# REPORT

## Sea Level Rise Vulnerability Assessment

### King Harbor, Redondo Beach

City of Redondo Beach
Public Works Department
Engineering Services Division

July 2019

NOBLE CONSULTANTS | GEC

# Redondo Beach King Harbor

# Sea Level Rise Vulnerability Assessment

Prepared for the City of Redondo Beach

In fulfillment of Assembly Bill 691 Reporting requirements

For the California State Lands Commission

Prepared by Noble Consultants-G.E.C., Inc.

July 2019

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## 1 Introduction

This report presents the results of a future sea level rise (SLR) vulnerability assessment of the City of Redondo Beach's King Harbor. Located at the south end of the densely populated Santa Monica Bay area, as shown in Figure 1. the man-made facility is a unique urban harbor complex that is one of the most valuable assets of the City. The mixture of sheltered mooring basins, commercial businesses, park and open space, and direct water access supports a variety of recreational opportunities that provide enjoyment for millions of residents and non-local visitors annually. As such, the harbor is an important source of income to the local economy. The purpose


**Figure 1. King Harbor and Vicinity**

of the study is to assess the potential threat that King Harbor may face due to SLR, and review possible management strategies that may be considered to preserve and maintain the public assets for as long as possible.

Sea level is rising due to the effects of global warming. Presently, no one knows with certainty how fast and how high the increase will be. By the end of this century, current estimates of ocean level increases in Santa Monica Bay range between one and ten feet. This broad forecast makes long term planning difficult as the potential threat associated with the two extremes varies significantly. To initiate a process of proactive preparedness, this report is intended to present an overview of the existing King Harbor setting, assess the potential vulnerability of assets to future SLR, and introduce preliminary concepts and measures that may be considered to begin a planning process on how best to address the issue.

This report is also intended to fulfill the City's obligation to report to the California State Lands Commission as mandated by Assembly Bill No. 691. The 2013 law requires that all legislatively granted public trustees submit a report that summarizes the potential impacts to tidelands that may occur due to future SLR, estimates the financial cost associated with such impacts, and describes how the trustee proposes to protect and preserve threatened natural resources and manmade assets.

The following five sections of this report provide relevant background information and describe existing conditions, assess future vulnerabilities and associated economic impacts, and outline conceptual adaptive management strategies. More specifically, Section 2 provides background information on existing conditions within King Harbor. Section 3 summarizes the current landscape of future SLR estimates. Section 4 discusses King Harbor's vulnerability to the potential future coastal hazards. Section 5 outlines estimated economic impacts that may be associated with future conditions. Finally, Section 6 introduces conceptual strategies to address future SLR scenarios.

## 2 The King Harbor Setting

King Harbor is a manmade facility that was developed between 1937 and 1965. The City began construction of the north breakwater in 1937, and that work was ultimately finished by the U.S. Army Corps of Engineers when Congress authorized the project in 1950. Upon completion of the breakwaters in 1958, the City commenced development of the interior basin to form what is today's harbor footprint. Fill was extended into tidelands to form three mooring basins and four new land areas (designated as Moles A, B, C, and D). The adjacent ocean pier complex, that dates to the early 1900s, and the uplands immediately behind it were incorporated within the total harbor footprint.

Figure 2 shows the harbor as it looked nearing the end of construction.

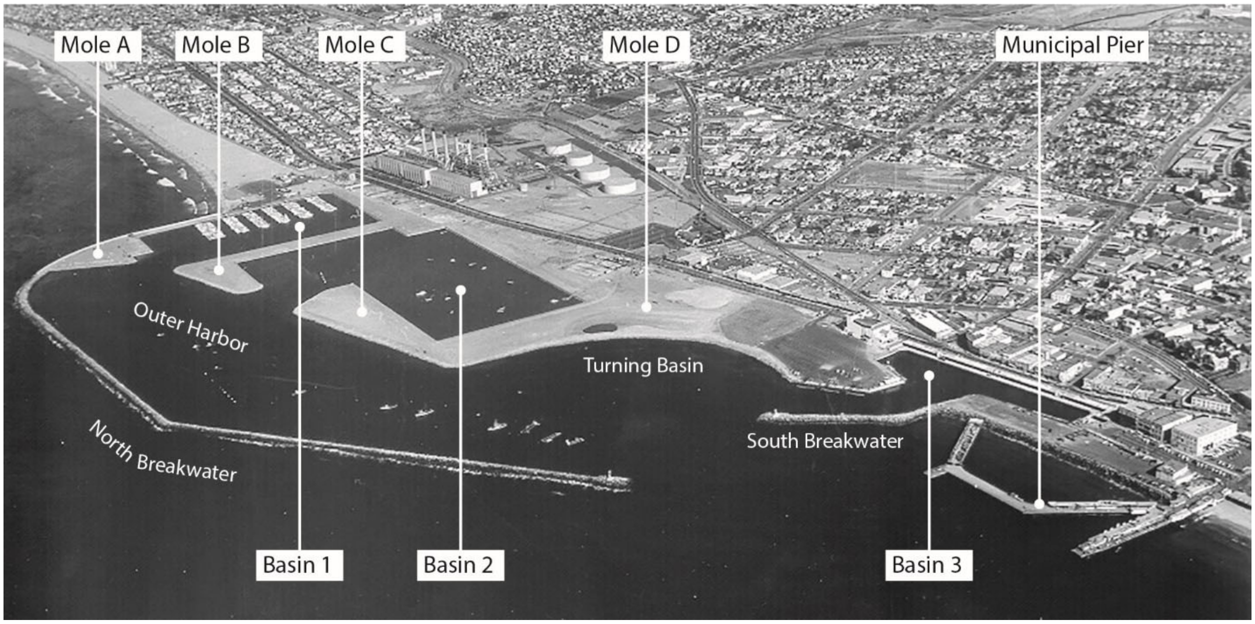


**Figure 2. King Harbor nearing completion in 1962**

King Harbor as it exists today is approximately 175 acres in size. Of that area the total water footprint is about 99 acres and consists of three mooring basins for wet storage of small craft, an outer harbor navigation channel and transient mooring area, and a turning basin that is offset from the main channel near the harbor entrance. The three marina basins total approximately 45 acres. About 36 percent of the 44-acre outer harbor area is dedicated as the harbor's main navigation entrance channel. The turning basin adjacent to Moles C and D comprises the remaining 10 acres of water area and serves as navigable waterway to and from Basin 3, temporary staging space for small craft, and recreation area for paddle sports activity.

Approximately 40 acres of the development is inland of the 1935 Mean High Water line that defines the demarcation between California tidelands and municipal owned land. The public trust grant for the offshore area was given to the City from the State in 1915 to yield the right, title, and interest in all State lands within the City limits seaward of the Mean High Tide line. At that time the dedicated lands were intended to be re-purposed for harbor development. The grant was later amended in 1971 to release four small parcels areas totaling about 8 acres in size from future navigation, commerce, or fisheries purposes.

The harbor footprint occupies about 132 acres of State tidelands. The Mole A, B, C, and D land portions were created by filling submerged land and stabilizing the perimeters with seawalls and stone slope protection. The resultant interior was subsequently partitioned into lease parcels in the 1960s to promote development and management of the harbor asset. Today, the harbor supports a variety of active and passive forms of water-related recreation and commercial businesses that promote public access to and enjoyment of the waterfront and ocean. Figure 3 shows an aerial plan of the existing King Harbor area with the general uses indicated.


**Figure 3. King Harbor Land Uses**

## 3 Future Sea-level Rise

The vulnerability of King Harbor's facilities will depend upon the magnitude of future SLR. As greenhouse gas emissions continue to impact the global climate, the warming of the atmosphere is projected to accelerate the melting of glaciers and polar ice sheets that will release more water into the oceans and cause thermal expansion. The cumulative effect of these physical processes will result in ocean levels that will be significantly higher than they are today. Predictions of the magnitude and rate of SLR are continually evolving as the science and understanding of the phenomenon becomes better understood and the ability to more accurately simulate the process with numerical models improves.

In the past 25 years, numerous studies have been published on the topic resulting in a number of forecasts that vary widely from one another. Figure 4 summarizes the current range of SLR forecasts that presently exist from a variety of respectable institutions and government agencies. The figure illustrates the dilemma that confronts engineers, planners and decision makers who are charged with management of King Harbor. The lack of certainty in the rate and magnitude of SLR makes it difficult to adopt implementation plans today for the future condition. This suggests that an adaptive management strategy may be the most appropriate path forward to address how best to maintain existing facilities and respond to future conditions as certainty becomes more focused.

The most current guidance for SLR planning was prepared by the California Coastal Commission in 2018[1] wherein the Ocean Protection Council's (OPC) 2018 guidance document[2] was endorsed as being the "best available science" on SLR in California. Accordingly, the Coastal Commission recommends using the OPC scenarios for planning and decision making.

The 2018 OPC guidance document introduces statistics to describe future SLR potential. Future projections are divided into three risk categories based upon probabilistic projections of increasingly more severe climate change scenarios. Depending upon the volume of future greenhouse gas emissions and the rate at which global warming and polar ice melt occur, there is estimated to be either a low (66% change of occurrence), medium-high (0.5% chance of

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1 California Coastal Commission, 2018. Sea level rise policy guidance, interpretive guidelines for addressing sea level rise in Local Coastal Programs and coastal development permits, November 7, 2018.

2 California Ocean Protection Council, 2018. State of California sea-level rise guidance, 2018 update, California Natural Resources Agency, 2018.

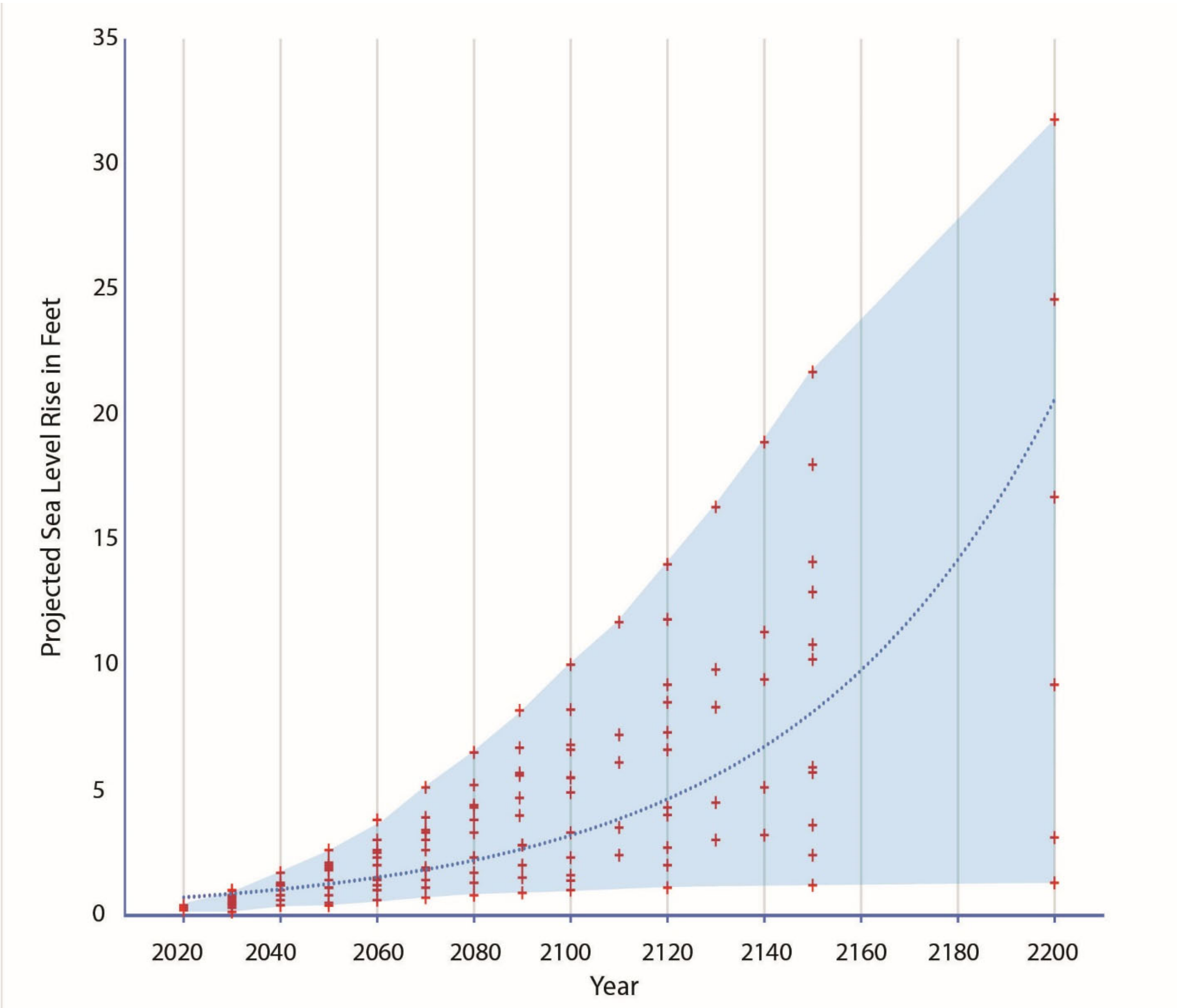


**Figure 4. Current range of global sea level rise projections.**

occurrence) and extreme (extremely rare occurrence) SLR risk aversion in the future. The extreme risk aversion scenario is so severe it currently has not been assigned a probability.

