2016 City of Imperial Beach Sea Level Rise Assessment

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Submitted to the City of Imperial Beach

By

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Acronyms/Abbreviations

CCC	California Coastal Commission
CEC	California Energy Commission
CIP	Capital Improvement Program
City	City of Imperial Beach
CoSMoS	Coastal Storm Modeling System of the USGS
CSBAT	California Sediment Benefits Analysis Tool
CURRV	Climate Understanding and Resilience in the River Valley
EFGS	Ecological Functions Goods and Services
EPA	Environmental Protection Agency
ESHA	Environmentally Sensitive Habitat Areas
MHW	Mean High Water
FEMA	Federal Emergency Management Agency
FIRMs	Flood Insurance Rate Maps
GHADs	Geologic Hazard Abatement Districts
GHG	Greenhouse gases
HMP	Hazard Mitigation Plan
IB	Imperial Beach
IPCC	Intergovernmental Panel on Climate Change
LCP	Local Coastal Program
NAVD	North American Vertical Datum 1988
NOLF	Naval Outlying Landing Field
NRC	National Research Council
PDO	Pacific Decadal Oscillation
SANDAG	San Diego Association of Goverments
SCC	California Coastal Conservancy
SPAWAR	Space and Naval Warfare Systems Command
TDR	Transfer of Development Rights
ToT	Transient Occupancy Tax
TRNERR	Tijuana River National Estuarine Research Reserve
TRV	Tijuana River Valley

TRVRT	Tijuana River Valley Recovery Team
TSDF	The San Diego Foundation
USACE	United States Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

Executive Summary

Introduction

Sea level rise and climate change threaten coastal communities and resources, presenting new management challenges to cities. Through this assessment the City of Imperial Beach is working to understand their vulnerabilities, as they prepare for a changing climate.

The purpose of the **2016 City of Imperial Beach Sea Level Rise Assessment ("Report")** is to enhance community understanding of future climate change impacts and potential adaptation strategies. There are three project goals:

1. Identify Imperial Beach-specific coastal vulnerabilities from sea level rise and coastal hazards;
2. Identify a range of adaptation strategies including tradeoffs and economics;
3. Recommend strategies over time that are politically digestible and economically feasible.

Adaptation is a process in which a community collaboratively seeks to understand and address climate-induced hazards, such as flooding and erosion resulting from sea level rise. Successful adaptation involves several key components:

1. **Analyze:** Assess existing and future vulnerabilities in relationship to changing conditions.
2. **Plan:** Identify "adaptation" strategies that reduce identified vulnerabilities to climate change, and align with the community's values and future vision.
3. **Act:** Implement adaptation plans, policies, and projects; and monitor to ensure the chosen strategies are effectively reducing vulnerabilities.

This project focused on the "Analyze" step by providing a science-based vulnerability assessment, and began to analyze a select few management options.

Vulnerability Assessment

Using coastal hazard models, provided by USGS and the Department of Defense, vulnerabilities in different sectors were analyzed under:

- Existing conditions, and
- Three future conditions, including 1.6 feet (0.5 meter), 3.3 feet (1 meter), and 6.5 feet (2 meters) of sea level rise.

The coastal hazards analyzed included:

- Coastal Flooding from a 100-year wave event
- Coastal Erosion
- Tidal Inundation
- Nuisance Stormwater Flooding

Based on the characteristics of the City's coastline and input from the City and steering committee, seven sectors were analyzed in the vulnerability assessment:

- Land Use
- Roads
- Public Transportation
- Wastewater
- Stormwater
- Schools
- Hazardous Materials

The primary focus for the report was to analyze vulnerability to climate change along Imperial Beach's Pacific shoreline (open coast). However, in recognition of the fact that IB is surrounded by water on three sides- the Tijuana Estuary (south), the Pacific Ocean (west), and San Diego Bay (north)- the vulnerabilities resulting from changing conditions along the Bay and Estuarine shorelines were integrated into the analyses.

The assessment considered vulnerabilities under the "No Action" scenario. In other words, if the City continues to manage their shoreline as they have historically, the City may experience the coastal hazard impacts, outlined in this report. Vulnerability assessments are conducted this way to highlight why action is important, while providing a baseline to which the City can compare future analyses that consider specific targeted management actions.

A summary of some of the key vulnerabilities are outlined in E.S. Table 1.

Analysis of Select Adaptation Strategies

In conjunction with the vulnerability assessment, detailed physical and economic analysis on 5 adaptation strategies were conducted, including

- Armoring of the entire IB coastline
- Phased relocation (managed retreat)
- "Business-as-usual" sand nourishment
- Hybrid dune and cobble approach
- 5 groins w/associated sand nourishment

The analysis assumed that each of the five strategies was implemented along the City's entire Pacific shoreline. This was to allow results to be easily comparable but it is not recommended that the City only implement one strategy. Successful adaptation will be a combination of multiple strategies, including policies and projects that not only strategically address specific vulnerabilities but also align with the community's vision for the future.

The study's economic analysis evaluated the tradeoffs between recreational use, ecological value, storm damages and construction, and maintenance costs.

A summary of some of the key findings from the analysis of these select adaptation strategies is outlined in E.S. Table 2.

Next Steps

As the City reviews these findings they will work to identify adaptation strategies that decrease vulnerabilities, and increase the community's resilience to a changing climate and coastal hazards. There are many policies, programs, and projects that provide avenues through which the City can adapt to current and future vulnerabilities. There are also a host of ways to implement all of these strategies.

Of particular importance to increasing local resilience to coastal hazards, is updating the **Local Coastal Program (LCP)** and its associated implementing ordinances and zoning. An effort of this nature should consider results from the Tijuana River NERR's *Climate Understanding and Resilience in the River Valley* (CURRV) project, the *Sea Level Rise Adaptation Strategy for San Diego Bay*, and results of the City's Ecotourism Study into an overall set of policies and implementing ordinances that set a long-term vision for the City.

As the City begins to outline a vision for the future, there are many important guiding principles to keep in mind as policies and plans are developed and implemented.

Hybrid solutions

In this assessment, the analysis of specific adaptation strategies applied a singular approach to the entire urbanized waterfront for methodological reasons. In other words, it was assumed that one strategy was implemented along the entire IB shoreline. This assumption was made for purely methodological reasons (i.e., to make economic comparison between strategies easier). In spite of this assumption, it is not recommended that IB only choose one strategy to implement. In reality there is no "one size fits all" and the adaptation strategies chosen for implementation will consist, of a yet to be determined combination of policies, plans, programs and projects. Strategies will likely be implemented in a phased approach with some strategies making more sense politically and economically at different time horizons. Different sections of Imperial Beach will choose to implement different strategies, and multiple strategies can even be integrated into one localized project.

Phased- Adaptation

Some strategies will need to be identified and implemented in the short-term (~30 years) but others may not need to be implemented until the mid-term (~60 years) or long-term (~90 years) planning horizons. This "phased" approach allows for the most critical vulnerabilities to be addressed, while allowing time to plan for emerging needs. One way to determine when to begin implementing different "phases" of the plan is to think about triggers. A trigger is an observation or experience that puts into motion the next phase of a plan. For example, a City could choose a trigger of 1 meter of sea level rise, meaning that when local tide gauges indicate seas haven risen 1 meter from current levels a certain set of policies or projects will begin. Another example, is a trigger that states that when a City experiences two floods of some magnitude in the same year an outlined set of policies or projects will begin. It's important to note that triggers often require monitoring and documentation of changes from current conditions.

However, when planning for what strategies to implement as a community it is important to recognize that strategies take time to implement, with some development projects taking decades to move through the planning phases to reach the implementation phase. This means that to be proactive, IB should begin to identify pathways they would like to explore not only in the short-term but in the mid- and long-term as well.

Monitoring

As the City moves from the assessment phase to the planning and implementation phases, monitoring current conditions, and the effectiveness of implemented policies and projects will be important in determining if actions are helping to reduce local vulnerabilities. An adaptive framework that integrates findings from monitoring will help to ensure that the City is able to implement their vision for their future and track progress towards success. Examples of conditions to monitor include:

- Physical environment to identify when the City is nearing thresholds;
- Study beach profiles to understand variability in sand supply, alongshore sediment transport and erosion;
- Conduct structural monitoring to understand the condition of existing structures and when maintenance or replacement will be required;
- Monitor inland extent, duration and depth of inundation and coastal flooding at key locations (e.g., South Seacoast, Seaside Point, Carnation and Bayview Elementary neighborhoods);
- Monitor pre-and post-storm conditions—erosion extents, high water marks, and inland locations of flooding.

Inter-jurisdictional Collaboration

Recognizing interrelated jurisdictional boundaries, it will be essential that the City participate in continuing regional dialogs related to coastal management, and climate change adaptation. The City can't adapt to climate change alone. The City should particularly coordinate with adjacent jurisdictions, including the Port, the City of Coronado, the Navy, and the Tijuana River National Estuarine Research Reserve (TRNERR). Through collaboration, the City and its partners can ensure that adaptation strategies are implemented in a fashion that maximizes overall benefits.

Aligning with Community Vision

In the end, how the community chooses to adapt will depend largely on the community's values and vision for the future. This discussion will require education and information coupled with economics and long term visioning.

Some key questions which may guide this community discussion include:

1. What do you value about IB today that you want to maintain into the future?
2. What are the long term priorities for the community? Discuss where trade-offs may need to occur (e.g., maintaining the beach vs. oceanfront development).
3. What adaptation strategies align with the community's vision for the future?
4. How can the City pay for adapting to coastal flooding and erosion?

It is important for the City to consider the natural, social, cultural, and economic characteristics of IB that are valued by its residents and the region. The analysis in this report provides the City an opportunity to begin to discuss what "adaptation" means in Imperial Beach, and how to ensure that the community is resilient long into the future.

Sector	E.S. Table 1 : Summary of Vulnerabilities
Land Use	• Neighborhoods in the South Seacoast, Seaside Point, Bayview Elementary and Carnation Ave areas are most vulnerable. Carnation Ave neighborhood sees a big increase in exposure with only 1.6 feet of sea level rise. • Residential structures and parcels are the most exposed land uses to existing and future coastal hazards. • With 6.5 feet of sea level rise, ~ 30% of all parcels could be exposed to coastal hazards with over 1500 parcels subject to episodic coastal flooding and 450 parcels subject to periodic tidal inundation. Coastal erosion hazards have higher economic vulnerabilities than all other coastal hazards combined with 594 parcels potentially being exposed to coastal erosion. • Tidal inundation has small impact under existing conditions, but impacts escalate between 3.3 feet and 6.5 feet of sea level rise.
Roads	• With 1.6 feet of sea level rise, coastal erosion without additional adaptation could impact ~90% of Seacoast Drive. • With 3.3 feet of sea level rise, nearly 20 miles of road could be closed temporarily from coastal flooding impacts and 4.3 miles of road could be destroyed by coastal erosion. About 1.2 miles could be exposed to routine tidal inundation along the low-lying parts of town. • With 6.5 feet of sea level rise, approximately ~40% of the City roads could be vulnerable to coastal storm flooding. Coastal Erosion could destroy up to 5.4 miles of roads, including the entire length of Seacoast Drive. Tidal flooding exposes 4.3 miles of roads to routine flooding.
Public Transportation	• With 6.5 feet of sea level rise, approximately 68% of the City bike paths, one-third of the bus stops, and 35% of the bus routes could be vulnerable to coastal storm flooding. Coastal erosion may result in closures of the bus and bike routes along Seacoast Drive.
Wastewater	• With only 1.6 feet of sea level rise, one pump station could become exposed to coastal erosion. With 6.5 feet of sea level rise, another pump station may be subject to tidal inundation. • Nearly 800 feet of wastewater pipe is exposed to existing erosion hazards, with 6.5 feet of sea level rise this increases to 2.7 miles. • With 6.5 feet of sea level rise, 45 manholes may be inundated by tides and 311 manholes subject to coastal flooding which would introduce additional water into the sewer system.
Stormwater	• The existing stormwater system is undersized without flap gates. Without adaptive measures, this may cause increases in tidal flooding. • With 1.6 feet of sea level rise, the potential erosion impact to oceanfront stormwater outfalls doubles. • With 3.3 feet of sea level rise more than half of the stormwater drainages are impacted by tides about 50% of the time. • With 6.5 feet of sea level rise, 7 of 9 stormwater drainages are impacted >90% of the tides, substantially increasing flood depths frequency.
Schools	• Six buildings at Bayview Elementary School are currently exposed during storm events and will become routinely exposed by tidal flooding with only 1.6 feet of sea level rise. With 6.5 feet of sea level rise, an additional building is exposed to coastal flooding. • With 1.5 feet of sea level rise, Westview Elementary becomes exposed to tidal inundation and coastal flooding. By 6.5 feet of sea level rise, the remaining school buildings become exposed.
Hazardous Materials	• With 6.5 feet of sea level rise, there is one auto-related Hazardous Materials site that becomes vulnerable to flooding by tidal inundation.

Adaptation Strategies	E.S. Table 2: Summary of Adaptation Analyses
Armoring of the entire IB coastline	• Armoring strategy leads to loss of beaches between 2050 and 2065 while protecting upland property. • Economic analysis indicates that armoring generally yields lower net benefits than other strategies, yielding the lowest net benefits over the medium (2069) and long-term (2100) time horizons. • As sea level rise increases coastal erosion and other hazards, the beach is lost and armoring becomes a much less economically viable strategy, as beach recreation and ecological value is lost. • Economic results indicate that armoring will reduce the City's income due to lower sales and transient occupancy taxes.
Phased relocation (managed retreat)	• The managed retreat strategy protects a beach through time at the expense of the upland development. • In the medium term (through 2069), managed retreat and groins have similar net benefits, which are significantly higher than armoring. If nourishment costs are high, managed retreat is a much more cost effective strategy. • Over the long run, managed retreat and groins yielded the highest net benefits with current (wide) beach width. • If the City wishes to construct a lease-back option, where it purchases property at risk and leases it back to the original owners (or someone else) the payback time is approximately 30-35 years.
"Business-as-usual" sand nourishment	• Nourishment maintains a beach while providing protection for upland development. To maintain a beach over time, will require substantial investment over shorter and shorter time periods between nourishment cycles. • Nourishment options are a potentially viable long-term choice, depending upon availability of sand, the cost of nourishment, environmental degradation, and community values.
Hybrid dune and cobble approach	• A hybrid dune option was based on the historic ecology and natural functioning of the beach, and maintains a beach while providing a more natural protection for upland development. To maintain a beach over time, will require substantial investment over shorter and shorter time periods between construction cycles. • Hybrid dune options are a potentially viable long-term choice, although expensive with the cost depending upon availability of sand and cobble, the cost of construction, environmental degradation, and community values.
5 groins with associated sand nourishment	• A groin and nourishment option is based on improving the original Army Corp concept to retain sand along Imperial Beach. • Short term, groins are slightly better than other options although this depends on assumptions made on beach width. • In the medium term (through 2069), managed retreat and groins have similar net benefits. • Over the long run, managed retreat (1st) and groins (2nd) yielded the highest net benefits with current (wide) beach width.

