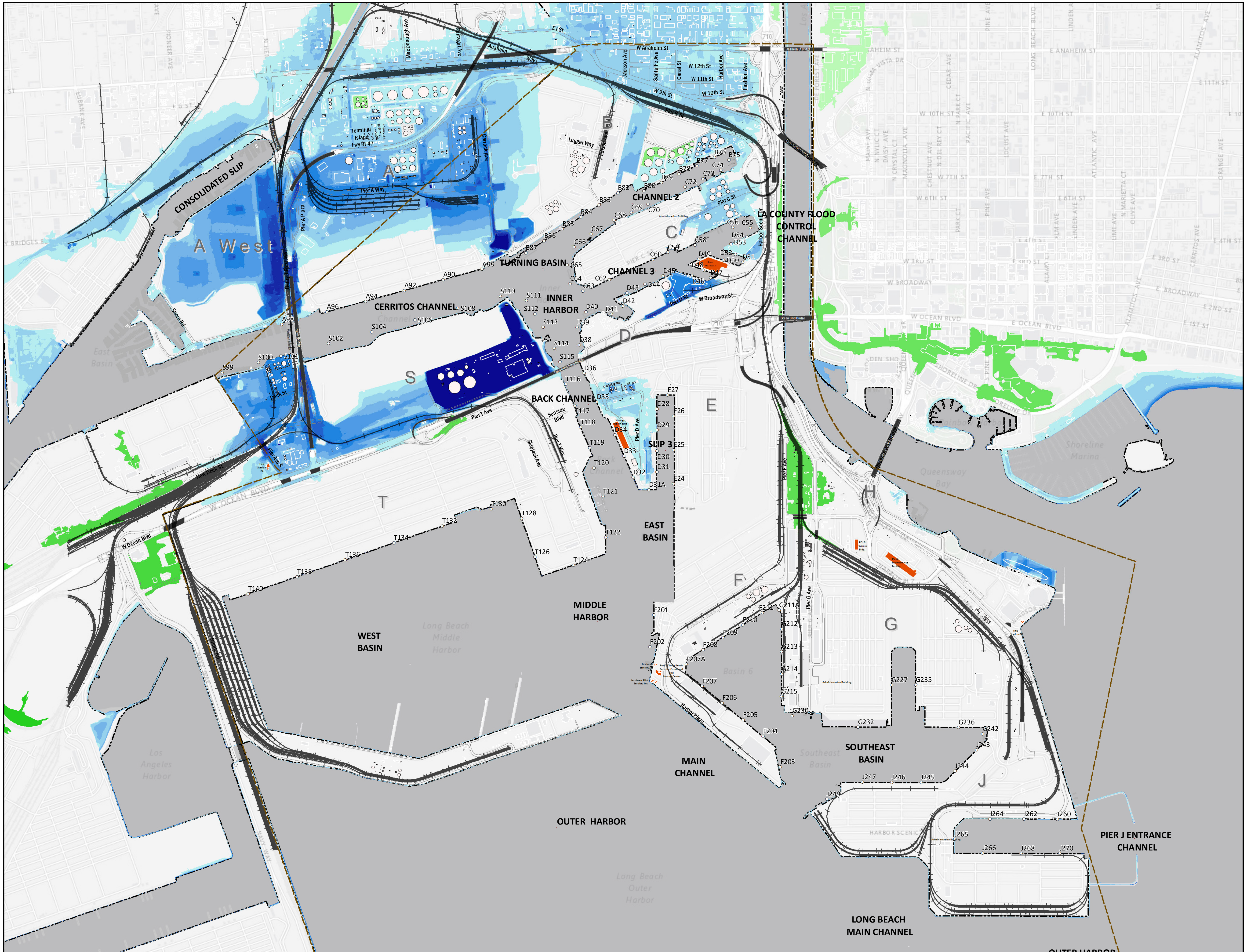

PORT OF LONG BEACH
Inundation Mapping

36" Sea Level Rise + 100-Year Stillwater Elevation

Depth in Feet
- 0 - 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- 10 - 12
- 12 - 14
- 14 - 16
- 16+
- Disconnected Areas > 1 Acre