As indicated by the OPC, the low risk aversion scenario is suggested for review of projects that have a higher ability to adapt or have limited damage consequences (e.g. unpaved trails) from future SLR. The medium-high rise aversion scenario is proposed for review of projects that would have lower adaptation capability and greater vulnerability to inundation and associated hazards (e.g. coastal housing or commercial development). The extreme rise aversion scenario is suggested for projects that have no adaptation capability, have considerable public safety or health concerns, or would be costly to replace or relocate (e.g. power plant).

Table 1 summarizes the specific SLR projection estimates for the tide gauge closest to

Redondo Beach (Santa Monica) in Years 2030, 3050 and 2100 that reference the 2018 OPC guidelines. The three years correspond to the future milestones requested by the AB 691 reporting requirement.

**Table 1. Projected Sea-level Rise in Santa Monica Bay**

| Projected Year | Emission Condition | Low Risk Aversion (ft) | Medium-High Risk Aversion (ft) | Extreme Risk Aversion (ft) |
|---|---|---|---|---|
| | | 66% Probability | 0.5% Probability | Single Severe Scenario |
| *2030* | High emissions | 0.5 | 0.8 | 1.0 |
| *2050* | | 1.1 | 1.9 | 2.6 |
| 2100 | Low emissions | 2.3 | 5.5 | |
| | High emissions | 3.3 | 6.6 | 10.0 |

*Notes: Low risk aversion implies a 66% chance that SLR can be as high as the projected value.*
*Medium-high risk aversion implies a 5% chance that SLR meets the projected value.*

Reference: COPC, 2018. "State of California Sea-Level Rise Guidance", 2018 Update

For purposes of this initial planning study, the medium-high risk aversion projection was selected as the most representative scenario of future SLR vulnerability that is consistent with King Harbor's purpose, development characteristics, and adaptation capability.

**Table 2. Future Sea level Rise selected for this study**

| Year | SLR (ft) |
|---|---|
| 2030 | 0.8 |
| 2050 | 1.9 |
| 2100 | 5.5 |

## 4 Vulnerability Assessment

As a starting point, King Harbor's vulnerability to future SLR may be simply assessed on the basis of comparing existing topography with projected ocean elevations. More refined estimates progress by considering the effects of concurrent storm wave and tide occurrence. Although the existing breakwaters provide a measure of wave protection today, higher stands of sea level in the future will effectively lower the breakwater crest elevation exposing the harbor's interior to residual ocean swell that can enter the harbor mouth, pass through the porous rubble-mound breakwater cross section, or overtop the crest.

Maps of static inundation for the years 2030, 2050, and 2100 due to SLR are summarized in Appendix A - Figures A-1 through A-12. The maps were developed by comparing a digital elevation model of the harbor's ground surface topography with the Table 3 future SLR projections concurrent with an extreme astronomical King Tide of +7.5 feet, MLLW.

The harbor's topography was modeled from the 2015/2016 LiDAR survey data obtained from the Los Angeles Regional Imagery Acquisition program (LARIAC4)[3]. The data consists of a point cloud rasterized into a 3-foot by 3-foot horizontal grid cell resolution density. Vertical accuracy is reported to be 0.16 meters (approximately 0.5 feet) at a 95 percent confidence interval.

The extreme tide level was selected from review of historical measurements recorded at the Santa Monica tide gauge. Figure 5 shows the recorded monthly tide levels that occurred at Santa Monica between 1999 and the present. Water level rarely exceeded +7.5 feet, MLLW over the 20-year time period. For purposes of this initial planning study, this limit was selected as the extreme astronomical tide level concurrent with the future SLR projections.

King Harbor was arbitrarily divided into four subareas for convenience to better present the inundation map results. The north area includes Mole A and B, the north central area consists primarily of Mole C, the south central area delineates mostly the Mole D, and the south area includes Basin 3, the municipal pier, and development immediately behind it. The mapping results are summarized in the following paragraphs.

3 http://egis3.lacounty.gov/dataportal/lariac/

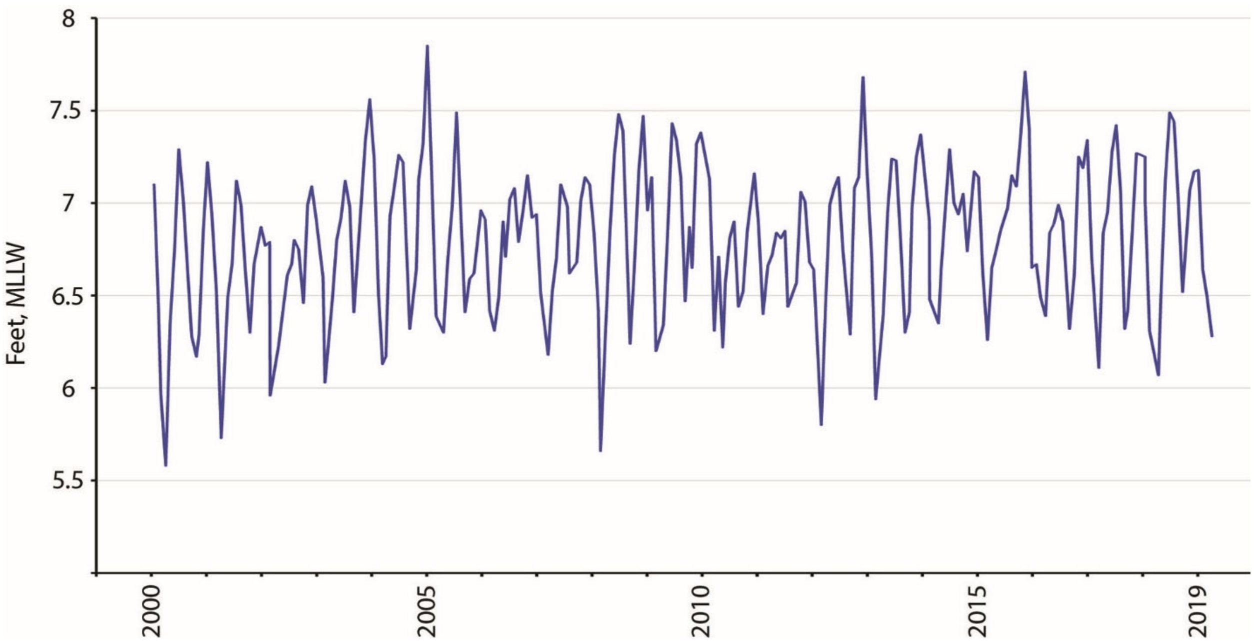


**Figure 5. Recorded monthly maximum tide levels at Santa Monica**

Source: Data from National Oceanic and Atmospheric Administration, 2019.

## 4.1 Year 2030

The impacts associated with the estimated 0.8-foot rise in sea level by 2030 will primarily be limited to the perimeter walkways around each marina basin as shown by the narrow cyan color bands in Figures A-1 through A-4. The seawalls that protect the basin perimeters were originally designed with a crest elevation of +10 feet, MLLW, but over time, land has subsided resulting in lower wall crest elevations that are now between +7 and +8 feet, MLLW.

King Harbor is within a zone of historical oil extraction that is known to have resulted in subsidence activity for many years. Between 1975 and 1989, it was estimated that structures within the harbor lowered about 1.5 feet. Earlier surveys indicate that at least 2.1 feet of subsidence occurred from 1945 to 1988[4] with most of the drop in elevation occurring between 1962 and 1988. Recent spot elevation at Basins 1, 2, and 3 locations measured for this study confirm that the perimeter walkways are now lower than +8 feet, MLLW which exposes them to flooding during extreme King Tides.

[4] US Army Corps of Engineers, 1989. General design memorandum no. 3, storm damage reduction for King Harbor (Redondo Beach), draft report, November 1989.

Pedestrian access around the marina basins is expected to worsen by 2030 as inundation depths may reach 2 feet for short durations during extreme spring tides. The immediate area around Basin 3 will experience the worst flooding that could impact the commercial businesses and access to the marina in this location.

### 4.2 Year 2050

The projected SLR of 1.9 feet by 2050 will translate to a potential water level of +8.4 feet, MLLW during an extreme King Tide and expose more areas of the harbor to short term flooding episodes. This increased exposure will be limited to periods of shallow inundation at the southeast corner of Mole A, the southern lobe of Mole B, eastern sections adjacent to Basins 1 and 2, and an isolated area within the western end of Mole C. Flooding within Basin 3 will worsen to periodic inundation depth occurrences of about 2 feet during extreme high tides. Figures A-5 through A-8 show the approximate limits of areas that may be impacted.

### 4.3 Year 2100

By 2100, the projected SLR of 5.5 feet concurrent with an extreme tide level of +7.5 feet, MLLW will cause significant inundation throughout King Harbor. As shown in Figures A-9 through A-12. Inundation depths will increase to as much as 4 to 5 feet. Most of Mole A, B, C, and D will likely be impacted.

### 4.4 Storm Wave Effects

The western portions of Mole A, B, C, and D will be further affected by an increased exposure to storm wave runup by 2100. Residual sea and swell that propagates into King Harbor will impact those sections of shoreline immediately adjacent to the Outer Harbor. The estimated storm wave vulnerability and wave runup hazard zone limit is illustrated in Figure 6. The hazard area is assumed to be limited to a 50-foot wide zone that will be most susceptible to the initial wave runup effects.