1. Planning Background

1.1 Introduction

Sea level rise is increasing the risk to coastal communities from storms, flooding, and erosion. In response to the increased risk from these coastal hazards, one of the California Coastal Commission's priority goals is to coordinate with local governments, such as the City of Imperial Beach (City), to complete a Local Coastal Program (LCP) amendment that addresses sea level rise impacts. An updated LCP can help cities address new coastal management challenges resulting from sea level rise and climate change.

As a first step to integrating sea level rise considerations into City planning processes, including its LCP, the City and its Study team prepared this **2016 City of Imperial Beach Sea Level Rise Assessment** ("Report"). The Study team was led by Revell Coastal, LLC in partnership with USC Sea Grant and the Tijuana River National Estuarine Research Reserve ("Study Team").

This report provides technical analysis using flood risk and shoreline change modeling, and fiscal impact analysis. Funding was provided by the State Coastal Conservancy (SCC) and The San Diego Foundation (TSDF). Project components include:

- Identification of existing conditions (SCC)
- Vulnerability assessment (SCC, TSDF)
    - Sea level rise modeling and mapping- U.S. Geological Survey (USGS) Coastal Storm Modeling System (CoSMoS 3.0) (SCC)
    - Nuisance flooding analysis (TSDF)
    - Updating City data on existing coastal armoring (TSDF)
    - Identification of adaptation strategies (SCC)
    - Physical response and fiscal impacts analysis (TSDF)
- Stakeholder Engagement (SCC, TSDF)
    - Steering committee meetings (SCC)
    - Informational workshops for City officials, including the City Council, the Tidelands Advisory Committee, and the Design Review Board (TSDF)

This project will inform the City's long-term effort to address a range of coastal and climate change hazards in planning and regulatory processes. This information will assist the City in making informed decisions regarding land use and development standards from the project level to the plan and policy level.

1.2 Location

Located in San Diego County, Imperial Beach (IB) is the southwestern-most city in the continental United States.

The City is mostly residential with a burgeoning coastal tourism industry along its 1.5 miles of coastline. IB is 4.5 square miles with approximately 27,000 residents (2015 Census). IB is bordered by the:

- City of Coronado and the Navy's Silver Strand Training Complex to the north,
- City of San Diego to the east,
- US- Mexico border and City of Tijuana, Baja California, the Tijuana River National Estuarine Research Reserve (TRNERR), and the Naval Outlying Landing Field to the south, and

- Pacific Ocean to the west including several assets in the Port of San Diego's jurisdiction.

The San Diego Unified Port District Act of 1962 gave the Port jurisdiction over the Tidelands in the Bay. By lease agreement, the City also gave the Port jurisdiction over 13 street ends, 2 parking lots, Dunes Park, and Pier Plaza. The Imperial Beach pier has been built and destroyed by storms a number of times since 1909. During the El Niño storms of the early 1980's, the City, financially exhausted, had the Port take over its reconstruction and ownership was then transferred.

Figure 1-1 Imperial Beach Overview (with topography – light grey areas have lower elevation)

Imperial Beach is susceptible to flooding as it is bound on three sides by bodies of water, including:

- San Diego Bay and Otay River to the north,
- Pacific Ocean to the west, and
- Tijuana River and Estuary to the south.

The Tijuana River and Estuary is publically managed as part of the TRNERR, which is a partnership between California State Parks, the National Oceanic and Atmospheric Administration (NOAA), and US Fish & Wildlife Service (USFWS).

1.3 California Coastal Commission Sea Level Rise Policy Guidance & Local Coastal Programs

The California Coastal Act requires local governments in the state's Coastal Zone to create and implement Local Coastal Programs (LCPs). Given that 87% of IB lies within the Coastal Zone (Imperial Beach General Plan), the City's LCP is an integral component of many planning processes. Each LCP consists of a Coastal Land Use Plan (~General Plan) and an Implementation Plan (Zoning Code). Using the California Coastal Act, the California Coastal Commission (CCC) and local governments manage coastal development, including addressing the challenges presented by coastal hazards like storms, flooding, and erosion.

The City had its first LCP certified in 1983 and was given permit jurisdiction. Under the 1994 LCP, as promulgated by Proposition P of 1992, armoring (i.e., revetments and vertical seawalls) along the coast is permissible.

Sea level rise and a changing climate threaten many coastal resources, presenting new management challenges to coastal cities. To address the increased risk of coastal hazards as a result of climate change, one of the CCC's priority goals is to coordinate with local governments, such as the City of Imperial Beach, to integrate sea level rise into LCPs.

In 2015 the CCC adopted the Sea Level Rise Policy Guidance document to aid jurisdictions in incorporating sea level rise into LCPs, Coastal Development Permit, and regional strategies. The document outlines specific issues that policymakers and developers may face as a result of sea level rise, such as extreme events, challenges to public access, vulnerability and environmental justice issues, and consistency with the California Coastal Act. The policy guidance document also lays out the recommended planning steps to incorporate sea level rise into the legal context and planning strategies to reduce vulnerabilities and inform adaptation planning (refer to figure 1-2 below). The policy guidance has a strong emphasis on using soft or green adaptation strategies.

The purpose of this report is to largely complete Steps 1-3, and begin Step 4 as outlined in the CCC's policy guidance document.

Step 1. Establish the Projected Sea Level Rise Ranges

Consistent with the CCC guidance the City is evaluating a worst-case scenario: using the best available model data from two federal agencies that look at 0.5, 1.0, and 2.0 meter (19.6, 39.6 and 78.72 inches) sea level rise. These sea level rise estimates are higher than those identified by the CCC. The National Research Council (2012) considered a high of 65.6 inches which is slightly lower than the hazard analyses provided by the USGS and Department of Defense. The relation of the sea level rise scenarios to English units and time horizons is shown in Table 1-1.

Table 1-1. Sea level rise scenarios used in this Study

Sea Level Rise (meters)	Sea Level Rise (feet)	Sea Level Rise (inches)	Time horizons
0.0	0.0	0.0	2010
0.5	1.6	19.7	2047
1.0	3.3	39.4	2069
2.0	6.5	78.7	2100

Step 2. Identify Potential Impacts from Sea Level Rise

Based on available modeling from SPAWAR and USGS (COSMOS 1.0 and 3.0 preliminary), the potential hazards for the City were identified including storm induced dune erosion, coastal flooding from wave run-up, and tidal inundation. Given the boundaries and setting of the City, the two most dominant hazards are 1) coastal flooding associated with major wave event and 2) coastal erosion.

Step 3. Assess the Risks and Vulnerabilities to Coastal Resources and Development

The following sectors were determined to experience some form of existing or future risk and related vulnerability to sea level rise (e.g., dune erosion and/or coastal flooding):

A. Land Use
B. Roads
C. Public Transportation
D. Wastewater
E. Stormwater
F. Schools and Parks
G. Hazardous Materials

Step 4. Identify Adaptation Measures

The City has begun to consider adaptation measures such as retreat, beach nourishment, armoring, groins, and dune restoration. Results from this report will be used to inform further discussion by the City and its residents about how to adapt to SLR along its Pacific shoreline.

1.4 The Planning Process

Steering Committee

A project Steering Committee met throughout the process to provide data and feedback, guiding the vulnerability assessment, identification of adaptation strategies, and economic analysis.

The Steering Committee included:

- A City Council member;
- Representative from the City's Tidelands Advisory Board;
- City staff from the Community Development & Planning, and Public Works departments;
- Staff from adjacent jurisdictions, including the Tijuana River NERR, California State Parks, the Navy and the Port of San Diego;
- Representatives from regional entities and nonprofits, including the San Diego Regional Climate Collaborative and Wildcoast; and
- State Coastal Conservancy.

The steering committee was convened regularly, as they were updated on project progress and given the opportunity to provide feedback throughout the process. The steering committees engagement is outlined below:

- **Existing conditions:** Steering committee helped the project team identify existing conditions, map current known nuisance flooding locations, and fill-in data gaps. (March 15, 2015)
- **Vulnerability assessment:** Steering committee identified sectors to be included, and helped guide which scientific information and modeling to integrate into the analysis. (November 16, 2015 & January 27, 2016)
- **Adaptation strategies & economic analysis:** Steering committee identified which adaptation strategies to analyze as part of the economic analysis, and provided input regarding how to compile the information in a way that would directly inform future decisions. (March 1, April 12 & May 10 2016)

- **Wrap-up:** Provided feedback on how to present the final findings and bring all the pieces together. (June 14, 2016)

Figure 1-2. California Coastal Commission Guidance for Including Sea Level Rise into Local Coastal Programs). This assessment focuses on steps 1-3, and begins step 4.

City Council Workshops

Two workshops were held to engage the public in the process, and to ensure that the City Council, Tidelands Advisory Board, and Design Review Committee were up to date on project progress and given the opportunity to provide feedback. These workshops were held on November 17, 2015 and May 11, 2016.

City Council Briefing

The City Council and the public were briefed on preliminary findings in preparation for the final report being released. This presentation was given on June 15, 2016.

1.5 San Diego Regional Context

Imperial Beach has been actively collaborating with partners throughout the region, expanding local capacity to address the impacts associated with sea level rise.

In 2012, The San Diego Foundation funded the development of the *Sea Level Rise Adaptation Strategy for San Diego Bay*. Through this project, the City of Imperial Beach joined the cities of Coronado, National City, Chula Vista, and San Diego; the San Diego Airport Authority; and the San Diego Port District in discussing how to adapt to coastal flooding around the Bay. Through this project, a number of adaptation strategies were identified that may help the City of Imperial Beach address potential SLR impacts along its northern shoreline bordering San Diego Bay and Otay River.

In addition, Imperial Beach collaborated with TRNERR on the *Climate Understanding and Resilience in the River Valley* (CURRV) project (funded by NOAA's Climate Program Office). Through the CURRV project, scenario planning was used to outline the Estuary's climate vulnerabilities, focusing on the relationship between sea level rise and riverine flooding. The results of the scenario planning process are informing the development of on-the-ground climate adaptation strategies for TRNERR, addressing the potential impacts that threaten the future resiliency of the Tijuana River Valley. The results of this project may help inform how the City adapts along its southern shoreline bordering the Tijuana River and Estuary.

Imperial Beach also continues to stay updated on the U.S. Navy's adaptation research and planning, as the Navy has a number of valuable assets and resources in and around Imperial Beach that may be impacted by sea level rise. The Navy is actively assessing how sea level rise may impact their assets, operations, and resources.

Additionally, IB has been actively engaged with the San Diego Regional Climate Collaborative (Collaborative). Through its Regional Sea Level Rise Working Group, the Collaborative is helping to coordinate multiple sea level rise planning processes occurring throughout the region. In addition to IB, multiple jurisdictions are actively assessing vulnerabilities, identifying adaptation strategies, and/ or updating LCPs. These include the cities of Oceanside, Carlsbad, Encinitas, Solana Beach, Del Mar, San Diego, and Chula Vista; the County of San Diego; Naval Base Coronado; Marine Corps Base Camp Pendleton; the San Diego Airport Authority; the San Diego Port District; and San Diego Gas & Electric. The Collaborative is helping to coordinate all these separate initiatives through the Resilient Coastlines Project of Greater San Diego (http://www.resilientcoastlines.org/), providing the City of Imperial Beach opportunities to leverage resources and share best practices for sea level rise adaptation.

1.6 Definitions

Adaptation: means anticipating the adverse effects of climate change and taking appropriate action to prevent or minimize the vulnerabilities and reduce the fiscal impacts.

Coastal Erosion: erosion of the coast caused by wave attack.

Coastal Flooding: flooding along the coast caused during a large storm wave event and typically includes wave uprush with momentum that can cause damages.

Economic Benefits: can be measured in two ways – market and non-market benefits. Market benefits are measured using market values. For example, to value a private residence one would use the market price of the home. Many of the benefits in this study are non-market benefits. Economists have developed a number of techniques to measure benefits when the price is set at zero. For example, beaches are free in California, but numerous studies indicate that visitors are willing to pay to go to the beach. This willingness to pay is non-market value. Our study incorporates the literature on non-market valuation to measure these changes.

Economic Costs: are measured similarly and can be market or non-market. In many cases in this study, costs are measured as replacement or repair costs. For example, this study measured the costs of roads at replacement cost.

Economic Impacts: measure the spending and economic activity resulting from a policy change. This study estimates the changes in spending from changes in beach recreation caused by changes in beach width.

Fiscal Impacts: measure not only tax revenue impacts, but also changes in costs to a city from a policy change. For example, if increased beach recreation requires increased public safety/lifeguards, a fiscal impact analysis would also incorporate these changes.

Tidal Inundation: flooding caused during predictable high tides that occur with some regularity.

Net Benefits: estimate the economic benefits minus the economic costs. Typically, these net benefits are discounted over time.

Nuisance Flooding: recurring flooding caused by high tides and potentially exacerbated with stormwater or precipitation.

Planning Horizon: The planning horizon is the future time that forecasts of climate impacts are made and the time that an organization will look into the future when preparing a strategic plan.

Tax Revenue Impact: measures the changes in taxes as a result of a policy change. This study estimate changes in sales taxes and transient occupancy taxes (TOTs) resulting from changes in beach tourism/recreation.

Vulnerability Assessment and Sector Profiles: A vulnerability assessment is the process of identifying, quantifying, and prioritizing (or ranking) the vulnerabilities in a system. There are a variety of vulnerable "sectors" within the City, ranging from building structures, stormwater, beach accesses, wastewater, and transportation.

2. Physical Setting

The City of Imperial Beach is located in San Diego County and surrounded by water on three sides. To the South is the Tijuana Estuary and River, to the North is the San Diego Bay, and to the west lies the Pacific Ocean. Imperial Beach is located near the western edge of a down dropped fault-controlled basin centered in San Diego Bay.

2.1 Geology and Historic Geomorphology and Ecology

The underlying geology of Imperial Beach is a combination of old Pleistocene aged paralic (estuarine) deposits and relatively recent Holocene sediments derived largely from the Tijuana River Valley. The weakly cemented Pleistocene sediments are found near the central portion of town while the recent Holocene sediments are largely found in the Tijuana Estuary (Figure 2-1).