TRANSPORTATION FEATURES

- Road Edge
- Bridges
- Rail

BASE LAYERS

- Pier
- Critical Facility
- Buildings
- Dock
- Berth
- Tanks
- Harbor District Boundary

0 0.1 0.2 0.4 Miles
1 in = 0.4 miles
1 inch = 1,874 feet
0 600 1,200 2,400 3,600 Feet

Projection:
California State Plane Zone 5, North American Datum 1983

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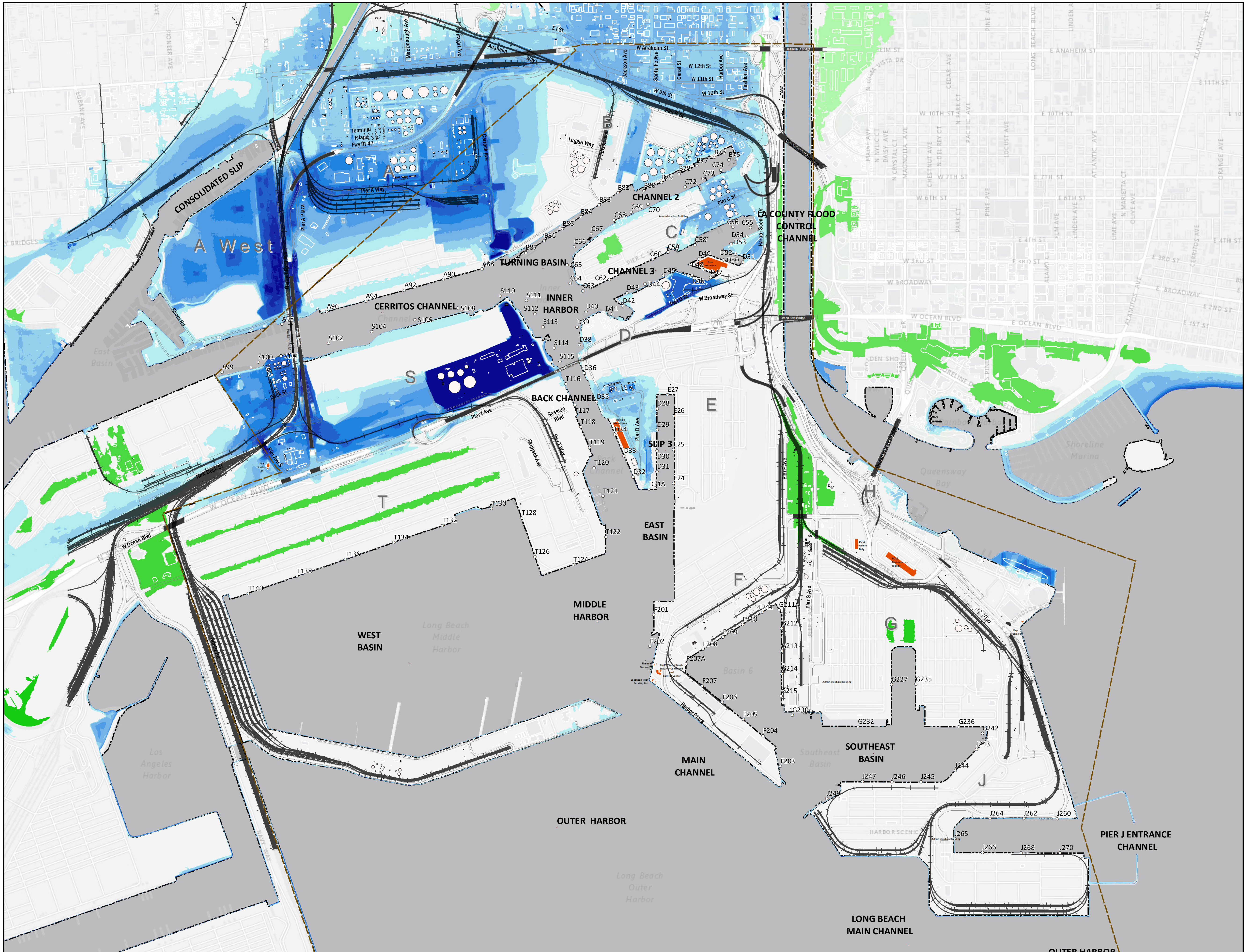