The problem will be exacerbated by the fact that the 5.5 increase in sea level by 2100 will effectively lower the outer breakwaters by that elevation rendering them similar in crest height to

Ocean storm swell
overtopping zone

| Mole B | Wave Runup Elev (ft, mllw) | | |
|---|---|---|---|
| | 2030 | 2050 | 2100 |
| 1-yr | 10.5 | 11.6 | 13.7 |
| 10-yr | 10.9 | 11.7 | 13.9 |
| 25-yr | 11.7 | 11.9 | 14.1 |
| 50-yr | 11.8 | 12.0 | 14.2 |
| 100-yr | 12.3 | 12.6 | 15.0 |

| Mole C1 | Wave Runup Elev (ft, mllw) | | |
|---|---|---|---|
| | 2030 | 2050 | 2100 |
| 1-yr | 11.7 | 11.8 | 13.9 |
| 10-yr | 11.9 | 12.0 | 14.1 |
| 25-yr | 12.2 | 12.3 | 14.5 |
| 50-yr | 12.3 | 12.5 | 14.8 |
| 100-yr | 12.6 | 12.9 | 15.2 |

| Mole C2 | Wave Runup Elev (ft, mllw) | | |
|---|---|---|---|
| | 2030 | 2050 | 2100 |
| 1-yr | 10.3 | 11.5 | 13.6 |
| 10-yr | 11.6 | 11.7 | 13.9 |
| 25-yr | 11.9 | 11.9 | 14.2 |
| 50-yr | 12.3 | 12.5 | 14.9 |
| 100-yr | 12.7 | 13.0 | 15.5 |

| Mole C3 | Wave Runup Elev (ft, mllw) | | |
|---|---|---|---|
| | 2030 | 2050 | 2100 |
| 1-yr | 9.6 | 10.7 | 13.3 |
| 10-yr | 10.1 | 11.4 | 13.5 |
| 25-yr | 10.3 | 11.5 | 13.6 |
| 50-yr | 10.9 | 11.7 | 13.8 |
| 100-yr | 12.5 | 12.8 | 15.1 |

| Mole D | Wave Runup Elev (ft, mllw) | | |
|---|---|---|---|
| | 2030 | 2050 | 2100 |
| 1-yr | 12.4 | 15.4 | 17.6 |
| 10-yr | 12.9 | 16.0 | 17.6 |
| 25-yr | 16.0 | 17.5 | 17.8 |
| 50-yr | 16.0 | 17.5 | 17.8 |
| 100-yr | 17.7 | 17.8 | 18.0 |

Horseshoe Beach storm
swell overtopping zone

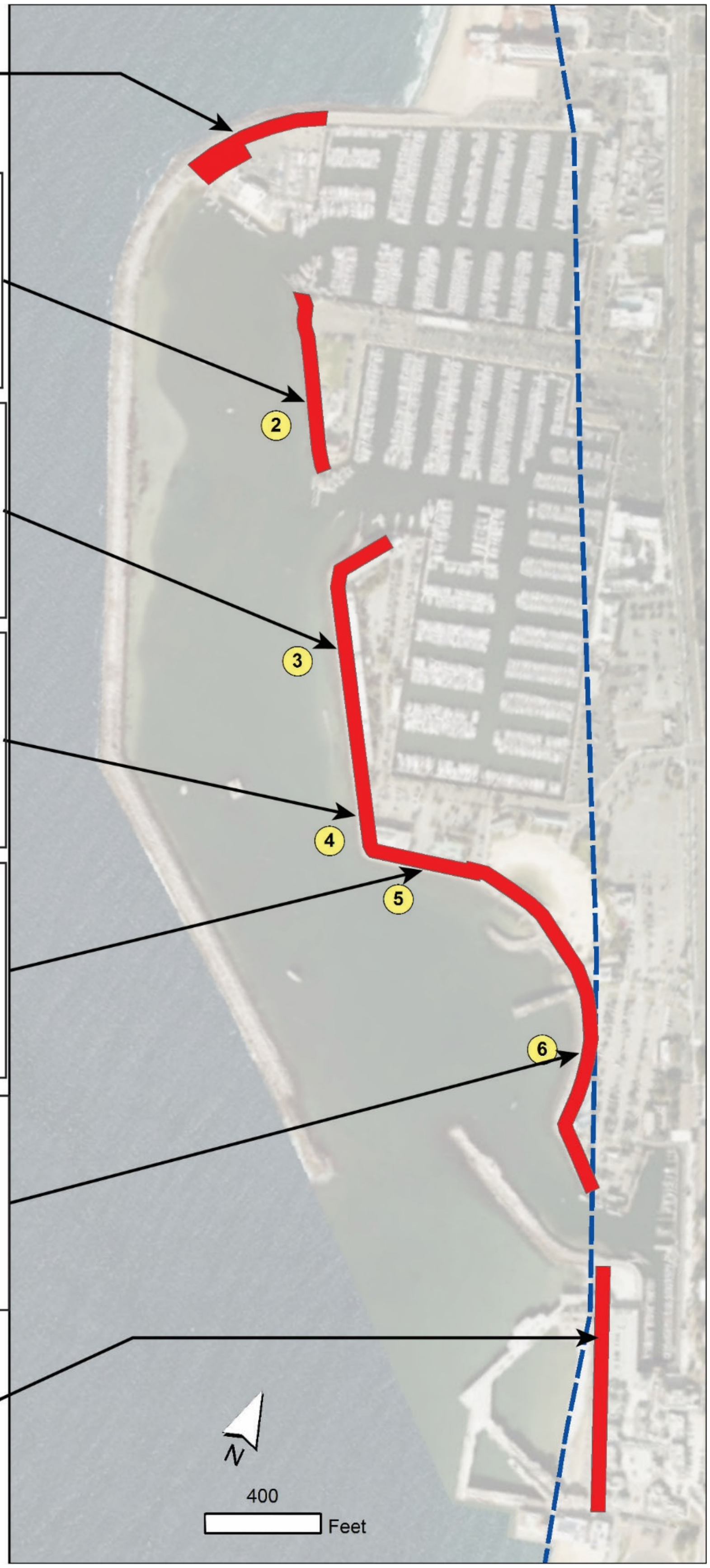


**Figure 6. Wave runup hazard**

conditions that existed during the destructive January 1988 storm. The wave energy that propagated into the Outer Harbor during that benchmark storm event, destroyed much of the shoreline development at Moles C and D[5]. This will also increase wave runup exposure to a portion of Mole A where infrequent occurrences of storm swell already create flooding issues at times. The additional buffer width at the western end of Mole A reflects the area most effected.

## 5 Economic Impacts

As previously mentioned, King Harbor is home to a diverse mix of recreation, entertainment, hospitality, restaurant, residential, and other commercial activities that contribute to the City of Redondo Beach's economy. Collectively, they provide significant revenue for the City, jobs for the labor force, and water oriented recreational opportunities and activities for the public.

Four marinas operate within the harbor's three mooring basins. The number of boats moored in the harbor marinas and moorings is summarized in Table 3.

**Table 3. Approximate wet storage slip count in King Harbor**

| Location | Total |
|---|---|
| Basin 1 | 498 |
| Basin 2 | 785 |
| Basin 3 (excludes concession dock) | 66 |
| Outer Harbor Mooring | 29 |
| Total | 1,378 |

In addition to the permanent boat slips, there are additional boats and watercraft kept within upland dry storage areas adjacent to the outer harbor. Over 70 sail boats are stored in a mast up yard at the King Harbor Yacht Club on Mole A, and a number of outrigger boats and ocean canoes are stored at the Lanakila and Nahoa Outrigger Canoe Clubs' site on Mole B.

Transient boat use in King Harbor consists of activity at the Mole D boat hoist facility, the outer harbor mooring field, day visitors who hand launch paddle craft from the Seaside Lagoon dock, and commercial vendors who rent peddle boats, kayaks, and standup paddle boards to the general public on an hourly basis. Tarsan in Basin 1, the Portofino Hotel at Rocky Point, and Paddle House and Fast Kayaks at the Redondo Beach Marina in Basin 3 are the four rental outlet

[5] US Army Corps of Engineers, 1988. Storm Damage Reduction, Redondo Beach – King Harbor Area, Los Angeles County, CA, Final feasibility report, March 1988, Los Angeles District.

locations.

Distributed throughout the uplands are three hotels, high density residential, office space, restaurants, attractions, and other businesses that cater to the public.

If not addressed, future SLR will affect King Harbor in two ways. Inundation will significantly impact access to the marinas, recreational facilities, hotels, restaurants, and other businesses throughout the harbor that will curtail or prohibit their function altogether. Table 4 shows the magnitude of the potential loss by 2100 in terms of lost revenue that the individual harbor tenants could experience and the associated City share that is derived from each lease agreement. Collectively, the businesses within King Harbor stand to lose almost $90 million of revenue income annually, and the City will no longer be able to collect its approximate yearly income of $8 million.

**Table 4. Estimate Loss of Revenue by 2100 due to future sea level rise**

| Harbor Area | Tenant Revenue | | City Revenue | |
|---|---|---|---|---|
| | Tidelands | Uplands | Tidelands | Uplands |
| North | $15,800,000 | $15,490,000 | $2,116,000 | $712,000 |
| North Central | $25,500,000 | $8,743,000 | $2,251,000 | $644,000 |
| South Central | $928,000 | $8,070,000 | $69,000 | $530,000 |
| South | $0 | $14,700,000 | $0 | $1,516,000 |
| Total | $42,228,000 | $47,003,000 | $4,436,000 | $3,402,000 |

Source: Data from City of Redondo Beach, 2019.

In addition to loss of revenue, the buildings and infrastructure within the harbor will experience damage due to inundation and wave runup. An order of magnitude estimate of the damage potential was made by inventorying the various improvements within the harbor, and estimating the inundation depth that each facility might experience. The inundation maps in Appendix A were consulted for this information. Depth-damage curves developed by the US Army Corps of Engineers were used to convert the inundation depths to a probable structural damage percentage. Much of this data has been refined from the post-storm review of Hurricane Sandy that impacted coastal structures of all types on the US East Coast.

The results are summarized in Table 5. Approximately 40 percent of the existing building structures are located in designated tidelands areas of the harbor with the remainder of the development located landward of the 1935 Mean High Tide line. By 2100, approximately $33 million dollars of structural damage could be experienced to buildings within King Harbor as a result of SLR related impacts. Of that amount, approximately $11 million will be within the tidelands portion.

**Table 5. Potential loss to harbor buildings by 2100 due to future sea level rise**

| | | | | | 2050 (+9.4 ft, MLLW) | | | 2100 (+13 ft, MLLW) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Inundation | Estimated | Estimated | Inundation | Estimated | Estimated |
| Asset | Location | | Size | Replace cost | depth | damage | loss | depth | damage | loss |
| | Tidelands | Uplands | sf | $/sf | ft | | $ | ft | | |
| Restaurant | ● | | 10,000 | $500 | 0 | 0% | | 2 | 30% | $1,500,000 |
| High density residential | ● | ● | | | | | | | | $0 |
| Office building | ● | | 14,000 | $350 | 0 | 0% | | 2 | 30% | $1,470,000 |
| Yacht club | ● | | 12,000 | $350 | 0 | 0% | | 3 | 35% | $1,470,000 |
| Commercial | | ● | 5,100 | $250 | 0 | 0% | | 2 | 30% | $382,500 |
| Commercial | | ● | 24,000 | $500 | 1 | 20% | $2,400,000 | 3 | 35% | $4,200,000 |
| Restaurant | | ● | 13,000 | $400 | 1 | 20% | $1,040,000 | 4 | 38% | $1,976,000 |
| City administration | ● | | | $400 | 0 | 0% | | 0 | 0% | |
| Hotel | | ● | 65,763 | $500 | 0 | 0% | | 3 | 35% | $11,508,525 |
| Restaurant | | ● | 12,000 | $400 | 0 | 0% | | 3 | 35% | $1,680,000 |
| Office building | | ● | 2,637 | $250 | 0 | 0% | | 4 | 38% | $250,515 |
| Hotel | ● | | 38,917 | $500 | 0 | 0% | | 2 | 30% | $5,837,550 |
| Restaurant | ● | | 10,000 | $400 | 0 | 0% | | 1 | 20% | $800,000 |
| Restaurant | | ● | 6,266 | $400 | 0 | 0% | | 0 | 0% | |
| Commercial | | ● | 5,379 | $250 | 0 | 0% | | 1 | 20% | $268,950 |
| Restaurant | | ● | 6,593 | $350 | 0 | 0% | | 0 | 0% | |
| Restaurant | ● | | 10,237 | $400 | 0 | 0% | | 1 | 20% | $818,960 |
| Restaurant | | ● | 6,908 | $350 | 0 | 0% | | 1 | 20% | $483,560 |
| Office building | | ● | 1,196 | $250 | 0 | 0% | | 4 | 38% | $113,620 |
| Office building | | ● | 1,421 | $250 | 0 | 0% | | 0 | 0% | |
| Total (rounded to nearest million $) | | | | | | | | | | |
| | Tidelands | | | | | | | | | $12,000,000 |
| | Uplands | | | | | | $3,000,000 | | | $21,000,000 |

Source: Data from City of Redondo Beach, 2019.