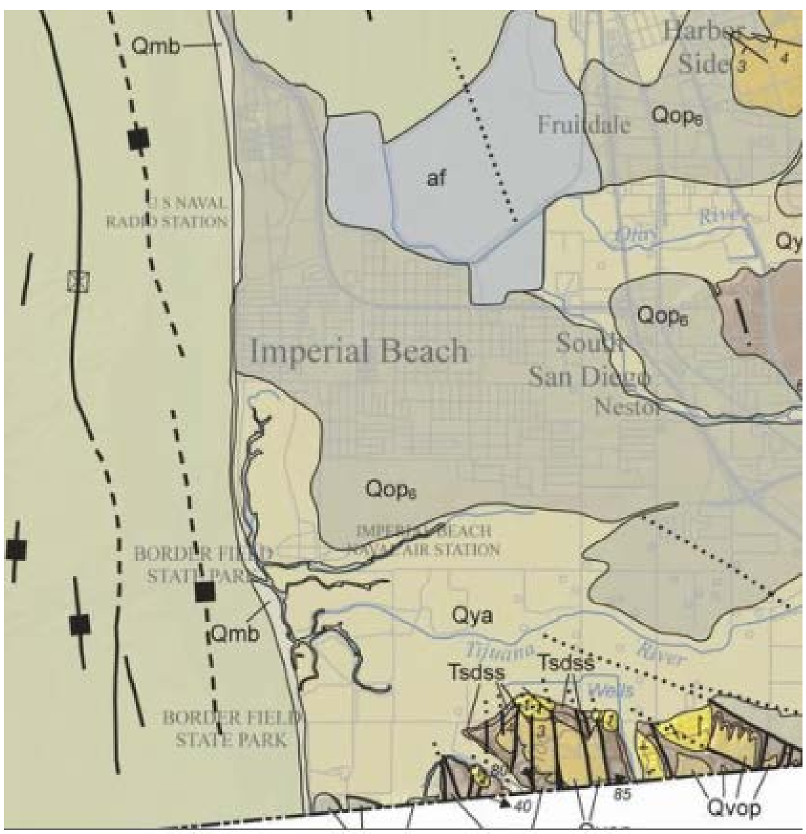

Figure 2-1 Imperial Beach Geologic Map. Source: Excerpt from USGS 2008

The coastal geology offshore of Imperial Beach is a shallow sloping continental shelf that has been dissected by the various Tijuana, Otay, San Diego, and Chollas Rivers. The Tijuana River has deposited a largely cobble delta that is roughly fan shaped and is still located at the mouth of the river. The delta extends seaward and is continually buried by fresh deposits of Tijuana River sediment.

Historically, the City consisted of a marsh plain, sand and cobble beaches, sand dunes, and upland scrub covering the coastline from north to south (Figure 2.2: Historic T-sheet). This system likely functioned as a bar built estuary which closed seasonally to the top of the beach and nursed southern steelhead and tidewater gobies. Adjacent salt marshes likely supported clapper rail and other now sensitive and endangered species.

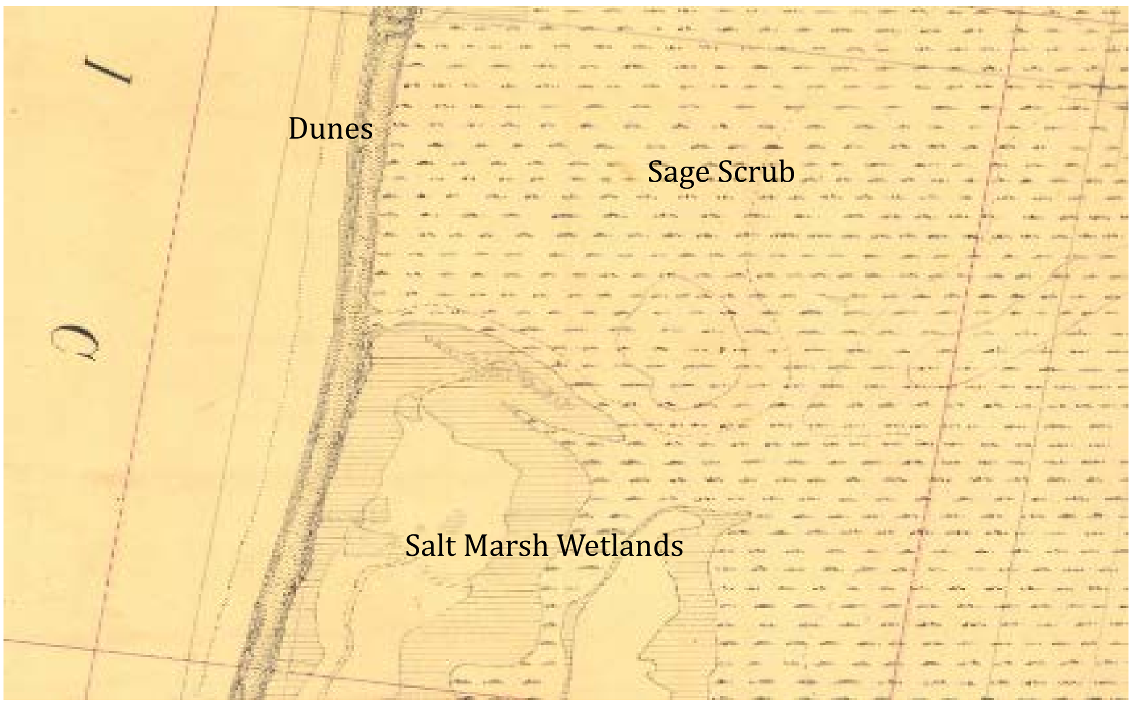

Figure 2-2. Historic T-Sheet 1852

Historically, the Tijuana River used to flow into San Diego Bay. Over geologic time as that floodplain and river channel migrated across the landscape, three remnant channels remain creating three areas across the city of relatively low lying elevation. These same paleo channels will likely reconnect San Diego Bay and the Tijuana River Estuary again in the future.

Sea level rise will affect the beach elevations, which will in turn affect the extents of inland flooding. Additionally, the old river channels further spread the flooding extent.

Our results show that a 100-year storm event, compounded by 2 meters of sea level rise would result in a convergence of flooding components that could result in severe flooding, potentially isolating large areas of the community. The region currently experiences substantial erosion rates (7.4 inches/year). Under such conditions, the entire area bounded by the Pacific Ocean, the San Diego Bay, the Tijuana Estuary, and 8th street could be surrounded by water.

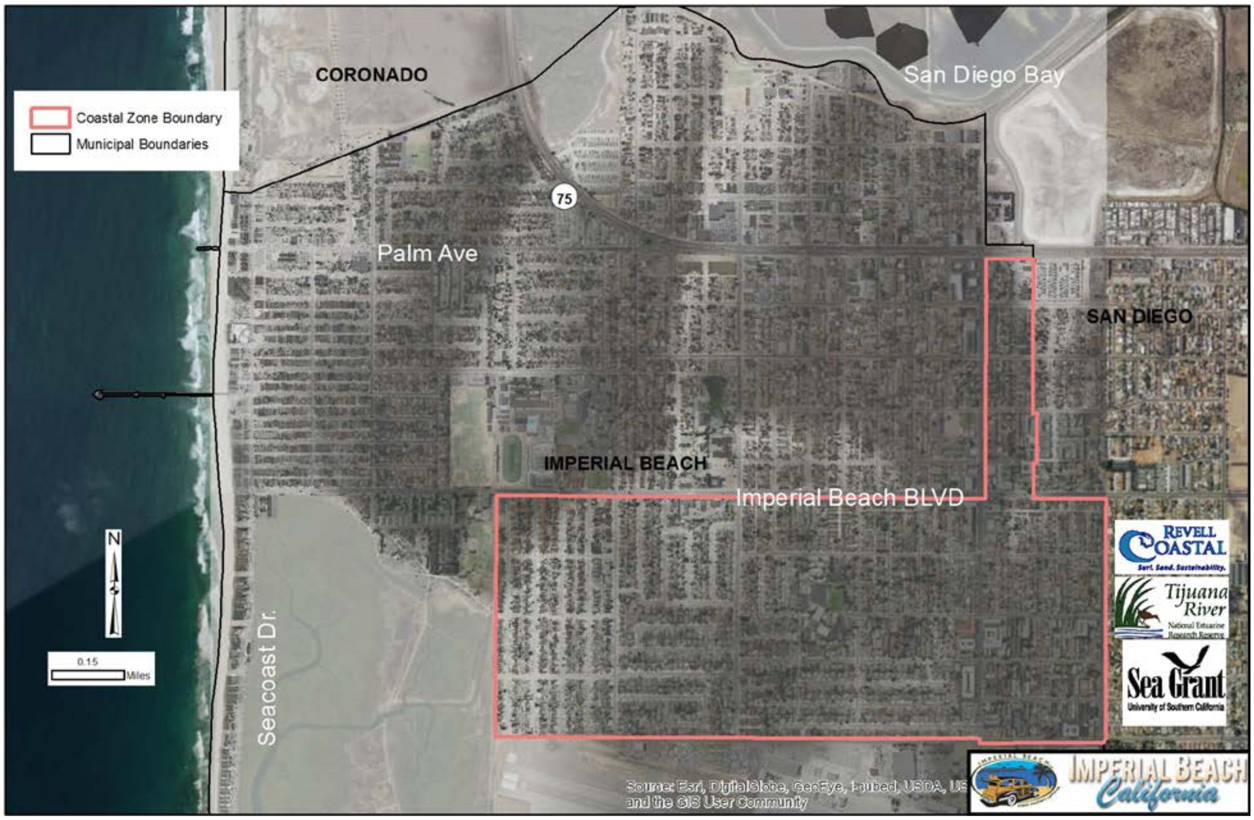

Figure 2-3 Topography showing low points along former Tijuana River channels (light grey areas).

2.2 Coastal Processes

Tides – tides in the Imperial Beach area are characterized as mixed semi-diurnal tides. Meaning that there are two high and two low tides of unequal height daily. The Spring tide range (largest tide swings) is 5.4 feet, while the mean tide range is 3.7 feet (NOAA 2016). Predicted tide levels can often be exceeded as a result of winds, wave set up, El Niño related thermal expansion and barometric changes. The elevation of ocean water levels above predicted levels can cause additional flooding. Based on historic observations, the 100-year tide water level recurrence is predicted by NOAA to be 7.4 feet NAVD. In addition, King tides which occur when the sun and moon are closest to the earth in their respective orbits create abnormally high tide. During the study period on 11/25/2015, the highest water level in San Diego Bay was recorded and tidal flooding occurred over the Bayshore bike path (Photo 2-1)

Photo 2-1 Overtopping at the Bayshore Bike path during an El Niño king tide 11/25/2015. Photo: C. Helmer.

Photo 2-2 January 1983 El Niño. Source: City of Imperial Beach.

Photo 2-3 January 1983 El Niño. Source: City of Imperial Beach.

Waves – Imperial Beach is a relatively high wave environment compared with much of Southern California. During the winter, wave energy from the northwest and west refracted around the Channel Islands move sand offshore and to the south. During the summer time, the distant south swells and more local hurricane swells move sand to the north. Using historic storm wave observations, the USACE determined that the 25, 50, and 100 year offshore significant wave heights are around 20 to 20.3 feet (USACE 2002). Everest Coastal reports calculations of the same 25, 50, and 100 year events ranging from 20.8, 23.0 and 25.0 feet offshore wave heights respectively (Everest 2001). Variations in alongshore wave heights breaking along the beach are caused by changes in the nearshore bathymetry (aka, underwater topography), wave period, and direction of wave approach. In most cases, the more westerly the wave approach and the higher the wave period, the higher the amplification of significant wave height to breaking wave height.

2.3 Littoral Cell

The beaches of Imperial Beach are within the 36-mile Silver Strand Littoral cell, which extends from Punta El Descanse 20 miles beyond the Mexican Border in the south, to Point Loma, 16 miles to the north. The Silver Strand littoral cell formed as a depositional beach with beach sediments in the region primarily composed of thin layers of sand, cobbles and gravel derived from the Tijuana River, erosion of the seacliffs in Tijuana, and artificial beach nourishment. The ultimate loss of the sand from the system occurs due to offshore sediment transport at the northwest end of the cell near the mouth of the San Diego Bay (USACE 1987, 1992, Patsch and Griggs 2007).

Sand supplied to the coast have been affected by 3 dams: Morena Dam, Barrett Dam and Rodriguez Dam. These dams impound about 70% of the entire watershed area draining through the Tijuana River (Patsch and Griggs 2007) and have reduced the sand supply by an estimated 49% (Willis and Griggs 2003).

Sand transport is dominated by wave transport with seasonal reversals in transport direction occurring due to the direction of wave attack. While the littoral cell has a high gross sediment transport, the net transport of sand is from south to north in the littoral cell driven primarily by the strong exposure to south swells and hurricanes.

As sediment sources into the cell have been blocked, due the constructions of dams, debris basins, and reservoirs along the Tijuana River, erosion rates at Imperial Beach have escalated. The lack of natural sediments has led to the multiple beach nourishment efforts in recent years (see discussion of beach nourishment in Section 2.6).

2.4 Geomorphology

The geomorphology of Imperial Beach has evolved as a direct result of human alterations.

Underlying the beach sediments along Imperial beach exist a large quantity of cobbles. These cobbles provide several important benefits to the Imperial Beach community. The first is that the cobbles once the sand is removed or transported offshore provides additional protection in the form of a natural cobble berm or dynamic revetment. Secondly, the cobbles form a layer in the beach upon which the groins and existing revetments can settle onto and reduce the amount of sinkage. This cobble layer thus has improved the resiliency of the existing coastal armoring structures.

Beach elevations are a result of sea level, tides, and waves. These elevations also vary seasonally. During the late summer and fall, beach berm crest elevations are around 12 to 15 feet North American Vertical Datum 1988 (NAVD).

Beach slopes, which affect wave run-up, also vary widely based on the time of year, precedent ocean conditions, and sediment grain size. Analysis of historic beach profiles show a range of beach slopes roughly between 0.04 and 0.10 (tanβ) or slopes of 1:25 and 1:10. However, it should be noted that the Regional Beach Nourishment Project II completed in 2012 added sediment that was substantially more coarse 0.53mm (larger grain sizes) than native sediment (~0.20mm). This has likely steepened the beach profile slopes and increased the wave run up (Ludka et al 2016).

Photo 2-4. Cobbles along south Seacoast (top) and fronting the Tijuana River Estuary March 1998 (middle) Tijuana River Estuary April 2016 (bottom). Photos courtesy of SANDAG.

2.5 Shoreline Change Rates

Erosion along Imperial Beach has been documented since 1937 (Inman 1976). Erosion rate estimates by the USACE have placed the annual erosion rate between 4.7 and 6.5 feet/year based on a sediment budget deficit of 100,000 cy / year (USACE 2002). However, these rates are complicated by the periodic nourishment cycles and large erosion events which have characterized this shoreline. One storm in particular in 1988 with a 7.5-foot high tide and 20 foot waves resulted in 50 to 150 feet of erosion along the entire Silver Strand Littoral cell (USACE 2002).