PORT OF LONG BEACH
Inundation Mapping

55" Sea Level Rise + 100-Year Stillwater Elevation

Depth in Feet
- 0 - 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- 10 - 12
- 12 - 14
- 14 - 16
- 16+
- Disconnected Areas > 1 Acre

TRANSPORTATION FEATURES
- Road Edge
- Bridges
- Rail

BASE LAYERS
- Pier
- Critical Facility
- Buildings
- Dock
- Berth
- Tanks
- Harbor District Boundary

0 0.1 0.2 0.4 Miles
1 in = 0.4 miles
1 inch = 1,874 feet
0 600 1,200 2,400 3,600 Feet

Projection:
California State Plane Zone 5, North American Datum 1983

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Cost of Sea Level Rise: A High-Level Financial Analysis

Introduction

The Port of Long Beach is subject to the California State Lands Commission Assembly Bill 691, passed in 2014, which requires the development of a Sea Level Rise (SLR) study that includes financial cost estimates on granted public trust lands.

To comply with this requirement, this high-level estimate considers the following: (1) potential cost of repair of damage and (2) the value of lost use of assets, (3) the anticipated cost to implement adaptation strategies, and (4) the anticipated benefits from adaptation at the Port of Long Beach. An overview of non-market values that may be impacted is also provided.

Methodology

This cost analysis uses a qualitative tiered categorization approach (e.g. “low”, “medium”, “high”) to classify impacts from three SLR scenarios in combinations with a 100-year storm event.

Using the asset inventory and the vulnerability profiles from the findings of the Port’s Climate Adaptation and Coastal Resiliency Plan (CRP), an estimate of the costs to repair damage was assessed using the order of magnitude replacement cost for damaged assets and gauged relative to the cost of Port mitigation actions. The order of magnitude value of lost use is based on the estimated value of the assets and cargo in the area impacted, and is gauged relative to the total economic output of the Port. Costs of implementing adaptation strategies are based on estimated level of effort for the Port, and are also gauged relative to the cost of Port actions. Next, implementation benefit is estimated based on how effective the adaptation strategy is in mitigating cost to repair and the value of lost use.

No direct financial impacts or cost estimates were released with this analysis due to the confidential nature of the value of cargo, port functions, and facility/equipment damage considerations, though these impacts and costs were considered in developing the cost classification for each scenario at an order of magnitude level. Even without direct financial or cost estimates, the relative relationship of losses under a no-action scenario compared to the cost of mitigation can be used to provide a threshold to estimate the relationship of costs and avoided losses, or benefits. This approach protects proprietary data, and allows for some level of cost variance within an order of magnitude context.

Cost and impact categorization definitions and criteria are further detailed in the table belowCost Estimation for Substation Relocation

Table B-1. Cost and impact categorization

Key	Cost to Repair / Adaptation Costs (asset damage)	Value of Lost Use / Adaptation Benefit (cargo damage and operation disruptions)
Low	No repairs, but storm surge flood waters need to recede before asset can be used / administrative, procedural, and/or permitting action	No loss of critical port asset and/or loss of high-value cargo staging area. Port operations temporarily disrupted
Mid	Repair infrastructure / installation of temporary protective measures	Temporary loss of critical port asset(s) and/or loss of high-value cargo staging area
High	Requires new capital construction projects.	Loss of critical port asset(s) and/or loss of high-value cargo staging area and/or port-wide infrastructure limitations

Sources used for this analysis include:
- *Vulnerability Profiles and Inventory from the Port Climate Adaptation and Coastal Resiliency Plan (CRP)*
- *Port Economic Impacts Report*
- *Center for the Blue Economy Library*
- *Duke Marine Ecosystem Services Partnership*
- *California Energy Commissions’ California Climate Change Center*