Estimates of potential impacts to harbor infrastructure were estimated by the City Department of Public Works. Based upon projected inundation limits for 2100, an inventory of existing sidewalk, pavement, wet utilities, street light, traffic signals, and signage improvements were assessed on the basis of replacement cost value. Appendix B contains GIS maps for the data on record that summarize the various City owned systems that may be impacted due to SLR associated events. The estimated order of magnitude loss associated with the future SLR in 2100 is summarized in Table 6. This estimate does not include power, communications, water, gas or any other utility infrastructure that is owned and maintained by individual utility service providers.

**Table 6. Estimate Loss of City Owned Infrastructure due to future sea level rise**

| Item | | Unit | Quantity | Unit Cost | Total Value |
|---|---|---|---|---|---|
| **Curb/Gutter** | | LF | 12,818 | $65 | $833,170 |
| **Impervious Surfaces (concrete)** | | SF | 73,274 | $65 | $4,762,810 |
| **Pavement (Asphalt)** | | SF | 321,122 | $17 | $5,459,074 |
| **Sanitary Sewer:** | | | | | |
| | Manhole | EA | 51 | $175,000 | $8,925,000 |
| | Smart Cover Manhole | EA | 2 | $2,000 | $4,000 |
| | Pump Station | EA | 4 | $2,000,000 | $8,000,000 |
| | Gravity pipes | LF | 9,051 | $750 | $6,788,250 |
| | Pressurized pipes | LF | 948 | $850 | $805,800 |
| | Lateral pipes | LF | 2,991 | $750 | $2,243,250 |
| **Signs** | | EA | 95 | $400 | $38,000 |
| **Storm Sewer - Catch Basins** | | EA | 57 | $50,000 | $2,850,000 |
| **Street Lights** | | EA | 143 | 25,000 | $3,575,000 |
| **Traffic Signals** | | EA | 7 | $275,000 | $1,925,000 |
| **Trees** | | EA | 48 | $12,000 | $576,000 |
| **Total Estimate Value (rounded to nearest million $)** | | | | | **$46,000,000** |

Source: Data from City of Redondo Beach, 2019

In addition to these assets, there will be impacts to the Municipal Pier, Sportfishing Pier, and other improvements within King Harbor. The historic timber portions of the Municipal Pier will need to be elevated to match deck levels of the newer concrete section. Similarly, the Sportfishing Pier will need to be rebuilt at a higher elevation. Costs to replace the pier and on deck structures will likely approach $20 million. The Seaside Lagoon recreational swimming complex will similarly require a multi-million dollar refurbishment to provide protections and adaptation to accommodate future SLR.

## 6 Management Strategy

King Harbor is an important municipal and regional asset that must be maintained to serve the large number of tourists and residents that visit it annually. The City provides and maintains a significant capital investment of facilities and infrastructure that is necessary to provide a safe and enjoyable visitor, commercial and recreation experience. With the Los Angeles County population expected to double by 2100, visitor and resident demand for water-oriented recreation and commercial uses is anticipated to similarly increase. Therefore, the challenge for the future will be how the City can best continue to maintain and provide adequate facilities despite the fact that they may become increasingly more vulnerable to future SLR.

As previously discussed, the vulnerability of King Harbor's facilities will depend upon the magnitude and rate of future SLR. If the extreme projections occur, the projected inundation assessment suggests the entire tidelands portion of the harbor will be significantly impacted. A considerable portion of the harbor landward of the 1935 Mean High Tide line will also be susceptible to adverse inundation.

Long-term options to deal with future SLR at any coastal harbor facility generally employ one or more of following approaches that are schematically illustrated in Figure 7 and as discussed below.

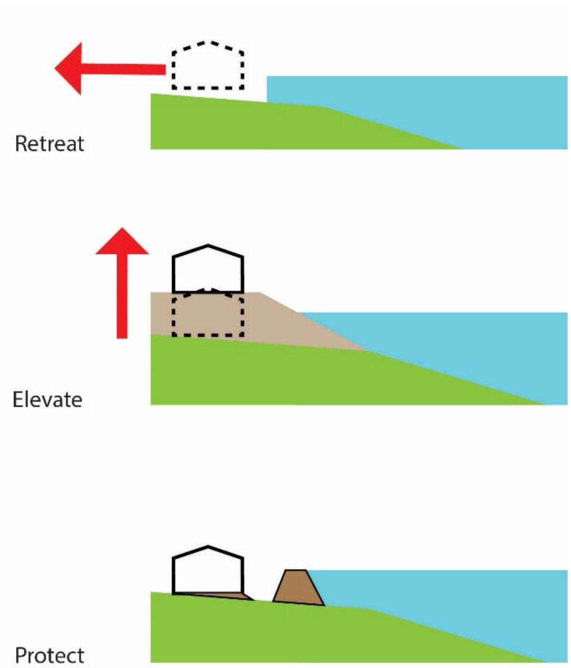


**Figure 7. General SLR adaptation strategies**

Retreat — As development and infrastructure become threatened by inundation, the assets are removed and re-located further inland. This option has limited opportunities at King Harbor since the primary purpose of the facility is to promote access to and enjoyment of the waterfront and ocean. The urban setting of Redondo Beach and the density of existing development adjacent to King Harbor will preclude consideration of any meaningful retreat scenario. The constraints of the existing private development, and other competing land uses, will not provide sufficient space to re-locate

King Harbor's footprint landward. The option is therefore considered to be non-viable.

Elevate — As sea level rises, buildings are raised on fill or pile supported foundations to seek higher ground. The strategy may be appropriate for localized buildings in some instances, but the option can only be effectively implemented in King Harbor by importing and placing land fill to raise the more expansive parking lots and public paths that are critically needed to promote access to and utilization of the harbor's facilities.

Protect — Within a harbor setting, this strategy consists of building perimeter dikes, berms, and/or bulkhead structures with higher crest elevations to prevent overtopping and rising ocean level from flooding inland areas.

Long term SLR management strategies require significant capital investment, and given the uncertainty of SLR rise estimates, additional information is needed before a commitment of public funds can be made to a specific approach. Currently, the tendency for planning has been to focus on the extreme projections which makes the present-day planning process difficult at best. The wide range in ocean level prediction suggests that the only practical way to deal with the issue will be implementation of tiered action plans that continue to deal with the known present-day issues and offer potential solutions to deal with future scenarios. Transitional and long-term management strategies can be periodically revisited and revised as projections on SLR become more certain. Only then can an appropriate long-term action plans and capital investment commitments be practically implemented.

At the two ends of the SLR vulnerability spectrum for King Harbor are the existing coastal hazards exposure and a potential severe future inundation scenario. In between lies a transitional period of uncertainty where today's asset management strategy becomes less practical and phasing in of additional adaptive measures will be needed to address future scenarios. It is imperative that as an initial step, the City adopt a program to monitor and track SLR data so that local policy makers can provide appropriate direction regarding implementation strategies.

To address King Harbor's existing and estimated future coastal hazards vulnerability, a phased adaptive plan strategy is suggested. The approach consists of implementing increasingly more robust shoreline protection modifications, improvements, and harbor development adjustments to keep pace with the anticipated SLR rate of increase over time. The plan starts by addressing the existing high tide flooding issues and evolves to significantly more extensive measures that may be required by 2100. The following sections outline the suggested approach in more detail.

## 6.1 Phase 1: Short-Term to 2030 (SLR less than 1.0 foot).

Inundation and flooding potential is currently limited to the pedestrian sidewalks and marina access around Basins 1 and 2, the low lying portion of the Basin 3 perimeter along the east and south ends, and portions of Mole A that are adjacent to the North Breakwater. Measures may be considered to raise the seawall crest in these areas with a short parapet wall amendment to prevent flooding of the accessways during extreme high tides. The existing seawalls around Basin 1, 2, and 3 would be elevated with a relatively modest retrofit to provide flood protection for the existing King Tide episodes and initial SLR to about 2030. The concept is illustrated in Figure 8.

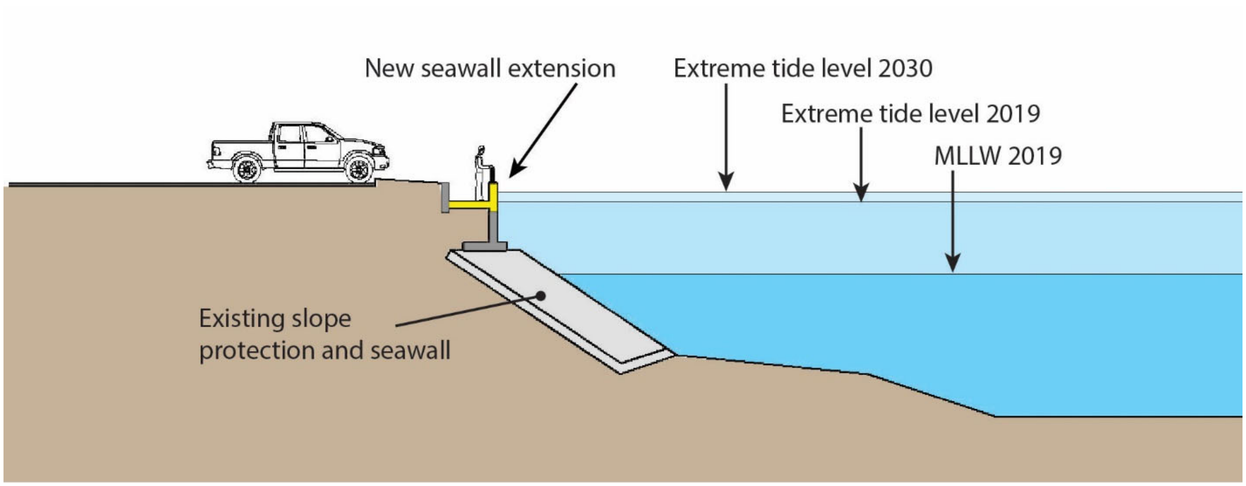


**Figure 8. Phase 1 SLR adaptation concept**

The existing revetment at Mole B and splash walls at Moles C and D should continue to be monitored and maintained. Construction of a new low height splash wall at Horseshoe Beach may be performed as required within this planning period to address the occasional overtopping that already occurs along the northern reach of this segment.

The North Breakwater is critical to the future wellbeing of King Harbor. The rubble-mound structure should be vigilantly maintained and assessed for modifications where appropriate. The segment adjacent to Mole A is prone to overtopping during certain ocean swell conditions, and a minimum crest elevation of +22 feet, MLLW is necessary to prevent storm wave overtopping elsewhere along the alignment. As sea level rises, it will be important that breakwater modification measures be implemented so that its crest elevation can similarly be increased to keep pace with new stands of ocean level. The Federal planning process that will be necessary to review and implement a future project will likely need 20 years to complete. A summary schematic plan of the short term adaptation plan is shown in Figure 9.