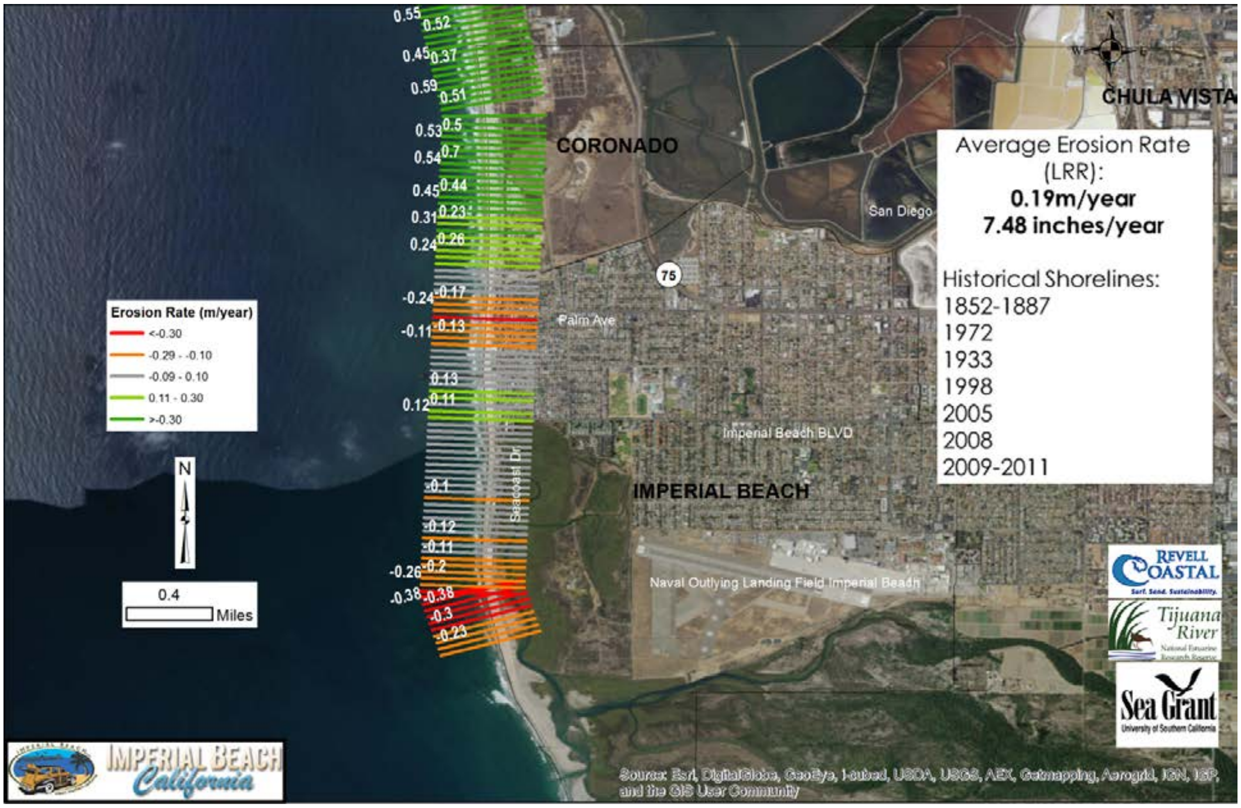

Figure 2-4. Shoreline change rates for 159yr historic year time period. Erosion hotspots shown in red. Green is accretion. Grey is within the range of uncertainty.

2.5.1 Shoreline Change Analysis

Shoreline change rates were calculated using the Digital Shoreline Analysis System (DSAS), developed by the United States Geological Survey. DSAS is a computer software that calculates shoreline changes by computing rate-of-change statistics.

Shoreline change rates were calculated for two beach transects, one just north of the pier (N1, running parallel to Date Av. for 500ft), and one near the south end of Seacoast Drive. These transects represented the range in beach widths observed in the historic record.

Dry sand widths were derived from the beach profiles based on a mean high water mark 4.41ft (MHW of 4.60ft – 0.19ft NAVD88). Further these widths were compared with aerial photos from google earth and ESRI's ArcGIS.

Table 2-1. Erosion Rates Accelerated using the 2.0 m Sea Level Rise Curve (feet/year)

Year	This Study	Low USACE	High USACE
2000	0.6	4.7	6.5
2005	0.6	4.7	6.5
2010	0.9	6.9	9.6
2015	1.2	9.1	12.7
2020	1.5	11.3	15.8
2025	1.8	13.5	18.9
2030	2.1	15.7	22.0
2035	2.4	17.9	25.1
2040	2.7	20.1	28.1
2045	3.0	22.3	31.2
2050	3.3	24.5	34.3
2055	3.6	26.7	37.4
2060	3.8	28.9	40.5
2065	4.1	31.1	43.6
2070	4.4	33.3	46.5
2075	4.7	35.5	49.7
2080	5.0	37.8	52.8
2085	5.3	40.0	55.9
2090	5.6	42.2	59.0
2095	5.9	44.4	62.1
2100	6.2	46.5	65.1

Multiple historical shorelines were used to calculate the long term shoreline change rates, including shorelines from 1852, 1887, 1933, 1972, 1998, 2005, 2008, and 2010. Shorelines were generated and downloaded from NOAA (ttps://coast.noaa.gov/dataviewer/index.html). Once all historical shorelines were added to DSAS, long term rates were calculated (Figure 2-4 – green transects indicate accretion, red and orange transects indicate erosion).

Based on the results above, an erosion rate of 7.48 inches per year was used as the historic erosion rate for the study. Future erosion rates were accelerated based on existing erosion rates and escalated with SLR curve. (Table 2-1).

For comparison purposes, by utilizing other published erosion rates from the USACE (2002) of 4.7ft/year or 6.5ft/year were accelerated based on the 2.0m SLR curve, we could expect much higher erosion rates accelerated 46.5 feet (14.2m) and 65.1 feet (19.9 m) /year by 2100. Note that while all of these rates include the impact of storms in the shoreline change calculations, they remain conservative in that they do not account for specific storms or El Niño related erosion events which could occur in any given year.

This study utilized the blue highlighted column to drive the physical response adaptation model.

2.6 Human Alterations to the Shoreline

Groins –In an effort to combat erosion following a particularly acute erosion even in the mid 1950's, the USACE constructed two of five proposed groins designed to stop erosion and create a wide beach. The first of the structures was partially constructed just north of the City boundary in the City of Coronado in 1959.

Photo 2-5. Existing Groins along Imperial Beach Coastline. Photo: D. Revell.

As the groin was ineffective at trapping sand, the USACE built a second groin in the early 1960s and later extended both of the groins. The groins never filled as intended and growing environmental concerns caused the Army Corps to abandon the project (Everest 2001, USACE 2002). Locals have observed that the west swell induced cross shore transport pulls sand off the beaches beyond the groins suggesting the length of the groins may be too short.

Any alterations, repairs or improvements to the groins would likely require involvement from the City, the City of Coronado, the Port of San Diego and the Army Corps of Engineers.

Coastal Armoring – as a result of the failure of the groins, individual property owners have constructed individual shore protection structures to protect their property. This has resulted in a parcel by parcel approach to coastal protection with 83 existing structures in a wide variety of forms of armoring including engineered revetments, random riprap placement, and vertical or recurved seawalls. Presently there are very few places along the ocean front without coastal armoring. (See Figure 2-5: Extents of different types of coastal armoring)

Based on available survey and permit data, the existing coastal armoring crest elevations range from 14.5 feet to 19.6 feet NAVD. Many of these crest elevations are only likely to provide protection for small wave run up events particularly with a narrow beach in front of the structure (Everest 2001).

Figure 2-5. Extents of different types of coastal armoring.

Beach Nourishment

From 1940 to 2005 beach nourishment projects added almost 40 million cubic yards of sand to this cell in an effort to mitigate coastal erosion (Patsch and Griggs 2007). Table 2-2 shows the history and quantities of beach nourishment to Imperial Beach and the Silver Strand Littoral Cell.

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Table 2-2. Historical Beach Nourishment

Site	Database	Date of project	Dredge/Fill Volume (yd3)	Fill Source/Site	Dredge/Transport Method	Dredge/Fill Characteristics
Imperial Beach	RW'94	1977	1,100,000			
Imperial Beach	TC'91	1977	1,100,000		1.0 mi long; ~150 ft wide	
Imperial Beach	Shaw'80	1977	999,855	San Diego Harbor		net migration to North
Imperial Beach	TC'91	1979	1,000,000			fill contained foreign matter
Imperial Beach	TC'89	1977, 1979	2,100,000			
Imperial Beach	FC	late 1984?	7,300	Tijuana slough and estuary	dragline and bulldozer dredging; placement on beach above MHW, leveling to grade	storm-deposited sands; no mud
Imperial Beach	FC	1994	51,000	Ballast Point, Point Loma Peninsula, San Diego	nearshore disposal	97% sand
Imperial Beach	FC	1994	240,000	San Diego Bay, Naval Station, Pier 2	disposal in nearshore (>10' MLLW)	predominantly sandy
Imperial Beach	RW '94	1994	<240,000	San Diego Bay, Naval Station, Pier 3		sandy portion of dredge spoils
Imperial Beach		5/22/01 - 6/04/01	120,000	Offshore (MB-1)	Trailing suction hopper dredge	Median grain size of fill = 0.24- 0.52 mm Vs. several receiver beaches received material with a median grain size as small as 0.14 mm (fine sand) source: RSBP-II
Imperial Beach	Annual Report	2012	450,000			The average median grain size (d50) varied from 0.48 mm to 0.66 mm (coarse sand).
Tijuana River National Estuary	FC	winter 96	?	connector channel between the Oneonta Slough and existing tidal lagoons	hydraulic cutterhead dredge for excavation; pipeline transport to surf zone; front end loader	65-75% sand

Tijuana River Management

Along the City's southern border is the Tijuana River Valley which contains one of the largest intact coastal wetland system in Southern California. Unlike most other coastal ecosystems in the region, which have been fragmented or lost altogether, the valley has contiguous beach, dune, salt marsh, riparian, and upland ecosystems. These habitats are largely in public ownership as part of the TRNERR, which is managed by the National Oceanic & Atmospheric Administration, US Fish & Wildlife Service, and California State Parks.

Sediment: As a result of being situated on the US-Mexico border, large amounts of sediment are transported across the border from Tijuana, Mexico into the Tijuana River Valley. This is a result of the City of Tijuana's population rapidly expanding and infrastructure improvements not being able to keep up with this growth (e.g., paved roadways). This expanded development has led to many natural drainage patterns being disturbed and vegetation from slopes being removed, resulting in high rates of erosion along hillsides and canyons in Tijuana. To control degradation, CA State Parks constructed two sediment basins in 2006 to store sediment and protect downstream habitats, particularly salt marsh, from being smothered under sediment. The excess sediment crossing the US-Mexico border provides an opportunity for the City to explore a partnership with TRNERR in designing a mutually beneficial sediment management plan (See Section 8). To learn more about how sediment is being managed in the River Valley, please refer to the Tijuana River Valley's Recovery Team Recovery Strategy (January 2012).

River Mouth: The Tijuana River crosses the US-Mexico border into the TRV and empties into the Pacific Ocean. The river mouth of the Tijuana Estuary, where the river enters the ocean, infrequently closes; however, during past El Niño years (1982-1983 and 2016) the mouth closed impacting habitat health (e.g., salt marsh), endangered species (e.g., Ridgway Rail), and surrounding infrastructure (e.g., street flooding). The 2016 mouth closure was due to elevated sea levels and large wave events, indicating possible increases in mouth closure in the future due to climate change. Through the *Climate Understanding and Resilience in the River Valley* (CURRV) project (funded by NOAA's Climate Program Office) TRNERR has used scenario planning to outline the Estuary's climate vulnerabilities, focusing on the relationship between sea level rise and riverine flooding. CURRV closely considers the potential relationship between river mouth closures and how these socioecological events may impact valuable coastal resources and surrounding communities informing the monitoring and managing of a healthy river-ocean connection.

Restoration: The Tijuana Estuary Tidal Restoration Program is a large multi-phased wetland restoration program involving up to 500 acres of restoration. Its primary objective is to restore valuable habitat processes that have been lost, and to increase the exchange of water in a tidal cycle. This will enhance flushing, improve water quality, and enhance natural processes that deliver sediment from the watershed to the ocean. This restoration will begin within the next several years.

3. Climate Science

3.1 Climate Cycles

Climate change is not to be confused with climate cycles, which also operate independently of human-induced climate change. Some of these climate cycles occur at long time periods and are related to the orbit of the earth around the sun, the tilt of the earth on its axis, and precession (subtle shift) of the earth's orbit. These Milankovitch cycles occur at approximately 26,000, 41,000, and 100,000 years and are responsible for the Ice Ages observed in the geologic record.

Some of these climate cycles are shorter; the most commonly known cycle is the El Niño/La Niña cycle, which is related to changes in equatorial trade winds and shifts in ocean temperatures across the Pacific Ocean. An El Niño brings warmer water to the Eastern Pacific, and this shift in ocean temperatures elevates sea level rise by about a foot above predicted tides in Southern California. These warmer ocean temperatures can increase evaporation, resulting in more atmospheric moisture and often substantially more precipitation. The 1982–1983 and 1997–1998 El Niños have caused both river and coastal flood damages in Imperial Beach and the Tijuana River Estuary. The January 27, 1983 wave event is considered to be the largest storm recorded by the La Jolla Tide gage on the open Pacific Coast. The highest water level ever recorded inside San Diego Bay occurred on November 25, 2015 associated with the 2015-2016 El Niño which caused tidal flooding over the Bayshore bikepath around 7th Street and into low lying areas of Imperial Beach.

One other climate cycle that impacts the Imperial Beach area is the Pacific Decadal Oscillation (PDO) that changes the distribution of sea surface temperatures across the Pacific. Its effects were first noticed by fishery researchers in Washington (Mantua et al. 1997) The index has been on the cool side, which tends to lead to less precipitation in Imperial Beach. One other implication of the PDO is that the rate of sea level rise is reduced in the Eastern Pacific (off the U.S. West Coast). Recent PDO research indicates that a shift in the PDO would likely result in much more rapid rise in sea levels off the U.S. West Coast than has been seen in the last three decades (Bromirski et al. 2011).

3.2 Climate Change

Human-induced climate change is a consequence of increased greenhouse gas emissions from the burning of fossil fuels that accumulate in the atmosphere and insulate the earth from outgoing long-wave radiation. As this atmospheric emissions blanket gets thicker, more heat is trapped in the earth's atmosphere, warming the earth and triggering a series of climate changes related to different feedback mechanisms. Once set in motion, many of the climate change feedbacks take centuries to millennium to stabilize.

Globally, sea levels are rising as a result of two factors related to increasing temperature caused by human-induced climate change. The first factor is the thermal expansion of the oceans. As ocean temperatures warm, the water in the ocean expands and occupies more volume, resulting in a sea level rise. The second factor contributing to eustatic (global) sea level rise is the additional volume of water added to the oceans from the melting of mountain glaciers and ice sheets. It is predicted that if all of the ice were to melt on earth, ocean levels would rise by approximately 220 feet above present-day levels. The rate at which it rises will largely depend on the feedback loop between the melting of the ice, which changes the land cover from a reflective ice surface, and the open ocean water, which absorbs more of the sun's energy and increases the rate of ice melt.

3.3 Future Climate Projections: Scientific Overview

Substantial research in California is currently underway to effectively downscale climate change models and to project various human-induced climate change impacts at a local scale. By analyzing the outputs of these downscaled models, Imperial Beach can better understand the range of likely climate impacts specific to Imperial Beach. The San Diego region, and thus Imperial Beach, is fortunate to have many of the leading climate researchers in its community at the Scripps Institution of Oceanography at the University of California, San Diego. Researchers from this region are often available to local communities to help them understand what impacts they may be facing with climate change. Several of the key climate change impacts are likely to include increased temperature, decreased precipitation, increased wildfire, and sea level rise.