Table B-2. Cost of Sea Level Rise Analysis

SLR Scenario	SLR Cost Impacts*		Cost of Adaptation	
	Vulnerabilities	Potential Impact	Recommended Adaptation Strategy	Implementation Cost + Benefit
16" SLR + 100-year event (proxy for 2030 -2050 scenario)	Pier S – Partial permanent inundation of berths, buildings, and tanks; complete inundation of roads (access to Fire Station #24 will be inundated) and railway.	Cost to Repair: Mid Value of Lost Use: High	Retrofit Pier S Seawall	Cost: Mid Benefit: High
	Pier D – Partial permanent inundation of berths, buildings, and tanks; inundation of roads and railways	Cost to Repair: Low Value of Lost Use: Low	None at this time – the vulnerable portions of the Pier are not currently leased	NA
	Pier A – Partial temporary inundation	Cost to Repair: Low Value of Lost Use: High	See below	Cost: Mid Benefit: High
	Pier B – Partial temporary inundation	Cost to Repair: Low Value of Lost Use: High	See below	Cost: Mid Benefit: Mid
	Pier C – Partial temporary inundation	Cost to Repair: Low Value of Lost Use: Mid	None at this time	NA
	Rail and Road: Piers E, F, G, J & T – partial loss of access	Cost to Repair: Mid Value of Lost Use: High	*Implement semi-permanent flood protection barriers that can be erected during temporary storm surges on Piers A and B to protect rail and road to minimize operation disruptions. Alternatively, consider developing a shoreline protection measure along the Dominguez channel that incorporates the findings from the SLR + riverine analysis to protect all assets.	Cost: High Benefit: High
	Freeway Route 47 – inundated	Cost to Repair: Low Value of Lost Use: Low	Addressed in Pier S recommendations	Cost: Low Benefit: Low
	Summary: 2 piers directly impacted with permanent inundation and all other piers impacted temporarily by storm surge or indirectly impacted by loss of access	***Cost to Repair: Mid*** ***Value of Lost Use: High***	▪ ***Improve Pier S Seawall*** ▪ ***Protect roadways and rail on Piers A & B from temporary inundation with semi-permanent flood protection barriers*** ▪ ***Update Port plans, policies, and design guidelines to include SLR considerations***	***Cost: Mid*** ***Benefit: High***

SLR Scenario	SLR Cost Impacts*		Cost of Adaptation	
	Vulnerabilities	**Potential Impact**	**Recommended Adaptation Strategy**	**Implementation Cost + Benefit**
16” SLR + 100-year event (proxy for 2030 -2050 scenario)	*Includes all 16” SLR impact compounded by greater flood levels*			
	Pier D – 2 additional areas temporarily inundated.	Cost to Repair: Low Value of Lost Use: Mid	Implement semi-permanent flood protection barriers that can be erected during storm surges to protect critical assets.	Cost: Mid Benefit: High
	Pier B – Partial temporary inundation of road	Cost to Repair: Low Value of Lost Use: Low	Implement semi-permanent flood protection barriers to protect critical assets.	Cost: Mid Benefit: Low
	Summary: 1 additional berth and 2 roads inundated	***Cost to Repair: Mid Value of Lost Use: High (includes 16” SLR scenario)***	▪ ***Protect critical assets on Piers B & D from temporary inundation with semi-permanent flood protection barriers.***	***Cost: Mid Benefit: High (includes 16” SLR recommendations)***
55” SLR +100-year event (proxy for 2100 scenario)	*Includes all 36” SLR impacts compounded by greater flood levels*			
	Pier A & B – Partial permanent inundation of buildings and tanks	Cost to Repair: Mid Value of Lost Use: Mid	Develop a shoreline protection measure where overtopping occurs and incorporate the findings from the SLR + riverine analysis.	Cost: High Benefit: High
	Pier A – railway permanently inundated	Cost to Repair: Low Value of Lost Use: High		
	Pier B – railway permanently inundated	Cost to Repair: Low Value of Lost Use: High		
	Rail: Piers F, G, & J – loss of rail access due to permanent inundation on adjacent piers	Cost to Repair: Low Value of Lost Use: High		
	Summary: Multiple buildings and tanks and 3 rail lines inundated with additional loss of rail access throughout the Port	***Cost to Repair: High Value of Lost Use: High (includes 16” & 36” SLR scenario)***	▪ ***Build/retrofit sea wall along all areas that are overtopped (Piers B, C, A West, and D) to protect the assets from permanent inundation.***	***Cost: High Benefit: High (includes 16” and 36” SLR recommendations)***

*Note: all costs are high level, order of magnitude estimates and are most relevant for comparison between alternatives as opposed to compared to baseline value. *Includes 100-year event flood levels. DISCUSSION OF FINDINGS*

Discussion Of Findings

The analysis of the above three SLR scenarios reveals varying levels of impacts for each scenario and the range of potential adaptation strategies to address them.