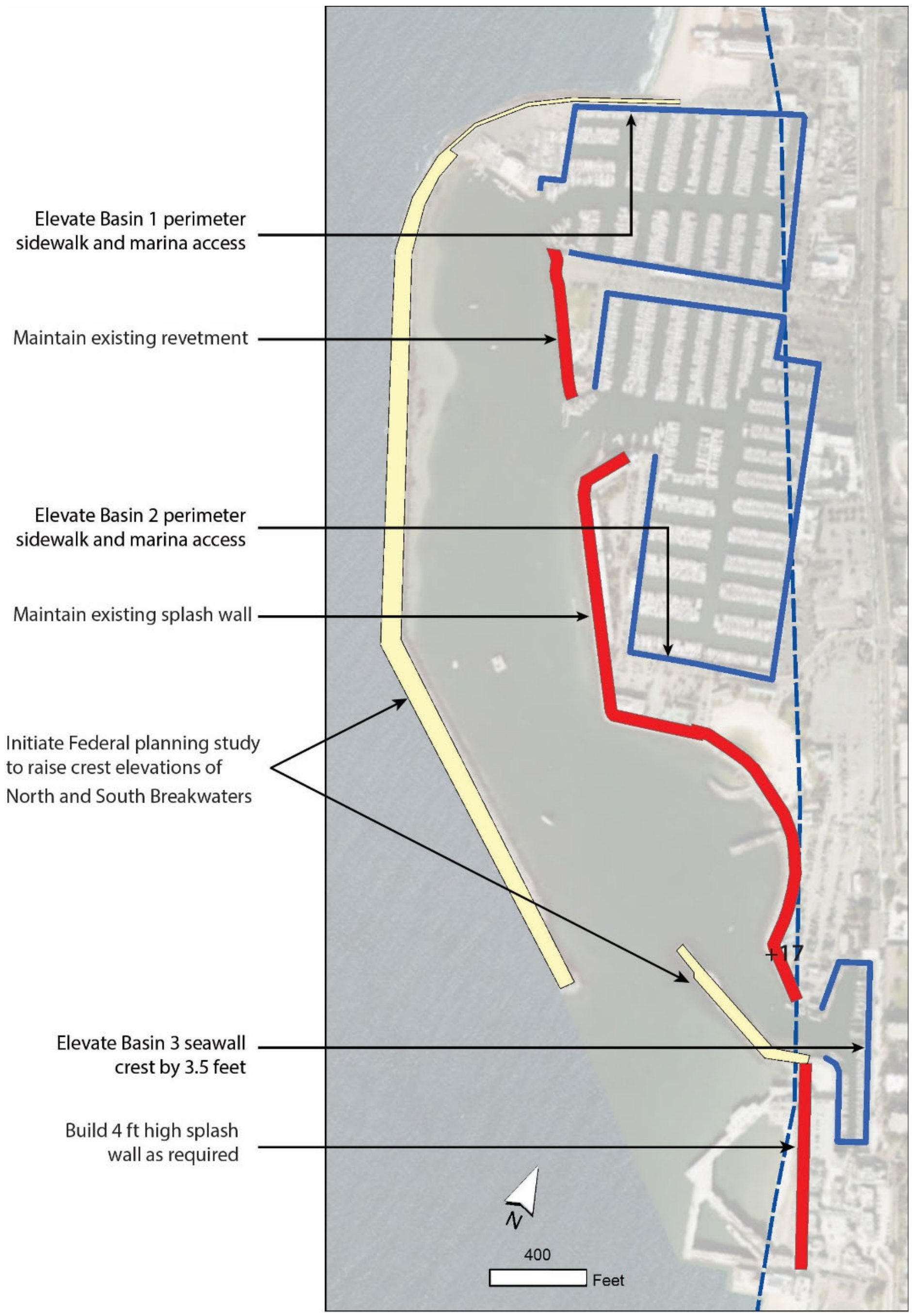


**Figure 9. Short term SLR adaptation plan**

6.2 Phase 2 Transitional Period 2030 to 2050 (SLR between 1 and 2 feet).

By 2050, the two-foot rise in sea level would begin to pose a threat to inland areas. The improvements completed in Phase 1 would be amended with the addition of a perimeter retaining wall to protect existing development and infrastructure from flooding. The concept is shown in Figure 10.

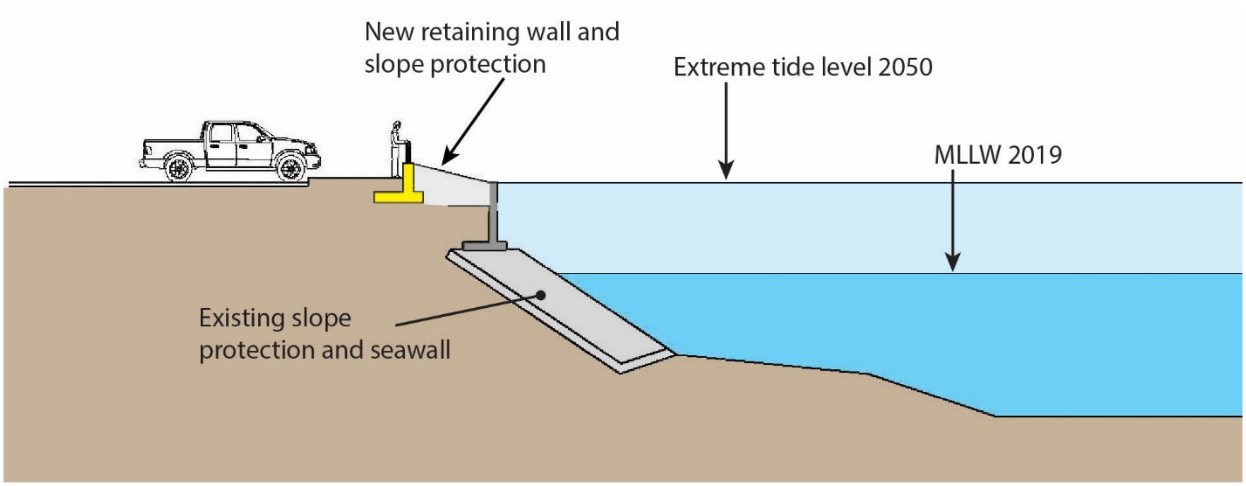


**Figure 10. Phase 2 SLR adaptation concept**

6.3 Phase 3 Long Term Period 2050 to 2100 (SLR of 5.5 feet).

A projected SLR of 5.5 feet, as forecast for 2100, will require that more extensive measures be taken to reduce King Harbor's vulnerability and protect assets. The Phase 3 amendment would extend the crest elevation of the landward retaining wall and increase perimeter protection via construction of extended basin slope protection that would extend into Basins 1 and 2. The concept is illustrated in Figure 11.

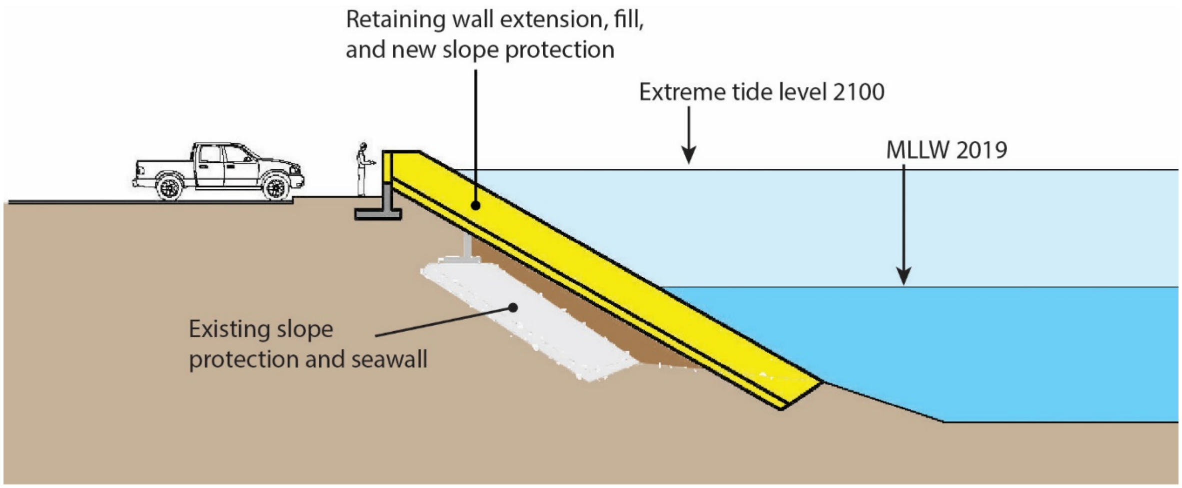


**Figure 11. Phase 3 SLR adaptation concept**

## 6.4 Phase 4 Post 2100 SLR adaptation.

Beyond 2100, protection of the King Harbor assets will require that more extensive measures be taken to protect assets and infrastructure. This last phase of adaptation will consist of a perimeter sheet pile seawall to reinforce inundation protection supplemented with adjustment of landward finished grades by fill placement. The landfill and seawall modification work will need to adjust backland grades to approximately +15 feet, MLLW at Moles A and B, +17 feet at Moles C and D, and +15 feet, MLLW at Harbor Drive inland areas. Figure 12 illustrates the protection strategy.

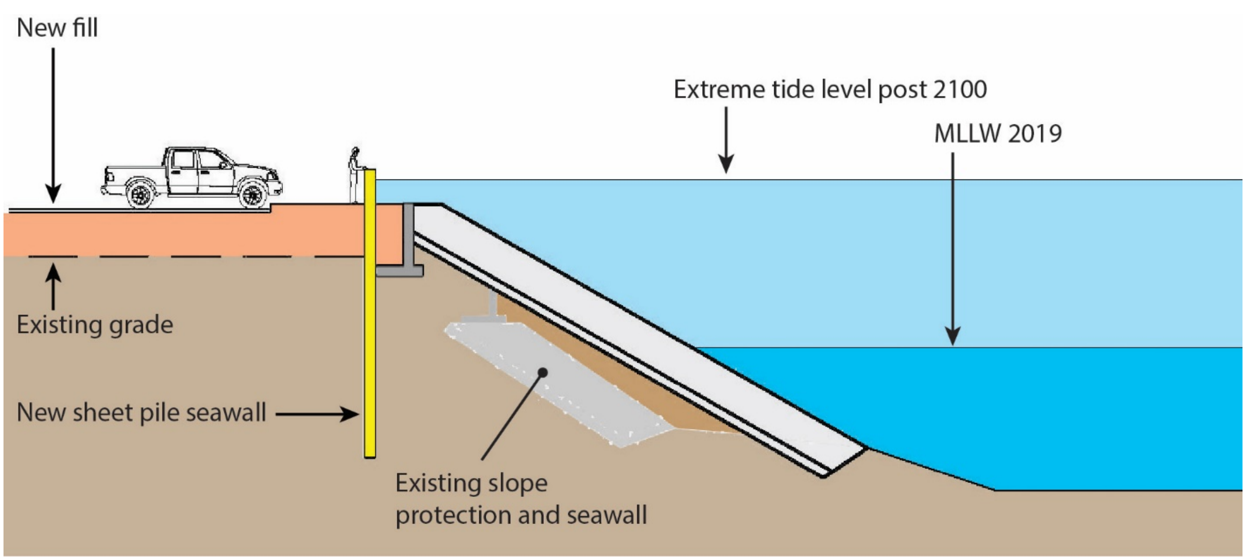


**Figure 12. Post 2100 SLR adaptation**

The ultimate long-range conceptual plan for the harbor is shown in Figure 13.  The elevations shown represent finished grade and do not reflect the amount of additional fill required.