In addition, the Climate Education Partners, which is comprised of multidisciplinary experts from the University of San Diego, UC San Diego's Scripps Institution of Oceanography, California State University San Marcos, The San Diego Foundation, The Steve Alexander Group and University of California San Francisco, has developed the report that summarizes much of the leading climate science for the San Diego region. "2050 is Calling" provides summaries of projected impacts to temperature, water resources, coastal flooding, wildfires and health, while also highlighting many of nature's benefits. The reports is available for download here: http://www.sandiego.edu/2050/ and we summarize several of the key findings below.

Temperature

Between 1985 and 2014, the report indicated that the San Diego region's temperature has on average increased by 1.7° Farenheit (F). By 2050, the average temperature is expected to increase to another 4.8° F over the 1985 baseline. The projections indicate that the region should expect more days of extreme high temperatures hotter and more humid heat waves (Figure 3-1A).

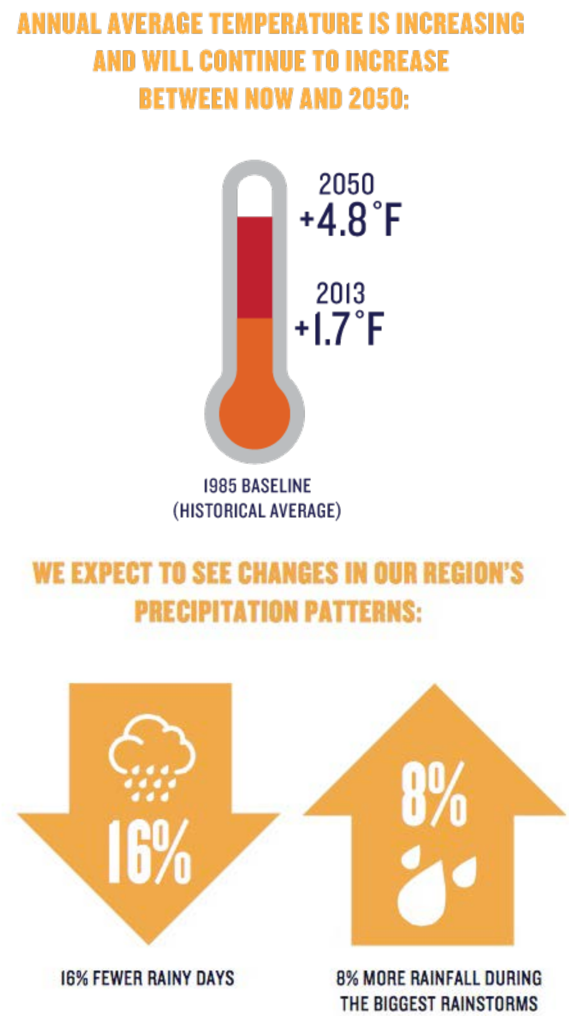

Figure 3-1. (A) Expected Changes in Temperature and (B) Precipitation Patterns by 2050 (courtesy of Climate Education Partners)

Precipitation and Water Resources

Latest downscaling climate results also suggest that the San Diego region should expect 16% fewer rainy days by 2050 but that these rainfall events will occur in more deluge-style storms that could lead to 8% more rainfall during the biggest storms. It is as yet unclear whether these precipitation trends will result in a net change in the amount of precipitation to the region overall. However, communities will need to consider how to manage larger rain events that will likely lead to increased precipitation-based flooding and stormwater management impacts.

At the same time, the 2050 report notes that as the population in the region - and temperatures - increase, water demand is expected to increase by 46% by 2035 for the San Diego region. Increased temperatures in the mountains is projected to lead to 12% less snowpack. Communities throughout Southern California rely on this snowpack as a storage system for the water, which then replenishes many of the region's water sources through spring melt run-off. While again the projections do not show a net loss of actual water amounts, the fact that precipitation shifts to a more rain-based form provides water storage, and therefore supply, problems for these regions.

As the hydrological system in any watershed is intimately connected from the top of the watershed to the oceans, linking management and adaptation strategies across the system will become increasingly important.

Wildfires

Taken in sum, warmer temperatures, with less frequent rainfall, will likely lead to more drought-like conditions akin to what all of California has been experiencing over the last several years. The amount of moisture in the atmosphere can either increase or decrease based on the amount of temperature changes affecting evaporation and changes in humidity. Precipitation and temperature also affect the wildfire risk. Increased precipitation increases plant growth, thereby adding more fuel, and increases in extreme heat can reduce vegetative growth (Cal Adapt 2016). Changes in both precipitation and wildfire are relative to percent changes from the time period between 1961 and 1990.

However, the precipitation variable (and thus the changes in wildfires that are dependent on precipitation) is one of the least certain of the climate change impacts. Models can vary widely, and this is an area of active research. As summarized in the 2050 report, the latest projections suggest that the fire season may become longer, generally trending to year round fire risk, rather than just the summer months. Increased fire can also lead to a higher number of poor air quality days, impacting human health (Climate Education Partners 2015).

Sea Level Rise

Sea level rise can increase flood risks in low-lying coastal areas and areas bordering rivers. A 5-foot increase in water levels caused by sea level rise, storms, and tides is estimated to affect 499,822 people, 644,143 acres, 209,737 homes, and $105.2 billion of property value in coastal areas (Climate Central 2014).

The time scales for sea level rise are related to complex interactions between the atmosphere and the oceans and the lag times associated with the stabilization of greenhouse gases in the atmosphere with the dissolution of those gases into the ocean. The Intergovernmental Panel on Climate Change (IPCC) that demonstrates that, due to the greenhouse gases already released into the atmosphere, the sea levels will be rising for the next several thousand years. Given this long-term perspective, it is not a question of if sea level rise will happen, but when it will happen and at what rate.

Sea level rise scenarios used in this analysis were selected consistent with the CCC's 2015 Sea Level Rise Policy Guidance (CCC 2015) and consistent with the science published by the National Research Council (NRC 2012. 1-1).

Relative Sea Level Rise

Sea level rise is not the same everywhere around the world. Because of local differences in tectonic uplift; subsidence caused by oil, gas, and groundwater extraction; and saltwater intrusion, the land itself is moving vertically. The difference between the local land motion and the global rise of sea level gives the relative sea level rise that will determine the magnitude of local sea level rise impacts. Vertical land motion in some studies would identify this relative rate from local tide gages. The La Jolla Tide Gauge reports the local sea level rise rate at a rate of approximately 2.19 (+/-0.27) millimeters per year (Figure 3-2). This tide gauge has been in place since the 1930s and provides an excellent time series that demonstrates the decadal ranges of relative sea level rise, but also demonstrate an unequivocal increase in sea levels over the years.

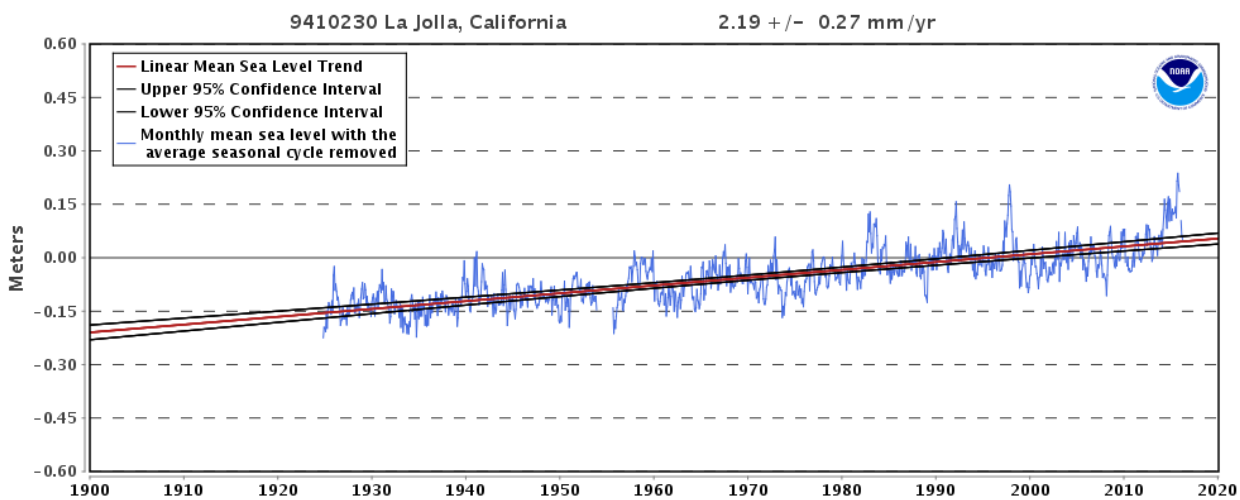

Figure 3-2. Tide Record and Sea Level Rise Trend from the La Jolla Tide Gage (NOAA Station 9410230)

Wave and Coastal Storms

While sea level rise and associated coastal erosion are clearly important climate impacts that need to be addressed by Imperial Beach, impacts to the coast will be underestimated significantly if these analyses are not done in coordination with an assessment of wave and coastal storm-related impacts to the shoreline. We describe the modeling information that is available for these types of analyses below and have incorporated them in this study's vulnerability assessment

3.4 Uncertainty

In any climate and sea level rise modeling, there is always a level of uncertainty on the model projections. Uncertainty can arise from the data sources used as inputs to the modeling systems such as bathymetry and topography, and from the digital elevation model upon which the flood extents are modeled.

Each model run also contains associated uncertainty. In the modeling utilized in this project (both CoSMoS and SPAWAR) there are a number of equations and model steps that provide the final projections. At each model step, there will be associated uncertainty and thus modelers generally provide a measure of uncertainty with their model projections. Because we are using preliminary results for the CoSMoS projections, we do not yet have a measure of uncertainty. SPAWAR does provide uncertainty bounds on the order of 95%.

There is also uncertainty in the sea level rise projections selected for the vulnerability assessment and the adaptation discussions. As can be discerned by the NRC projections listed in Table 1.1 – the range (to account for uncertainty in projections) in the sea level rise projections increase with time. This uncertainty stems from the modeling uncertainty described above, but it is also due to uncertainty in human behavior in future emissions of greenhouse gases (GHG).

With our history of GHG emissions, we are locked into an increasing trend of sea level rise for the next millennia. However, the rate at which we will *continue* to emit GHG is unknown. Should the global community meet the Paris accords and work to truly curtail GHG emissions, keeping global temperature increase to under 2° F, we can consider planning to the lower range of the projections. However, current global emissions are on track or exceed the business-as-usual scenario in which we continue to emit GHGs at an unprecedented rate, thus making it likely that we will need to plan for the highest rates of sea level rise, if not higher.

As a community works to develop an adaptation plan, it is equally important for that community to also assess its mitigation (or GHG emissions-reducing) goals as carbon emissions are intimately connected to the rate of sea level rise, which will ultimately dictate which sea level rise projection will prevail. The City is currently seeking funding to complete its GHG inventory and develop a climate action plan to reduce their overall community emissions.

3.5 Other Regional Scientific Initiatives

Currently, there are a wide variety of scientific investigations studying and modeling the impact of climate change and downscaled global models in San Diego County that will provides regional level information that is useful for Imperial Beach. The studies discussed below demonstrate the most promise and focused applicability to Imperial Beach.

USGS Coastal Storm Modeling System (CoSMoS) 1.0

The USGS Coastal Storm Modeling System (CoSMoS) 1.0 was developed for a pilot study conducted for the entire Southern California bight from Pt. Conception to the U.S./Mexico border. The modeling team hindcast a storm that impacted the Southern California region during January 2010. This storm sat along the coast for a several days and led to extensive flooding up and down the coast. The storm was estimated to be a 10 year return interval winter storm; i.e. a storm that has a 10% chance of impacting the Southern California coast during a given year. The model then projected this 10-year storm for two sea level rise scenarios: 0.5 meters (or 1.6 feet) and 1.4 meters (or 4.6 feet) (Barnard 2009). CoSMoS 1.0 was a pilot project. It did not explicitly model embayments such as San Diego Bay and did not include an assessment of other coastal hazards such coastal erosion or impacts to sandy and cliff-backed beaches.

USGS CoSMoS 3.0

In 2015, USGS was funded by the California State Coastal Conservancy, the City of Imperial Beach, TRNERR and California Department of Fish and Wildlife to update the CoSMoS 1.0 model to specifically model the embayments and provide projections of long-term shoreline change.

The CoSMoS 3.0 results utilized in this study are initial results that project the impacts of a 100-year winter wave event (or an event that has a 1% change of occurring in a given year) at current sea level, 0.5 m, 1.0 m, 1.5 m and 2.0 m of sea level rise.

A detailed "Frequently Asked Questions" (or FAQ) has been developed that lists the data sources utilized in developing CoSMoS 3.0. It also provides more detail on the details of the modeling methodology. It can also be downloaded from the San Diego Regional Climate Collaborative website: http://sdclimatecollaborative.org/wp-content/uploads/2016/05/CoSMoS-FAQ_Final_5.16.16.pdf

SPAWAR (2014)

This project funded by Department of Defense developed a methodology to evaluate impacts of sea level rise and coastal hazards to coastal military installations over the next century. Fortunately, the pilot project focused on Naval Base Coronado as one of the sites and analysis included all of the urban portions of the City of Imperial Beach. Model results mapped future projections of coastal erosion, coastal flooding, tidal inundation and depth of flooding along with various recurrence intervals. These results of the tidal inundation, coastal erosion and depth of flooding were integrated into this Report. Results of the Coastal Flooding analysis was combined with USGS COSMOS 3.0 and 1.0 to show the maximum extent of the coastal flooding.

4th California Climate Assessment (anticipated 2018)

There are many project underway through the 4th California Assessment that are focused on the San Diego region. Two are focused on providing downscaled climate information for the region and several others begun identifying the vulnerability of critical energy-related facilities. Dr. David Pierce, Dr. Cayan and Dr. Laurel Dehann are leading an effort to downscale a suite of 32 climate models to the 1/16° spatial resolution (about 6km, or 3.7 miles). For communities that cannot utilize the 32-model dataset, they will also provide analysis of how a subset of 10 of these models – and a further reduced subset of 4 of these models – combine to project climate impacts for the region. These projections will then be utilized by Dr. Dan Cayan and colleagues to provide probabilistic sea level rise projections to support the vulnerability and adaptation planning studies underway under the 4th climate assessment.

San Diego Gas and Electric Vulnerability Assessment (anticipated Summer 2017)

San Diego Gas and Electric (SDGE) are conducting a vulnerability assessment to evaluate the impacts of climate change on the electrical and natural gas infrastructure. This vulnerability assessment is including sea level rise and coastal hazards as well as other climate variables such as temperature and precipitation changes, extreme heats and wildfires. The assessment is funded by the California Energy Commission with the intent of identifying component level adaptation strategies. These regional strategies will support regional community adaptation planning as quite often these critical infrastructure form the bottlenecks to longer range adaptation planning.

Sea Level Rise for the Coasts of Oregon, Washington and California (NRC, 2012)

In 2011-2012, the National Research Council (NRC) assembled a team of experts to provide projections of sea level rise for the Pacific coast, from Washington to California. This study incorporated global sea level rise forcing as well as local geophysical processes, such as regional subsidence and tectonic activity. Their scenarios are divided into projections for north of Cape Mendocino (where tectonic uplift is currently outpacing sea level rise) and south of Cape Mendocino (where tectonic activity is not expected to outpace sea level rise.) The NRC projections have been adopted by the State of California as the best available scientific projections for sea level rise (OPC 2013 and CCC 2015).