The overall impacts of the 16” SLR plus 100-year storm event scenario are estimated to have a medium cost to repair but would prove to be high impact in terms of disrupted port functions and inoperable facilities/equipment. Recommended mitigation strategies include improving the susceptible seawalls, install semi-permanent/temporary barriers to protect key transportation links, and updating the Port’s overall plans, policies, and design guidelines to address SLR effects. The estimated cost of implementing the recommendations on the effected piers is medium, and implementation is anticipated to result in a high level of benefit. Because the benefit from implementation outweighs the cost, recommended strategies are expected to be cost-effective to implement.

The overall impacts of the 36” SLR plus 100-year storm event scenario include all impacts and benefits associated with the 16” SLR scenario, assuming a compounding effect given the anticipated higher flood levels. In addition to the exacerbated effects from higher flood levels, minor additional impacts are anticipated with the 36” scenario. The projected impacts are estimated to have a medium cost to repair, and would be high cost in terms of disrupted port functions and additional lost use of transportation infrastructure. Recommended mitigation strategies—in addition to 16” SLR scenario recommendations—include improving the seawall to protect overtopping at Piers A, B, C, and D. The estimated cost of implementing the recommendations on the effected piers is high given the expected construction and design costs of improving the seawalls. The anticipated benefit is also estimated to be high given the seawall improvements would protect critical port assets and functions. In this case, the benefits are likely to exceed costs, and recommended strategies are expected to be cost-effective to implement as they address both 36” SLR and 16” SLR scenarios with 100-year storm events.

Total impacts for the 55” SLR plus 100-year storm even scenario include all impacts and associated benefits of the 16” and 36” SLR scenarios, assuming a compounding effect with higher flood levels. In addition to the exacerbated effects of higher flood waters, additional impacts are anticipated with the 55” SLR scenario. Impacts are estimated to have a high cost to repair and a high cost in terms of disrupted port functions and additional loss of transportation infrastructure. Recommended mitigation strategies—in addition to all other SLR scenario recommendations—include installing semi-permanent/temporary barriers to protect key transportation routes and links. The estimated cost of implementing the recommendations on the effected piers is high with an associated high benefit across all scenarios.

Non-Market Values

SLR poses a broad range of economic risks to coastal communities. Generally these risks are estimated for goods and services where market prices are available, allowing for measurement of economic vulnerability in a relatively straightforward manner. However, coastal environments, including public trust lands like beaches and wetlands that are vulnerable to SLR, provide a number of important ecological, social and cultural services that do not have an explicit market price, but do have economic value.

Economists have devised a number of nuanced techniques to estimate the non-market value of coastal resources. These methods, which generally require extensive study, can help illustrate additional economic values that are important to consider when making adaptation investments and their potential outcomes to the built and natural environment.

Future consideration of non-market effects from SLR to Port managed public trust lands can provide a more comprehensive accounting of economic vulnerability and the pros and cons of different adaptation strategies. One potential avenue for future investigation could include the way in which SLR could affect coastal habitats like eelgrass beds that support coastal species and broader food web dynamics in the nearshore environment.

Note: The Port is an industrial and built-up seaport environment that has very few natural resources such as open space, intertidal and submerged wetlands, beaches, or rocky intertidal habitat. The Long Beach Harbor includes a nominal amount of shallow water habitat as well as a few small, seasonal areas of California giant kelp growth. Climate change mitigation resulting from existing biological resources in the Harbor was considered for purposes of vulnerability assessments but was determined to be insignificant as mitigation or for inclusion in feasible adaptation strategies.