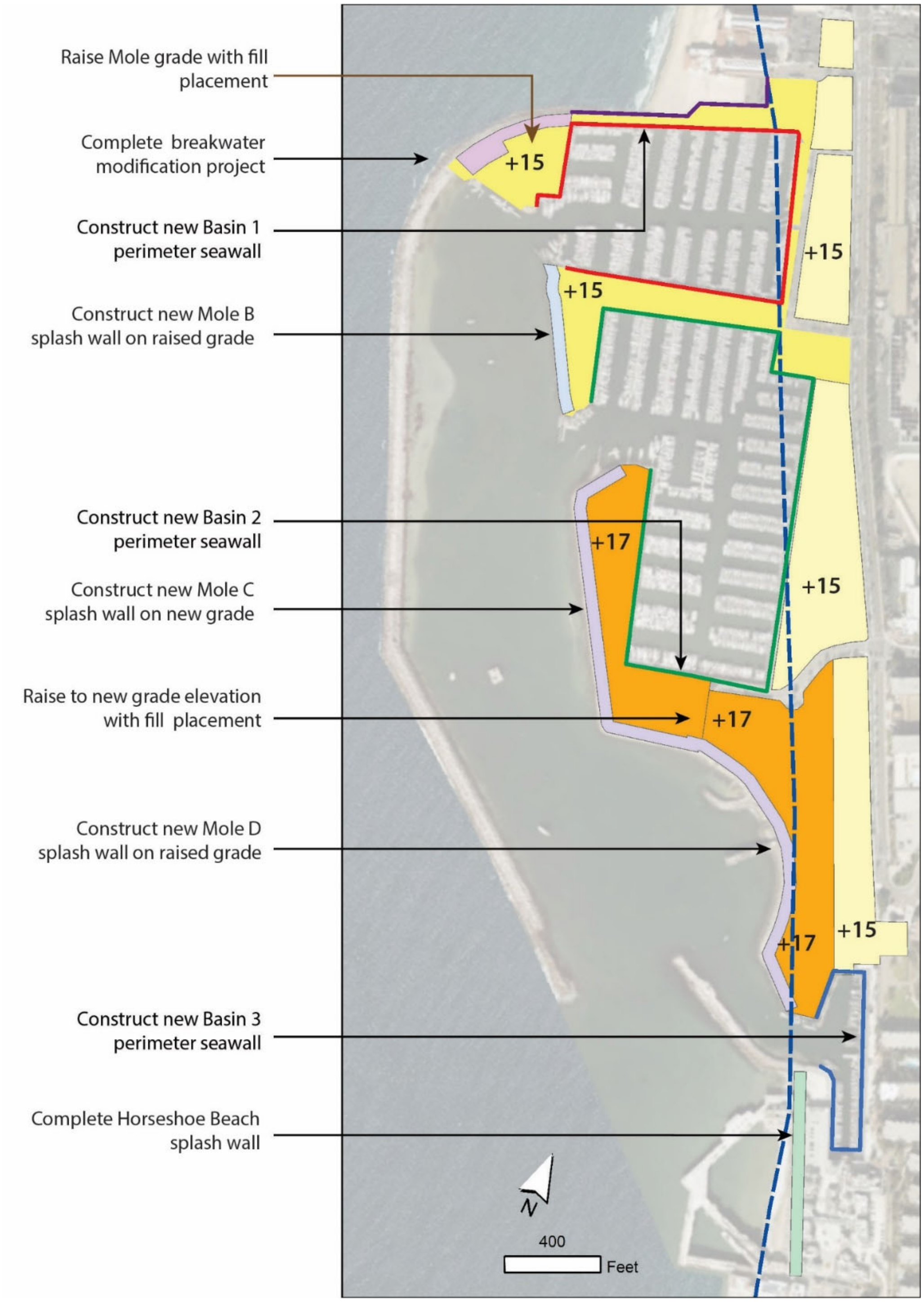


**Figure 13. Long range SLR adaptation plan**

## 6.5 Estimated Cost for SLR Adaptation

The potential cost to implement a long term SLR adaptation plan for King Harbor will depend upon many factors that are highly variable. For purposes of this study, it is assumed that development and land uses within the harbor will be maintained and preserved in their present form to the maximum extent practical. A rough order of magnitude estimate of the potential construction cost for the phased improvements discussed in this report is summarized below:

| | |
|---|---|
| Phase 1 Adaptation:<br>Perimeter marina basin protection to address existing and short term SLR risk for pedestrian sidewalk and marina access through 2030. | $5,000,000 |
| Phase 2 Adaptation:<br>Adjustment to perimeter inundation improvements to provide additional inundation protection for adjacent landside areas through 2050. | $6,000,000 |
| Phase 3 Adaptation:<br>Perimeter dike construction to increase and expand inundation protection for landside areas. | $20,000,000 |
| Phase 4 Adaptation:<br>Seawall construction, landfill, relocation of utilities, and redevelopment to raise base floor elevations to protect the entire harbor footprint. | $260,000,000 |
| Estimated order of magnitude cost in 2019 dollars to protect King Harbor assets through 2100. | $291,000,000 |

Protection of tidelands grant areas are roughly estimated to comprise about 75 percent of the future cost requirements through Phase 3 adaptation implementation. Thereafter, the more significant Phase 4 adaptation cost is considered to be split between the tidelands and uplands land areas at a ratio of approximately 40% to 60%, respectively. These estimates do not include various improvements that may be required within existing leaseholds nor any costs that may be incurred by other agencies to improve the outer breakwall.

## Appendix A

King Harbor Sea level Rise Vulnerability Maps


**Figure A-1**

**Year 2030 Inundation - Area 1**

NOBLE CONSULTANTS | GEC


Figure A-2

Year 2030 Inundation - Area 2

NOBLE CONSULTANTS GEC


Figure A-3

Year 2030 Inundation - Area 3


Figure A-4

Year 2030 Inundation - Area 4


Figure A-5

**Year 2050 Inundation - Area 1**


Figure A-6

Year 2050 Inundation - Area 2


Figure A-7

Year 2050 Inundation - Area 3


Figure A-8

Year 2050 Inundation - Area 4


Figure A-9

**Year 2100 Inundation - Area 1**


**Figure A-10**

**Year 2100 Inundation - Area 2**


**Figure A-11**

**Year 2100 Inundation - Area 3**


Figure A-12

**Year 2100 Inundation - Area 4**

## **Appendix B**

King Harbor City Owned and Maintained Infrastructure Impacted by Future Sea Level Rise


Year 2100 Inundation
Curb Gutter (12,818 ft)
Inundation Zone
1st St
1st Ct
Lyndon St
Palm Dr
Herondo St
Hermosa Beach
Redondo Beach
Anita St
N Pacific Coast Hwy
Agate St
PETCO
N Francisca Ave
N Catalina Ave
N Elena Ave
Beryl St
Whole Foods
Rite Aid
N Guadalupe Ave
N Gertruda Ave
N Broadway
Carnelian St
W Beryl St
N Harbor Dr
Pacific Ave
Redondo beach City Hall
Czuleger Park
The Vig
The Pier Shopping Center
Redondo Beach Pier
S Broadway
New High Ct
Torrance
Veterans Park
George Freeth
S Catalina Ave
More To Sea
redondo BEACH
Sources: Esri, HERE, Garmin, USGS, Inte
Esri Japan, METI, Esri China (Hong Kong)
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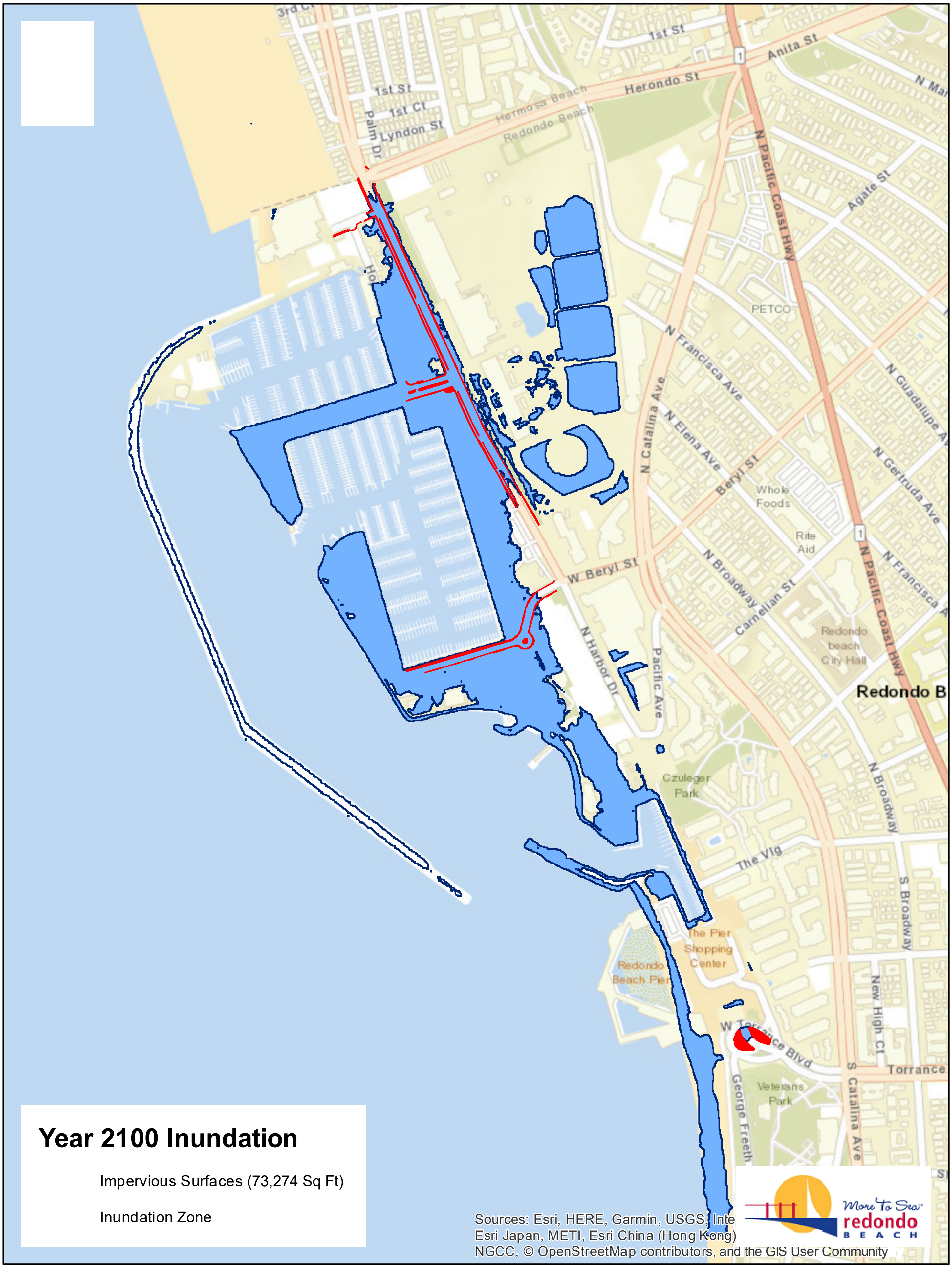