2016 FEMA Pacific Coastal Flood Mapping

FEMA is currently updating the Pacific Coastal flood maps for FEMA Region IX. The California Coastal Analysis and Mapping Project is conducting updates to the coastal flood hazard mapping with best improved science, coastal engineering, and regional understanding. The project incorporates regional wave transformation modeling and new run-up methods and will be revising the effective flood insurance rate maps for coastal flood hazard zones. This will include revised VE (wave velocity), AE (ponded water), and X (minimal flooding) zones. The anticipated completion date is 2018.

4. Existing Conditions and Vulnerability Assessment

4.1 Introduction

This chapter provides an overview of the methodologies employed to assess existing and projected vulnerability from coastal hazards and nuisance flooding. We also highlight key findings from these analyses. Detailed overviews of vulnerabilities, coupled with recommended initial adaptation considerations are presented in the Sector Profiles (Appendix A).

Understanding current and projected vulnerabilities from coastal hazards is the critical first step a community must take to identify appropriate climate adaptation strategies. For the purpose of this report, we assessed four coastal hazards which are individually defined as:

- **Coastal Flooding:** Flooding caused by a 1 percent annual chance storm wave event.
- **Coastal Erosion:** Long-term coastal erosion coupled with a 1 percent annual chance storm wave event.
- **Tidal Inundation**: Periodic inundation caused during a high tide event.
- **Nuisance Stormwater Flooding:** Flooding associated with a precipitation, high tide flooding event.

This report used several primary data sources:

- ○ **USGS Coastal Storm Modeling System 1.0:** Information included projected coastal flood hazards associated with a historic ~10 year even from January of 2010 with 1.4 m of sea level rise.
- ○ **USGS Coastal Storm Modeling System 3.0 (Initial Results)**: Information utilized included projected coastal flooding from a 100 year wave event at 0, 0.5, 1.0 and 2.0 m of sea level rise. These helped inform both the existing conditions analysis as well as the vulnerability assessment.
- ○ **SPAWAR:** These model projections were used to provide information on projected coastal erosion, coastal flooding from a 100 year wave event, depth of flooding and tidal inundation. These results were primarily used for analysis during the vulnerability assessment.
- **City Data:** Spatial and locational data available from the City of Imperial Beach, the County of San Diego, EPA, and NOAA, for sector analysis of vulnerabilities from nuisance flooding and coastal hazards.

4.2 Existing Conditions - Overview

Overview

Examining historical records and identifying current known vulnerabilities is a traditional and helpful starting point for communities as they begin sea level rise and coastal impacts adaptation planning. Areas that are prone to flooding under historical or existing conditions are likely to be the first areas to experience more persistent, longer-lasting and more extensive flooding in the future. A community can anticipate that as the coast erodes and sea levels rise, flooding and other impacts will presumably expand from these already known locations.

Imperial Beach has a long history of withstanding impacts from coastal storms. The City's first pier was built in 1910, along with a two block boardwalk and bathhouse. The pier disintegrated and was washed out to sea during a 1948 winter storm. The bathhouse and boardwalk were also destroyed during winter storms in following years (1949 and 1953, respectively). One particular storm in January 1988 produced large waves estimated as a 100 year wave event caused 50 to 150 feet of beach erosion across the Silver Strand Littoral Cell (USACE 2002).

The 1982-83 and 1997-1998 El Niños led to extensive flooding and beach loss (See photos 2-2 and 2-3) along the entire length of Seacoast Dr. and associated street ends. The El Niño from 2015-16, while it had larger waves than usual didn't cause substantial damages to properties. However, the El Niño impacts to ocean water levels during the King Tide on November 25, 2015 caused the highest water level ever recorded at the San Diego Bay Tide Station (NOAA #9410170).

But, even recent offshore hurricanes such as Hurricane Marie (September 2014) led to increased wave heights and energy that led to significant beach erosion and scarping.

Considerable coastal impacts are expected during these recurring large wave and storm events.

Photo 4-1. Imperial Beach. Photo: S. Dedina.

FEMA Repetitive Loss

Since its inception, in 1968, the National Flood Insurance Program (NFIP), administered by the Federal Emergency Management Agency (FEMA) has paid out more than $38 billion in claims. More than a third of payments has gone to the one percent of policies that experienced multiple losses and are classified as "repetitive loss properties" (RLPs). RLPs, are properties that suffered multiple flood losses over the years. FEMA provides flood mitigation grant programs that can be a significant source of funds to mitigate future losses supporting social, environmental, and economic objectives through the reduction of flood exposure, restoration of natural resources, and efficient use of governmental funds.

From 1968 to 2010, three Imperial Beach properties were classified as Repetitive Loss Properties, two on Seacoast Drive, and one north of the pier. These three locations filed 7 claims against NFIP from 1968 to 2010 (Fig. 4-1 – locations are approximate to protect the privacy of property owners)

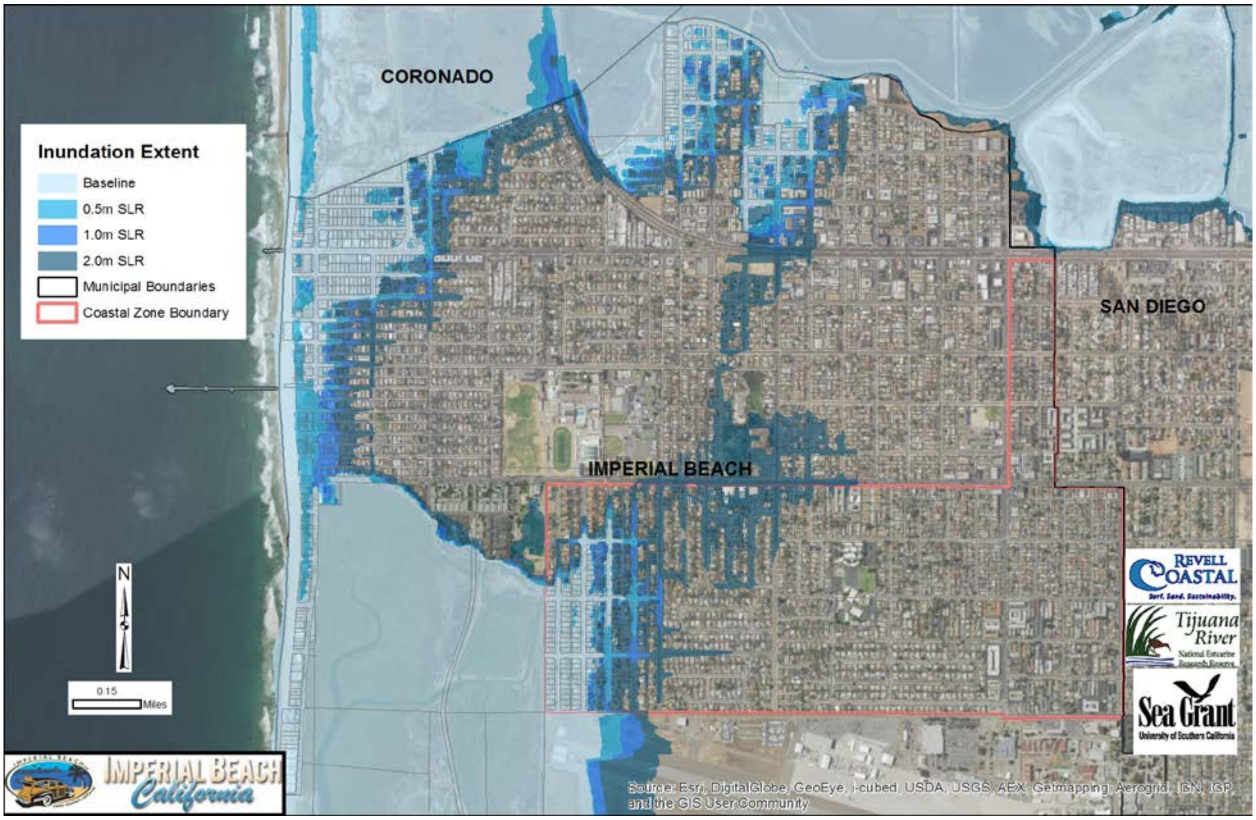

Figure 4-1 Locations of FEMA Repetitive Loss Properties (Sources: FEMA, Calil et al. 2015)

Existing Conditions - Methodology

Initial Information Gathering

The Study Team held individual department and focused interview meetings in December 2014 and February 2015 with key City officials. These included representatives from Planning, Public Works, the City Manager's Office, Lifeguards, Public Safety, and Mayor Serge Dedina. We also met with several regional interests to gain a broader understanding of impacts beyond solely those under the City's jurisdiction. This included discussions with: a member of the Design Review Board and coastal engineer familiar with many of the City's coastal infrastructure projects; representatives from the Port of San Diego; and representatives from the Tijuana River NERR. The goal of these meetings were to:

- Identify known locations of coastal flooding during high tides and significant wave event as well as nuisance flooding;
- Identify, collect, and review relevant datasets and studies; and
- Collect historic images depicting coastal flooding throughout the City.

Geospatial Analysis

Following the individual meetings, the GIS team utilized the USGS CoSMoS 1.0 100-year flood information to develop a quantitative measure of impacts to a suite of City sectors today under a severe 100 year winter wave event. The sectors analyzed included:

- Land Use
- Roads
- Public Transportation
- Wastewater
- Stormwater
- Schools
- Hazardous Materials

We were not able to examine current vulnerabilities to the City's potable water system or to utilities because data are not publicly available and we were not provided the information by the service providers. However, San Diego Gas & Electric is currently conducting their own vulnerability assessment with anticipated results released in 2017 (See p. 3-6 for more information). For each sector, metrics were identified to help describe how much of the assets critical to those sectors were vulnerable during a severe winter storm under current conditions. Detailed findings from the existing conditions analysis are included in the sector profiles in Appendix A.

The results of the geospatial analysis, as well as collated information from the individual meetings, were presented to the Steering Committee at a study team workshop (March 24, 2015). Steering Committee members were able to provide further clarification and insight on these initial findings, providing a strong foundation to commence the vulnerability assessment phase of the project.

Update of Armoring Database

Since 2001, the CCC has maintained a coastal armoring database that includes information on the shoreline protection structures in the coastal zone. Due to lack of funds and personnel, this database is not updated as often as would be preferred. As part of this project, the study team worked with the City to update the information in the database. This updated information will support the City in anticipating maintenance permit applications and in adaptation planning as the City attempts to identify which adaptation strategies to prioritize and implement.

4.3 Existing Conditions - Key Findings

The existing conditions identified the following key findings.

- Tidal Inundation already impacts many of the key storm water outlets that drain into the Bay and Estuary particularly during high tides.
- Nearly 800 feet of wastewater pipe is currently exposed to existing erosion hazards.
- 5 pump stations are currently vulnerable to coastal flooding.
- Presently, 1.7 miles of roads are potentially subject to coastal erosion from a 100-year wave erosion event.
- All of the beach accesses and oceanfront properties are in existing coastal erosion and coastal flood hazard zones associated with a 100-year wave event. From historic storm observations beach erosion of 50 to 150 feet in a single storm event is possible.

4.4 Vulnerability Assessment Methodology

Combined Hazards

The Coastal Hazards used to conduct this vulnerability assessment were modeled from two primary data sources. USGS CoSMoS and SPAWAR's study on the *Impacts Of Sea Level Rise On Coastal Military Installations* (2014)

Coastal erosion hazards used in the study were from SPAWAR and represented a 100-year wave event induced erosion with sea level rise.

Tidal inundation hazards used in the study were also from SPAWAR and represented a 100-year tide level with sea level rise.

Coastal flooding hazards used in the study were produced by combining model results from three sources: i & ii) Coastal Storm Modeling System versions 1.0 and 3.0, developed by the USGS; and iii) SPAWAR. Each source, provided spatially explicit hazard layers for 100-year storms under current conditions (baseline), and under four Sea level rise projections (of 0.5, 1.0, 1.5, and 2.0 m by 2100 relative to 2000). Initially, the project intended to only use the newly published preliminary CoSMoS 3.0 results. However, after comparing with other available data sets and consulting with USGS modelers, the decision was made to combine the CoSMoS 3.0 with data from version 1.0, as well as with the SPAWAR model (Figure 4-2) This need arose from each model capturing different aspects of flooding resulting from variations in model inputs, topography, and future conditions the steering committee advised that we combine these data sources to represent the maximum extent of coastal flooding.

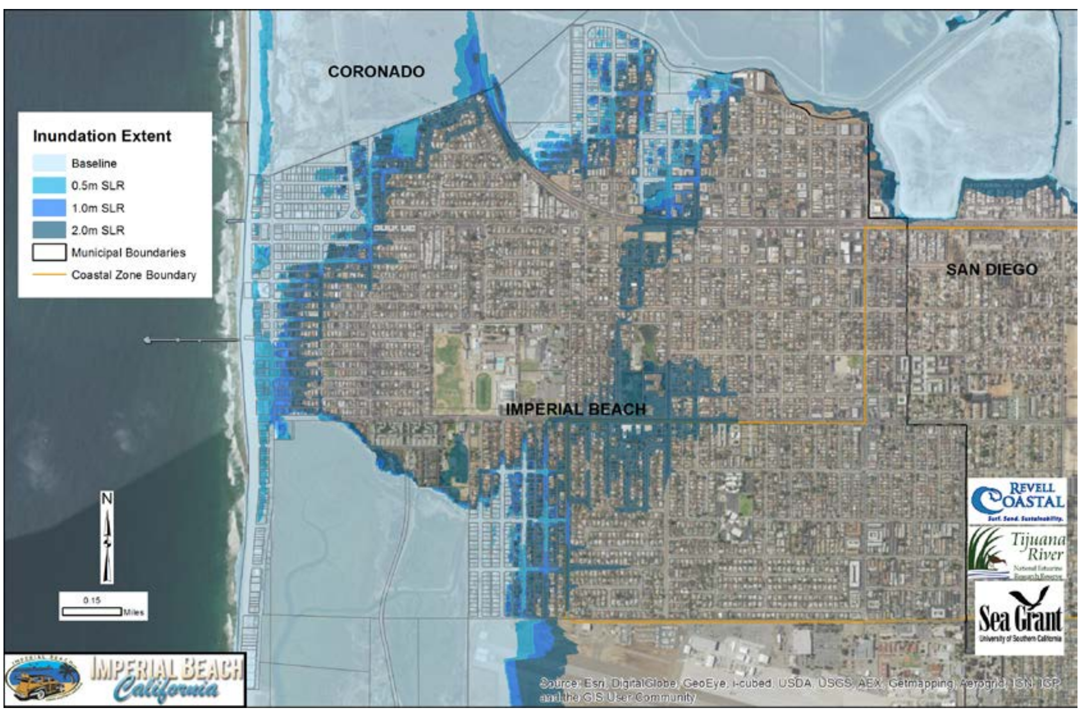

Figure 4-2. Coastal flooding hazard extents combining USGS CoSMoS 1.0, 3.0 Preliminary, and Department of Defense - SPAWAR

Modeling Assumptions

As with all modeling, assumptions have to be made due to the complexity of coastal systems and flooding. Below are some of the more important modeling assumptions made in the SPAWAR and CoSMoS modeling methodologies.

As discussed above, CoSMoS 1.0 was a pilot study that hindcast a January 2010 storm (which is approximately equivalent to ~10 year return interval storm, or a storm that has a 10% chance of occurring in a given year). The model did not include shoreline erosion and did not explicitly model embayments.

The results utilized in this study from CoSMoS 3.0 are initial results of the 100 year return interval storm at today's sea level and with an additional 0.5, 1.0, 1.5 and 2.0 m of sea level rise. CoSMoS projects storms based on a suite of cascading models that downscale global climate models to regional wave conditions and then to local future storm conditions. CoSMoS 3.0 does provide shoreline change projections for the Imperial Beach area, but these were not used for this study. The initial flood results do not include long-term erosion in the flood extents though the final deliverables will. It is expected that when coastal erosion is included in the flooding, the extents will likely translate landward. The initial CoSMoS 3.0 results utilize a "hold the line" approach, assuming that if there is a shoreline protection measure in place, the flooding will not extend beyond that shoreline armoring structure. These structures were identified by both LiDAR and a visual inspection of google earth images with the goal of capturing any structures that were not adequately mapped by the Lidar overflights.

SPAWAR assumed that once existing coastal armoring was overtopped that the structure failed. Since wave run-up exceeded the crest of the existing structures at present time this assumption was to ignore the existing coastal armoring. This probably resulted in overstating of the potential coastal erosion hazards in existing conditions.

Vulnerability Assessment Methodology

The vulnerability assessment involved geospatial analysis. For each of the sectors the identified measures of impact were analyzed based on the intersection of the sector assets with the four different coastal hazard types. This geospatial intersection analysis was conducted for each sea level rise elevation. The results were tabulated and interpreted.

For some data sets such as the building structures, additional steps were required to extract building footprints from the multiple return LiDAR. These building footprints were then intersected with the assessors parcel data base to enable the updated assessors attributes to be applied to the economic analysis.

4.5 Nuisance and Stormwater Flooding

Photo 4-2. Combined Storm flooding (rain, waves, and high tide) during January 1988. Image: San Diego Union Tribune

Nuisance Floods are minor recurrent events, which take place at high tide and presently cause minor inconveniences, such as flooded street corners, and in some rare occasions road closures (See Figure 4-3).

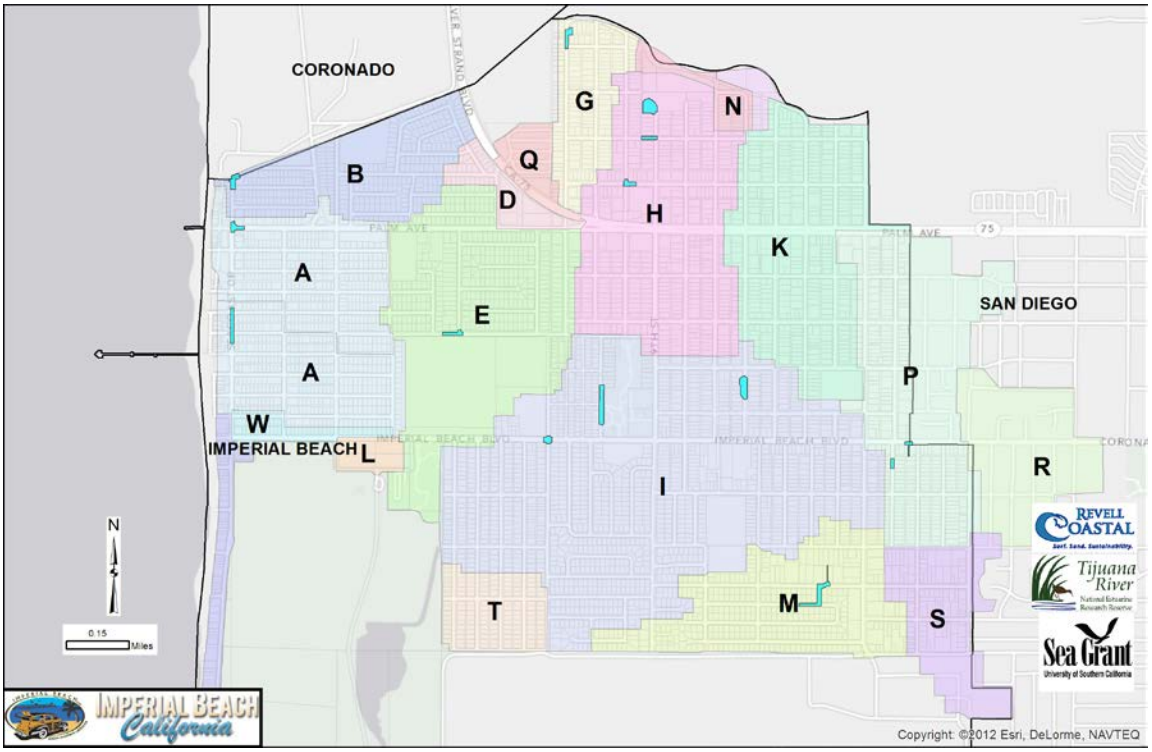

Figure 4-3. Stormwater drainage basins in the City. Letters correspond to basin results in Table 4-1.

Stormwater flooding occurs during combined rainfall and high tides. Analysis examined how the change in sea levels may affect the stormwater drainage. Imperial Beach is divided in multiple storm drainage basins, designed to drain rain water into the San Diego Bay, Tijuana Estuary, and the Pacific Ocean. However, in some areas of the city, storm drains are being filled by salty waters during high tides. Figure 4-3 shows the extent of such recurring nuisance floods.

Table 4-1 was calculated from the curves above, and shows the expected change in nuisance flood events for Imperial Beach (for specific drainage basins and multiple SLR scenarios.

According to historical tide data, from 1991 to 2015, tides exceeded 4.3ft of elevation 18% of the time. With an additional 1.0m of SLR, areas under 4.3ft could be flooded 81% of the time (Table 4-1, drainage basin "I").

Our results also show that with 1.0m SLR, areas that currently flood under high tide about 20% of the time (tides of 4.1ft), are likely to be flooded almost 40% of the time.

Moreover, nuisance floods fill in low-elevation storm drains blocking their ability to drain storm waters into the ocean, the San Diego Bay, and the Tijuana Estuary. The map below shows Imperial Beach's pipelines which would be flooded 50% of the time, due to tide elevation.

The extent of pipeline flooding shown in Figure 4-4, was calculated by Intersecting the top elevation of existing pipelines, with tide elevations expected to occur 50% of the time (i.e.

daily, from mid to high tide) under four SLR scenarios (2.6ft for baseline, 4.2 ft. for 0.5m of SLR, 5.9 ft. for 1.0m of SLR, and 9.2 ft. for 2m of SLR).

The colored pipelines in the map below indicate the sea levels at which they would remain flooded half of the time. The extent of SLR is also color coded.

Table 4-1. Changes in tidal influence on the stormwater drainage system.

Drainage Basin	Elevation top of Pipe - (ft NAVD)	Baseline	0.5m	1m	2m
I	4.3	18%	49%	81%	100%
G	4.7	12%	40%	75%	100%
I	4.8	11%	38%	74%	100%
I	5.1	8%	32%	69%	99%
H	6	2%	16%	49%	96%
I	6.5	1%	10%	38%	93%
K	6.6	0%	9%	36%	92%
K - P	9	0%	0%	3%	56%
E	12.1	0%	0%	0%	5%

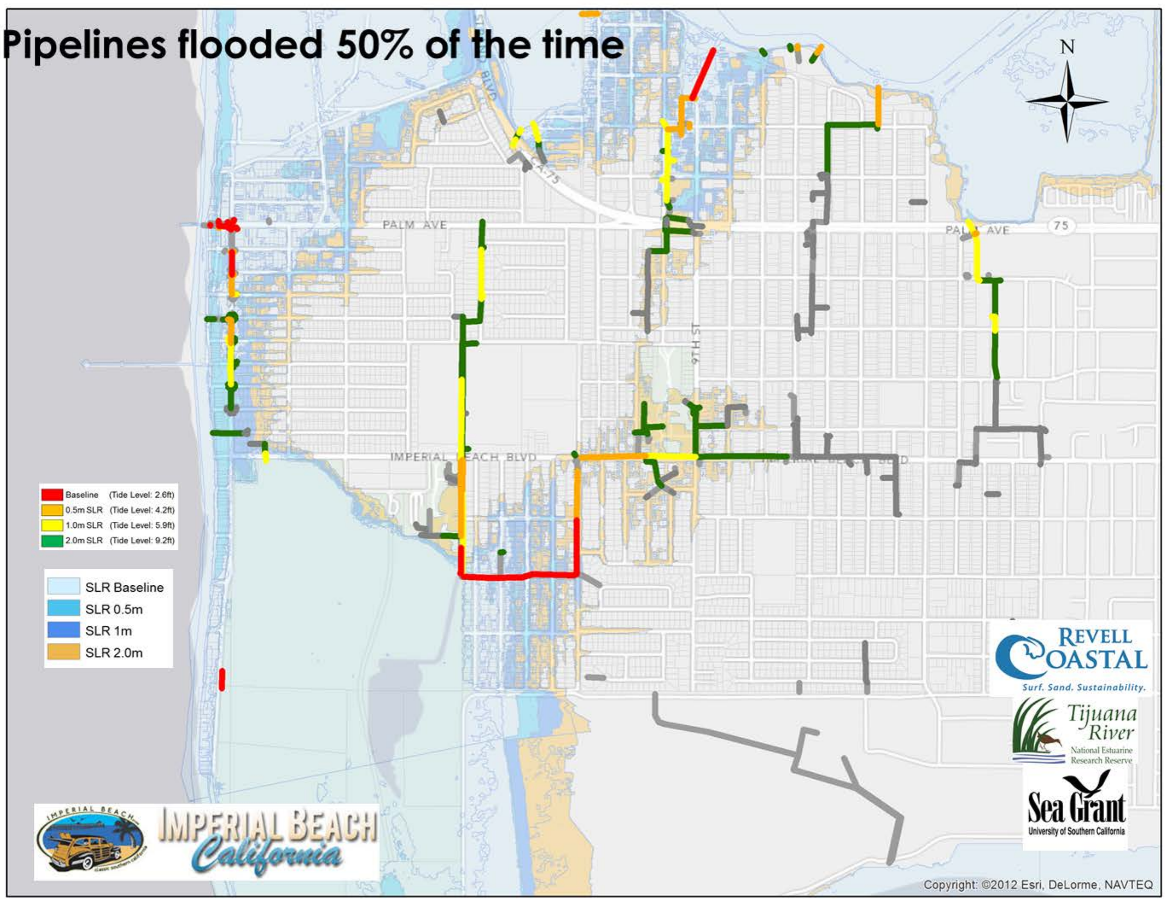

Figure 4-4. Pipelines Flooded 50 percent of the time.

4.6 Economic Analysis Methodology

The economic analysis prepared for this project is designed to identify the potential costs of vulnerabilities and benefits of adaptation to the City. This analysis will also include changes in transient occupancy taxes and sales taxes (from tourist spending) that result from altering the beach profile at Imperial Beach.

In evaluating these benefits and costs, the key factors to be considered are the following:

- Changes in beach recreation
- Changes in coastal ecology
- Erosion and flood losses to private residences and businesses including land and structures.
- Losses to public property and infrastructure.

The economic analysis for this study considers both market and non-market goods and services. Markets goods are valued by their price when sold. In the case of real estate, where sales are infrequent, we estimate the current market price for land and structures based on comparable market values. Infrastructure such as roads and wastewater pumps were valued at replacement cost (see discussion below).

In addition to market goods, the coast also provides substantial non-market goods and services. Imperial Beach's beach provides recreation for hundreds of thousands of visitors per year. Although the weather and other recreational amenities provided by these beaches are lower than many iconic southern California beaches such as Venice Beach or Torrey Pines beach, the recreational value is still high.

Less appreciated and understood, beaches provide significant recreational, storm damage prevention and other ecological functions, goods, and services (EFGS). These services are valuable to humans and other species, but placing a dollar value on the EFGS provided by beaches and other coastal ecosystems is challenging.

The economic analysis prepared for this project is designed to identify the potential costs of adaptation that the City or another entity would be responsible for in the case of a storm being exacerbated by sea level rise or due to coastal erosion. This analysis will also include changes in transient occupancy taxes and sales taxes (from tourist spending) which result from altering the beach profile at Imperial Beach.

This study identified existing land, buildings, and infrastructure (roads, waterlines, etc.) within the erosion and flood zones for 0.5 meters of sea level rise (forecast for 2047), 1.0 meters of SLR (2069) and 2.0 meters of SLR (2100). In order to estimate the costs of replacement or mitigation, this analysis relied on various sources discussed in more detail below.

For land and structures subject to property tax (generally land/structures not owned by a governmental entity), this report used a Parcel Database obtained from the City of Imperial Beach, which contains detailed information on the size of the parcel (in square feet) as well as the size of the structure (also in square feet). In California, Proposition 13 caps any increase in the assessed value of the land/structure at 2 percent a year, until the parcel is resold.

The cost of infrastructure replacement was estimated based on interviews with experts/engineers. Where this information was not available, reasonable metrics (e.g., the cost of replacing overhead power lines) were found from reputable sources, generally in Southern California.

Recreation

Data on recreation came from two sources: (1) interviews with lifeguards and other public safety officials; (2) survey data and counts from previous studies prepared for the San Diego Association of Governments (SANDAG). Lifeguards at Imperial Beach generously provided us with their count data. In addition, Dr. King has prepared two studies for SANDAG on the economics of its nourishment program, including Imperial Beach. The survey data contains information on the residence and preferences for Imperial Beaches' visitors. Our data indicate that 25% of beach visitors currently come from out of town with the remaining visitors being local residents. As Imperial Beach's amenities and hotel rooms grow, it is very likely that beach visitation from non-residents will increase over time. Unlike many other beaches in San Diego County, Imperial Beach has adequate parking and good access. More discussion of our analysis of parcel data is available in section 6.1.2.

Property Analysis

Private Property

Coastal flooding and erosion are existing risks to public and private land, structures and other facilities in Imperial Beach. Economists and engineers have developed and refined a number of methodologies to assess these risks. Our analysis began with property tax data provided by the City of Imperial Beach. This data contains detailed information for each parcel subject to property tax. This "parcel data" contains detailed information about the size of the parcel, the size of the structure, the type of structure, (e.g., single family dwelling, multiple family dwelling), and the elevation of the parcel. This data was provided to us in a GIS file and the relevant economic data was exported to an Excel file, where it is easier to manipulate. More discussion of our analysis of parcel data is available in section 6.1.2.

Infrastructure

The two most important types of infrastructure estimated in this project are roads and water pumps. We assumed that all roads/infrastructure would need to be replaced when threatened by erosion. Our team determined the timeline and "trigger points" where replacement would occur. Our analysis does not include the additional costs of finding a new site for rebuilding.
Pumps were valued at replacement costs.