Year 2100 Inundation
Impervious Surfaces (73,274 Sq Ft)
Inundation Zone
1st St
1st Ct
Lyndon St
Palm Dr
Herondo St
Anita St
Hermosa Beach
Redondo Beach
N Pacific Coast Hwy
Agate St
PETCO
N Francisca Ave
N Elena Ave
N Catalina Ave
Beryl St
Whole Foods
Rite Aid
N Guadalupe Ave
N Gertruda Ave
W Beryl St
N Broadway
Carnelian St
Redondo beach City Hall
Redondo B
N Harbor Dr
Pacific Ave
Czuleger Park
The Vig
The Pier Shopping Center
Redondo Beach Pier
W Torrance Blvd
Veterans Park
George Freeth
S Catalina Ave
New High Ct
S Broadway
Torrance
More To Sea
redondo
BEACH
Sources: Esri, HERE, Garmin, USGS, Inte
Esri Japan, METI, Esri China (Hong Kong)
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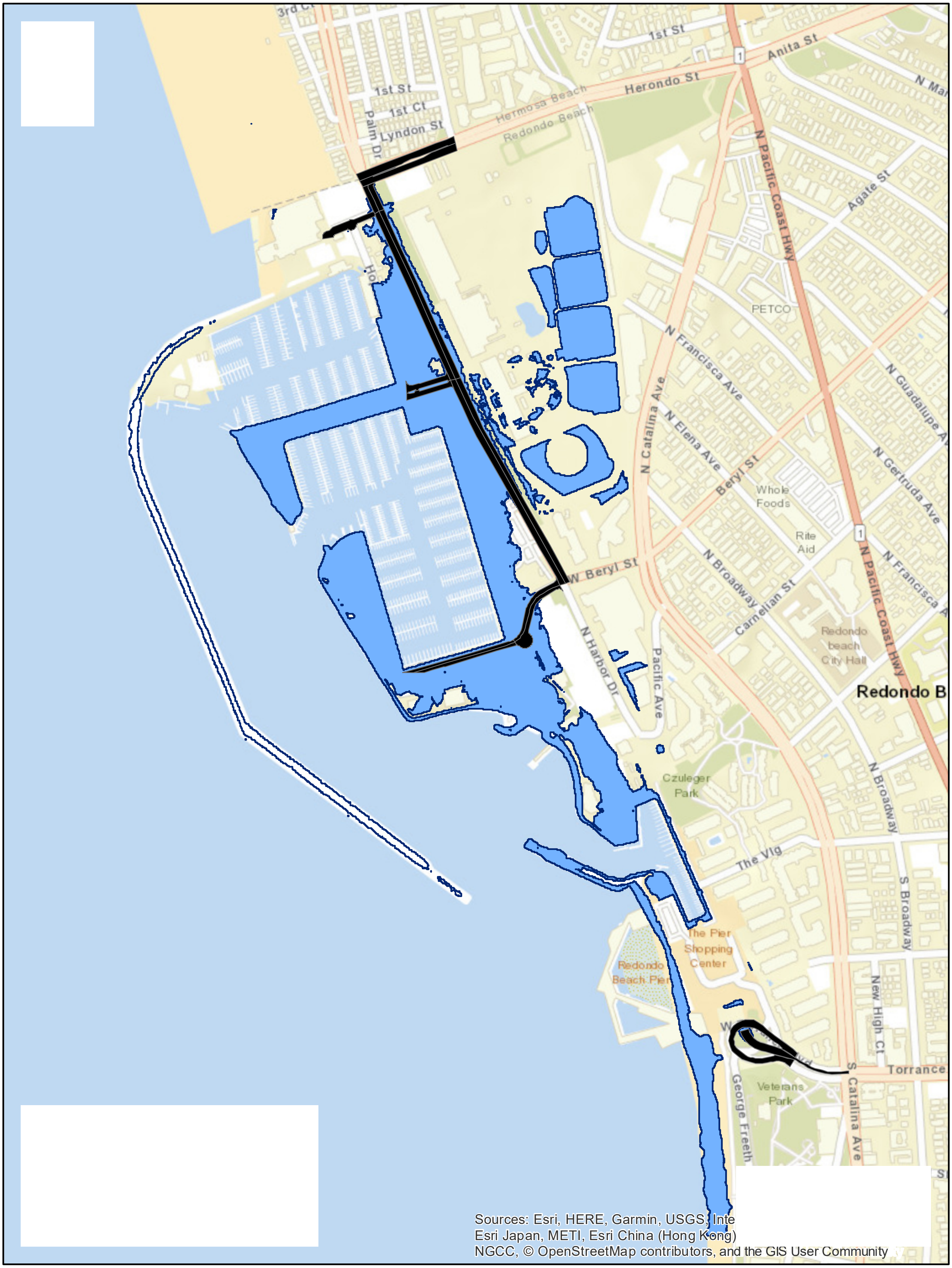

1st St
Anita St
Herondo St
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Lyndon St
Palm Dr
Hermosa Beach
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Agate St
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N Francisca Ave
N Catalina Ave
N Elena Ave
N Guadalupe Ave
N Gertruda Ave
Beryl St
Whole Foods
Rite Aid
N Broadway
Carnelian St
W Beryl St
N Harbor Dr
Pacific Ave
Redondo Beach City Hall
Redondo B
Czuleger Park
The Vlg
The Pier Shopping Center
Redondo Beach Pier
S Broadway
New High Ct
Torrance
Veterans Park
George Freeth
S Catalina Ave
Sources: Esri, HERE, Garmin, USGS, Inte
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Year 2100 Inundation
Sanitary Sewer Network
Manhole (51)
Smart Manhole (2)
Pump Station (4)
ss Gravity Main (9,051 ft) (55)
ss Pressurized Main (948 ft) (3)
ss Service Lateral Line (2,991 ft) (129)
Inundation Zone
PS
S
1st St
1st Ct
Lyndon St
Palm Dr
Herondo St
Anita St
Hermosa Beach
Redondo Beach
N Pacific Coast Hwy
Agate St
PETCO
N Francisca Ave
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N Elena Ave
Beryl St
Whole Foods
Rite Aid
W Beryl St
N Broadway
Carnelian St
N Guadalupe Ave
N Gertruda Ave
Redondo beach City Hall
Redondo B
N Harbor Dr
Pacific Ave
Seaside Lagoon
Czuleger Park
The Vlg
Redondo Beach Pier
W Torrance Blvd
Veterans Park
George Freeth
S Catalina Ave
New High Ct
S Broadway
Torrance
More To Sea
redondo
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Sources: Esri, HERE, Garmin, USGS, Interm
Esri Japan, METI, Esri China (Hong Kong), E
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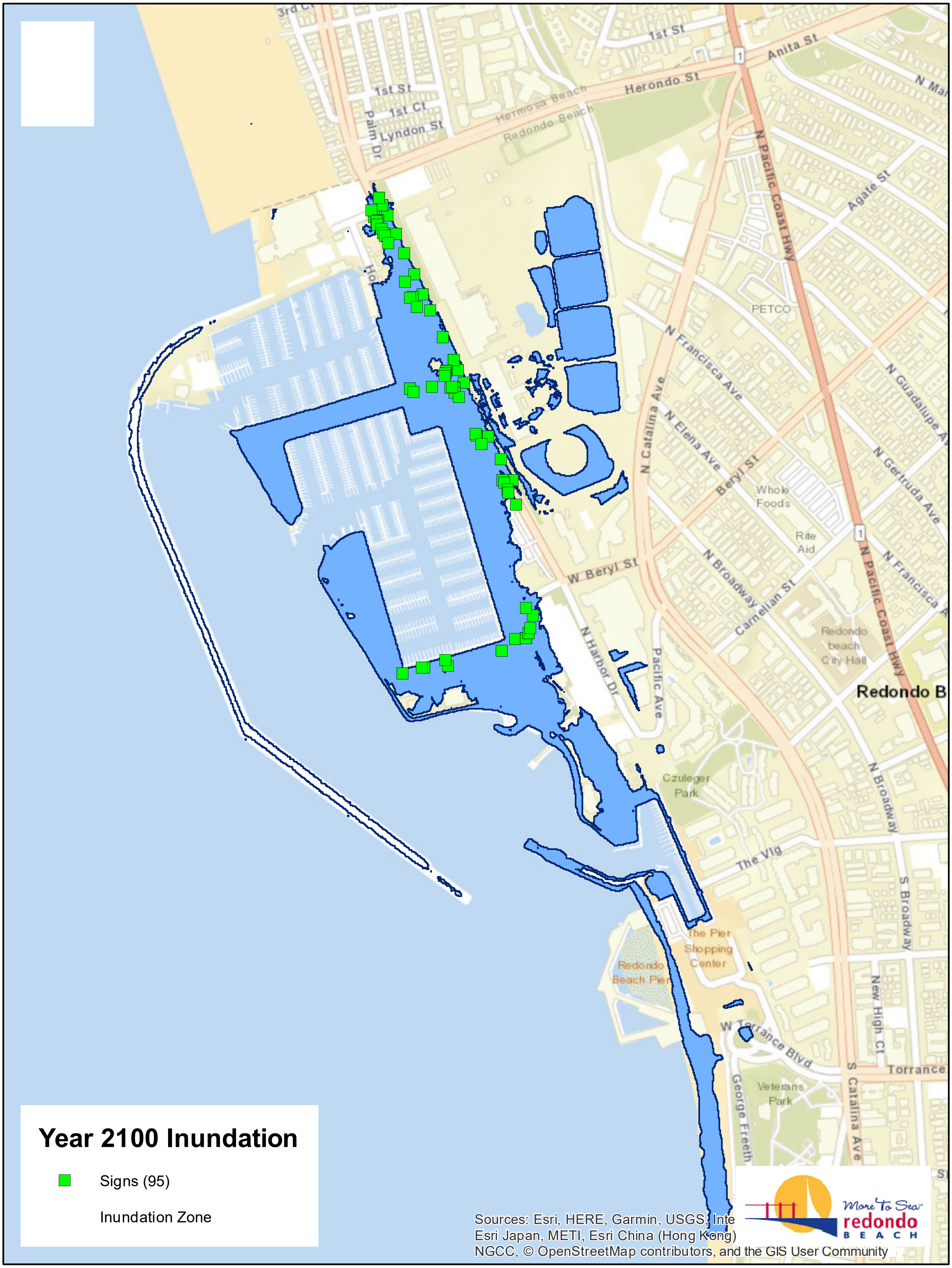
Year 2100 Inundation
Signs (95)
Inundation Zone
Sources: Esri, HERE, Garmin, USGS, Inte
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More To Sea
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3rd Ct
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N Catalina Ave
N Elena Ave
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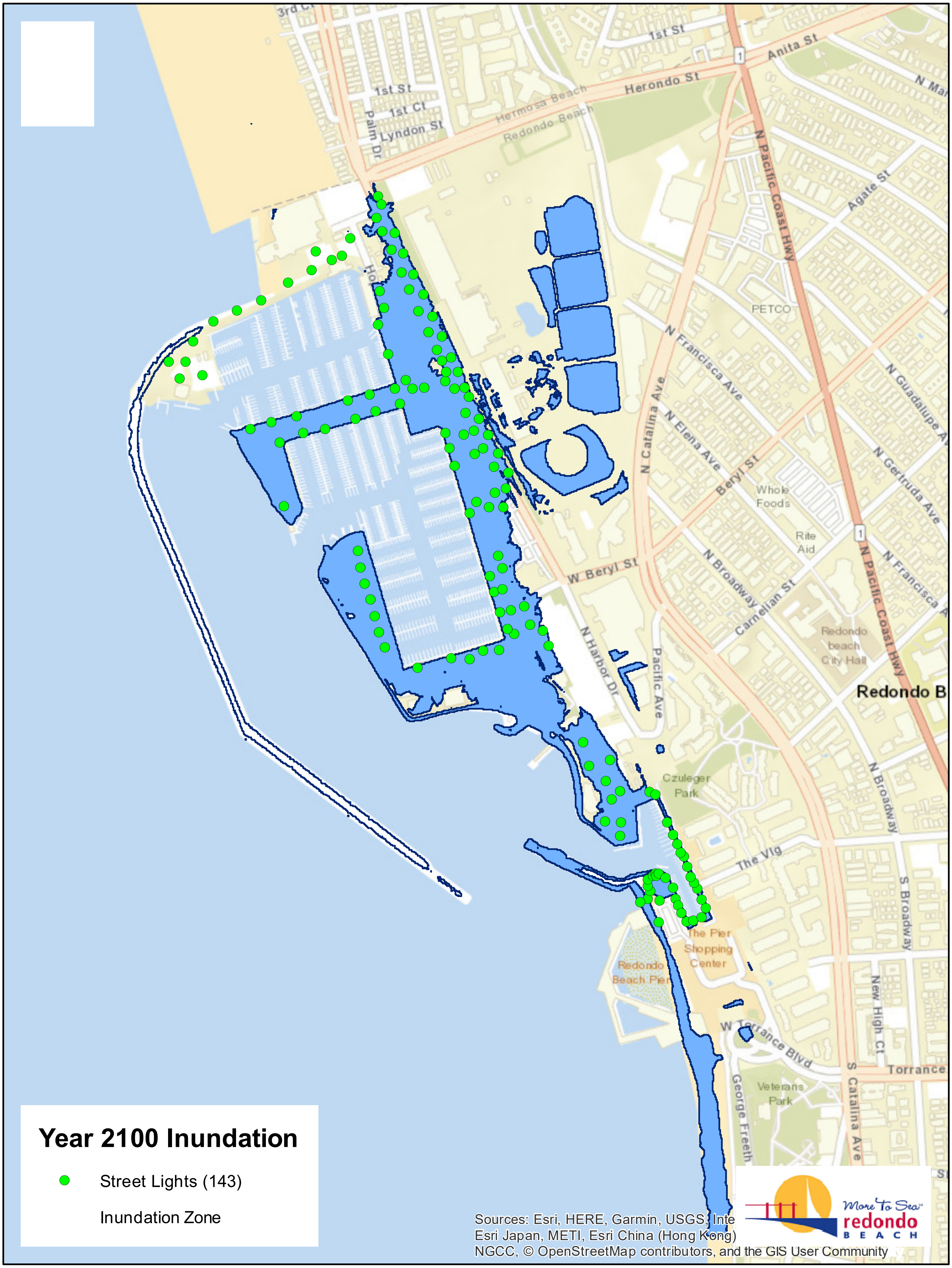
Whole Foods
Rite Aid
N Guadalupe Av
N Gertruda Ave
W Beryl St
N Broadway
Carnelian St
Redondo beach City Hall
Redondo B
N Harbor Dr
Pacific Ave
Czuleger Park
The Vig
S Broadway
The Pier Shopping Center
Redondo Beach Pier
W Torrance Blvd
Torrance
Veterans Park
George Freeth
S Catalina Ave
New High Ct

# Year 2100 Inundation Storm Sewer Network


Year 2100 Inundation
Street Lights (143)
Inundation Zone
Sources: Esri, HERE, Garmin, USGS, Inte
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More To Sea
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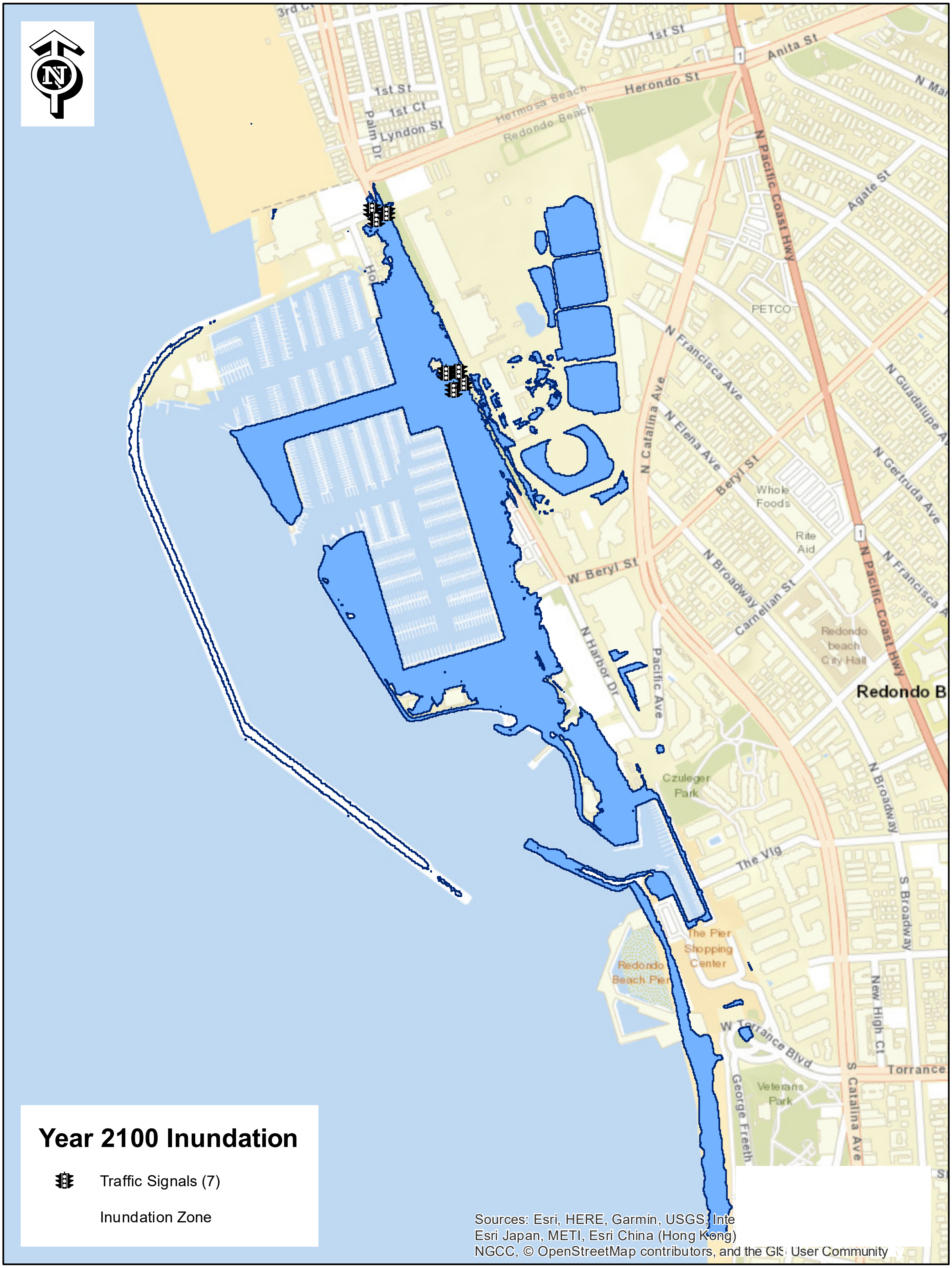
Anita St
Herondo St
Hermosa Beach
Redondo Beach
N Pacific Coast Hwy
Agate St
PETCO
N Francisca Ave
N Catalina Ave
N Elena Ave
Beryl St
Whole Foods
Rite Aid
N Guadalupe Ave
N Gertruda Ave
W Beryl St
N Broadway
Carnelian St
N Harbor Dr
Pacific Ave
Redondo beach City Hall
Redondo B
Czuleger Park
The Vig
The Pier Shopping Center
Redondo Beach Pier
W Torrance Blvd
Veterans Park
George Freeth
S Catalina Ave
S Broadway
New High Ct
Torrance


Year 2100 Inundation
Traffic Signals (7)
Inundation Zone
N
Sources: Esri, HERE, Garmin, USGS, Inte
Esri Japan, METI, Esri China (Hong Kong)
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1st St
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Rite Aid
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N Broadway
Carnelian St
N Harbor Dr
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Redondo beach City Hall
Redondo B
Czuleger Park
The Vig
The Pier Shopping Center
Redondo Beach Pier
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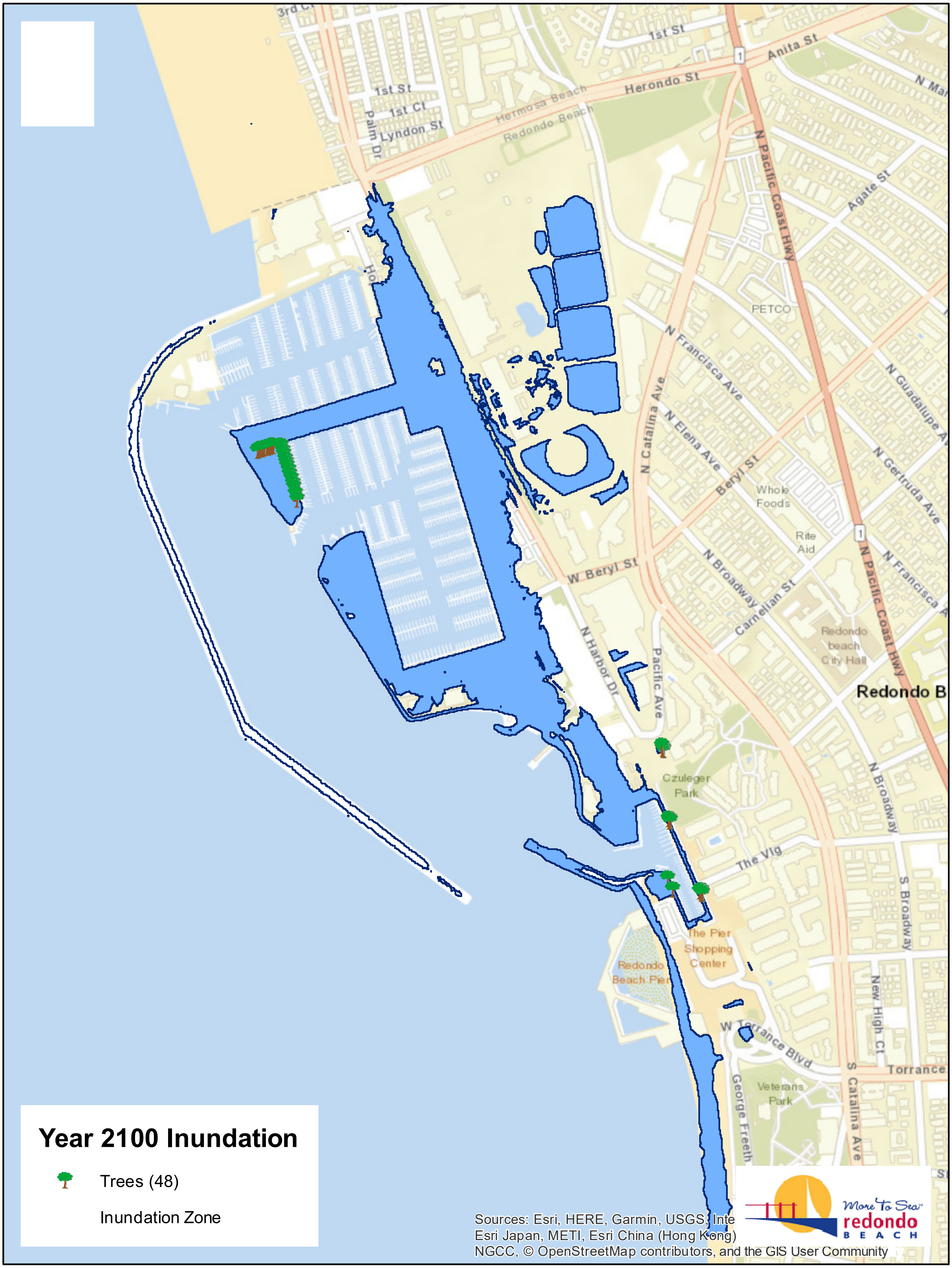
Veterans Park
George Freeth
S Catalina Ave
S Broadway
New High Ct
Torrance
N Guadalupe Av
N Gertruda Ave



Year 2100 Inundation
Trees (48)
Inundation Zone
Sources: Esri, HERE, Garmin, USGS, Inte
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More To Sea
redondo
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Herondo St
Anita St
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Lyndon St
Palm Dr
Hermosa Beach
Redondo Beach
N Pacific Coast Hwy
Agate St
PETCO
N Francisca Ave
N Elena Ave
N Catalina Ave
Beryl St
W Beryl St
Whole Foods
Rite Aid
N Broadway
Carnelian St
N Harbor Dr
Pacific Ave
Redondo beach City Hall
Redondo B
Czuleger Park
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The Pier Shopping Center
Redondo Beach Pier
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S Broadway
New High Ct
Torrance
N Guadalupe Av
N Gertruda Ave