Adaptation Costs

Each adaptation strategy entails additional costs that must be financed by the City of Imperial Beach or some other mechanism. In the case of nourishment and dune restoration, our analysis factored in the costs of repeated nourishment using the costs of SANDAG nourishment as a basis. The Study Team assumed that these costs would increase (faster than the overall rate of inflation) by 1% a year over time. Similarly, or approach to the costs of armoring incorporated the engineering and maintenance costs of revetments, etc.

For "retreat" we factored in not only the losses due to flooding and erosion, but also the demolition costs for structure removal.

5. Adaptation

5.1 Introduction

Adaptation to climate change involves a range of small and large adjustments in natural or human systems that occur in response to already experienced or expected climate changes and their impacts. Adaptation planning involves a wide range of policy, project-level, and programmatic measures that can be taken in advance of the potential impacts, or reactively, depending on the degree of preparedness and the willingness to tolerate risk. Good adaptation planning should improve community resilience to natural disasters.

Adaptation measures that reduce the ability of people and communities to deal with and respond to climate change over time are called maladaptation. Maladaptation has several characteristics that help identify when it is occurring.

- creates a more rigid system with a false sense of security and severe consequences;
- may increase greenhouse gas emissions; and
- reduces incentives to adapt.

An example of this is the levee system for the City of New Orleans. While the levees provided short-term adaptation and allowed communities to remain in areas below sea level, they actually increased the long-term vulnerability—both by providing a false sense of security and underestimating the impact that storm events could cause.

While the City has a long history of combatting coastal hazards, this is the first focused endeavor by the City of Imperial Beach to identify possible responses to climate change impacts, including adaptation strategies based on preparedness, avoidance, and/or protection from the risks projected to occur over time.

Good adaptation stems from a solid understanding of the City's specific risks, the projected timing of impacts and the physical processes responsible for causing the risk, now and in the future.

5.2 Adaptation Planning

Adaptation planning requires considering each vulnerable sector and taking effective and timely action to alleviate the range of consequences. One adaptation measure may reduce the risk to one sector but cause issues in another sector or lead to unintended secondary consequences. One of the most important secondary consequences that the City must consider is the impact of the various strategies on the long-term health of the beaches.

Good adaptation planning considers these secondary impacts and how the different adaptation measures that could be used to alleviate vulnerability in one sector interact with the other measures in developing a sustainable community adaptation strategy.

Good adaptation planning is also "collaborative", considering interconnected ecological, social, political, and economic systems. Through collaboration with adjacent jurisdictions, including the Tijuana River NERR, the Navy, Coronado, and the Port, unintended secondary consequences to neighboring jurisdictions can be avoided and local resources can be leveraged.

Risks can be addressed by reducing vulnerability or exposure. First, the City has to choose what level of risk it is willing to tolerate. Increasing infrastructure resilience, transferring the risk, negating the risk through technological change or retreat, or revising policies can accomplish these objectives.

As not all issues can or should be addressed at once, it is important that risks be prioritized and phased to maximize the use of the City's resources while avoiding a costly emergency response. It is quite probable that an overarching adaptation strategy will take a variety of approaches ranging from protect, accommodate and retreat as the sea level rise impacts exceed the various strategies capacity to reduce the vulnerabilities.

Many of these adaptation strategies take substantial time to implement. As a result, advanced planning and fundraising is key. Factors to consider when prioritizing projects include: public health and safety, available funding sources, legal mandates, planning consistency, capacity and level of service, cost-benefit relationship, environmental impacts, and public support. Risks that present the most serious consequences and are projected to occur first should raise a project's level of priority. (See Figure 5-1.)

This report should increase the City's understanding of the vulnerabilities associated with coastal hazards and encourage decision-makers to consider these impacts without creating further vulnerabilities or liabilities. As this is the beginning of the City's process of developing its adaptation response, many early initiatives are exploratory in nature and aim to identify potential changes or actions to respond to the impacts of concern.

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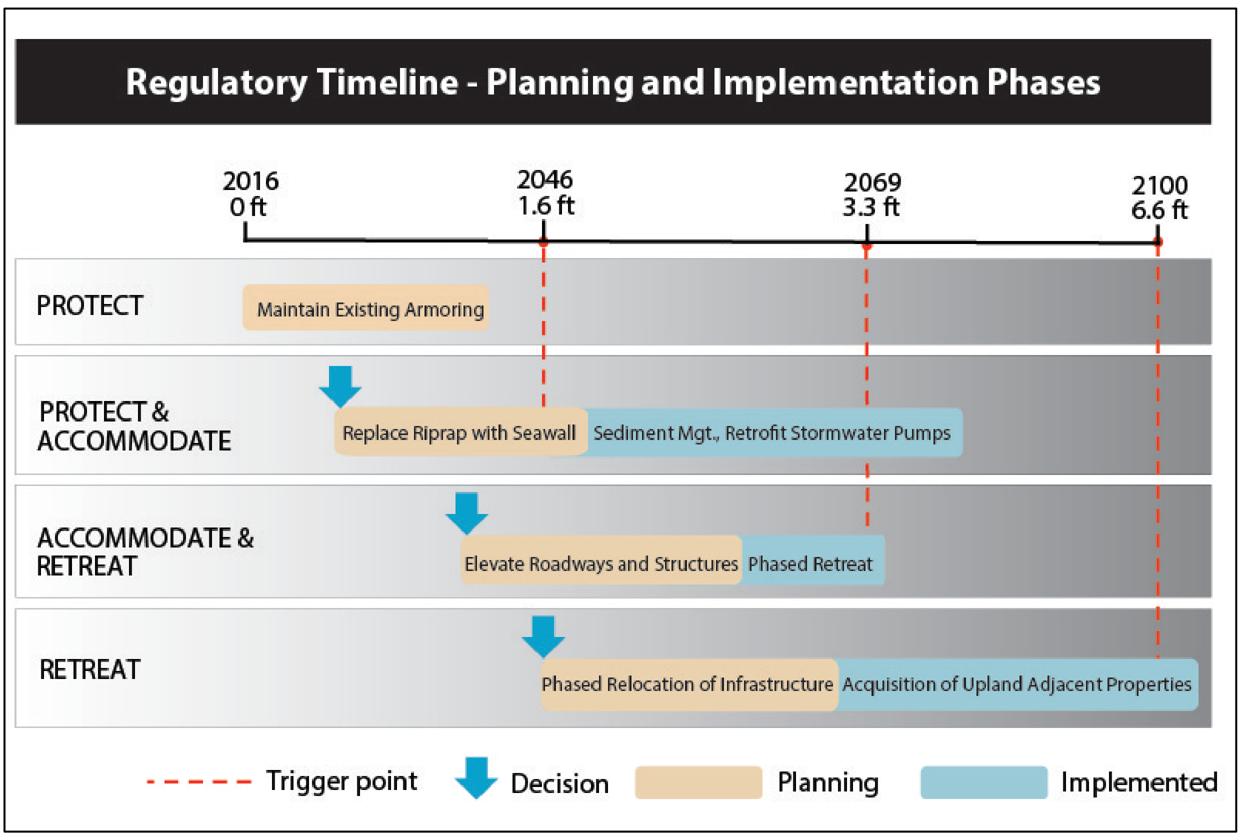

Figure 5-1. Implementation Timeline and Sea Level Rise Accommodation

Reviewing current City programs and policies associated with risk reduction such as those around coastal armoring is the first step to identify immediate adjustments to alleviate or eliminate risks. Where adjustments to current practices will not sufficiently address the risks, then more substantial actions will be identified and should be implemented.

Of utmost importance to the successful implementation of an adaptation strategy is communicating the issues and proposed responses to the community. Studies repeatedly show that a knowledgeable community and educated decision-makers that understand how to respond to extreme events is far more resilient to the impacts. An informed community is also more likely to implement programs and make decisions that reflect its knowledge of the projected changes and enable them to contribute to developing a prosperous, livable, and affordable City in the face of climate change

5.3 Maladaptation

Maladaptation is a trait that is (or has become) more harmful than helpful, in contrast to adaptation, which is more helpful than harmful. One of the most significant concerns with maladaptation is that it reduces incentives to adapt while simultaneously diminishes the capacity to adapt in the future. Maladaptation occurs when efforts intended to "protect" communities and resources result in increased vulnerability, often realized indirectly or too late after a direction has been set. For instance, previously unaffected areas can become more prone to climate-induced hazards if the system that is being altered is not sufficiently understood. Likewise, if too much focus is placed on one time period—either the future or the present—effects on the other can be ignored, resulting in an increased likelihood of impacts from climate-induced hazards. Avoiding maladaptation is critical to a successful climate adaptation strategy. To do so, the City must first be able to make informed decisions based on an accurate vulnerability assessment, and to determine its own level of tolerance. Flexibility and a precautionary approach are key to avoiding maladaptation in the adaptation planning process.

5.4 Challenges

Adaptation planning does come with its challenges. A single jurisdiction like Imperial Beach cannot adapt to climate changes on its own. A successful process requires regional dialog and partnerships to identify, fund, and implement solutions. Challenges range from acquiring the necessary funding for adaptation strategies, communicating the need for adaptation to elected officials and local departments, and gaining commitment and support from federal and state government agencies to address the realities of local adaptation challenges. Lack of resources and limited bridges between local, state, and federal agencies make it difficult for cities to make significant gains in adaptation. Regional partnerships and dialogs between adjacent jurisdictions, including the Port of San Diego, the Navy, TRNERR, and Coronado, and regional governments, such as SANDAG, will be paramount in developing and implementing sound regional strategies.

When identifying appropriate adaptation responses, the City should consider taking a precautionary approach by using the following seven principles (Barnett and O'neill 2010):

1. Strategy should not increase greenhouse gas emissions.
2. Strategy should support the protective role of ecosystems and their sustaining physical processes.
3. Strategy should avoid disproportionately burdening the most vulnerable citizens.
4. Strategy should avoid high-cost strategies unless holistic economic work (including

ecosystem services, recreation, and damages) demonstrates a strong net benefit over time.

5. Strategy should incentivize adaptation (e.g., reward early actors).
6. Strategy should increase flexibility and not lock the community into a single long-term solution.
7. Strategy should reduce decision-making time horizons to better incorporate new science.

5.5 Protect, Accommodate, and Retreat

According to the California Coastal Commission, coastal adaptation generally falls into four main categories: do nothing, protect, accommodate, or retreat.

The Protection Approach

Protection strategies employ some sort of engineered structure or other measure to defend development (or other resources) in its current location without changes to the development itself. Protection strategies can be further divided into "hard" and "soft" defensive measures. A "grey", "hard" approach would be to engineer a seawall or revetment, a "soft" approach may be to nourish beaches, while a "green", "soft" approach may be to restore sand dunes. Although the California Coastal Act clearly provides for potential protection strategies for "existing development," it also directs that new development be sited and designed to not require future protection that may alter a natural shoreline. It is important to note that most protection strategies are costly to construct, require increasing maintenance costs, and have secondary consequences to recreation, habitat, and natural defenses. Many of these are forms of maladaptation, especially if applied as a long-term solution.

The Accommodation Approach

Accommodation strategies employ methods that modify existing or design new developments or infrastructure to decrease hazard risks and therefore increase the resiliency of development to the impacts of sea level rise. On an individual project scale, these accommodation strategies include actions such as elevating structures, performing retrofits, or using materials to increase the strength of development such as to handle additional wave impacts; building structures that can easily be moved and relocated; or using additional setback distances to account for acceleration of erosion. On a community-scale, accommodation strategies include many of the land use designations, zoning ordinances, or other measures that require the above types of actions, as well as strategies such as clustering development in less vulnerable areas or requiring mitigation actions to provide for protection of natural areas.

The Retreat Approach

Retreat strategies relocate or remove existing development out of hazard areas and limit the construction of new development in vulnerable areas. These strategies include creating land use designations and zoning ordinances that encourage building in less hazardous areas or gradually removing and relocating existing development. Acquisition and buy-out programs, transfer of development rights programs, and removal of structures where the right to protection was waived (i.e., via permit condition) are examples of strategies designed to encourage retreat.

The Hybrid Approach

For purposes of implementing the California Coastal Act, no single category or even specific strategy should be considered the "best" option as a rule. Different types of strategies will be appropriate in different locations and for different hazard management and resource protection goals. The effectiveness of different adaptation strategies will vary across both spatial and temporal scales. In many cases, a hybrid approach that uses strategies from multiple categories will be necessary, and the suite of strategies chosen may need to change over time. Nonetheless, it is useful to think about the general categories of adaptation strategies to help frame the discussion around adaptation and the consideration of land use planning and regulatory options in the City.

The Do Nothing Approach

There are a number of options for how to address the risks and impacts associated with sea level rise. Choosing to "do nothing" or following a policy of "non-intervention" may be considered a form of adaptation. However, in most cases, the strategies for addressing sea level rise hazards will require proactive planning to balance protection of coastal resources with development.

5.6 Secondary Impacts

Almost all adaptation strategies have secondary impacts associated with them. Some of these impacts are associated with construction or escalating maintenance costs. Others impacts can degrade ecology or limit recreational opportunities. Finally others can affect community aesthetics or property views. Often one of the most controversial impacts is associated with the long-term preservation of a beach which often pits private versus public interests against each other with strong overtures to social justice and community inequality.

Some of these are minor issues, such as short-term habitat impacts following removal of infrastructure or undergrounding of overhead power lines. Others can be quite confounding and expensive, such as the burial of beaches under rocks following construction of revetments, or a retrofit to a critical infrastructure component. Another example is the potential impacts to visual resources associated with accommodation strategies that elevate buildings or coastal armoring through increased height limits to protect against elevated levels of flooding.

Many communities have relied on setbacks in an effort to reduce hazard risk, and some are currently experimenting with establishing setback lines that are based on modeled predictions of where the new coastline will be. Setbacks alone could be considered potentially maladaptive because they eventually lead to structures being at risk. Therefore, it is important to have elements of retreat, such as movable foundations or locations for transfer of development. Further, triggers for action, such as relocation through public acquisition, should take the place or work in conjunction with regulatory setback policies. However, like any form of public acquisition, whether through bonds or other means, can be very costly to the local and/or federal agencies.

Shoreline protective devices (e.g., coastal armoring, flood control levees) can also adversely affect a wide range of other coastal resources and uses that the California Coastal Act protects. They often impede or degrade public access and recreation along the shoreline by occupying beach area or tidelands and by reducing shoreline sand supply.

Current policies in the IB LCP, require that new armoring and substantive repairs require the armoring to be a vertical seawall located entirely on private property.

However, protecting the back of the beach ultimately leads to the loss of the beach as sea level rise and coastal erosion continue on adjacent unarmored sections. Shoreline protection structures therefore raise serious concerns regarding consistency with the public access and recreation policies of the California

Coastal Act. Such structures can also be placed in coastal waters or tidelands and harm marine resources and biological productivity, which is in conflict with California Coastal Act Sections 30230, 30231, and 30233. They often degrade the scenic qualities of coastal areas and alter natural landforms, which is in conflict with Section 30251. Finally, by halting disrupting landscape connectivity, structures can prevent the inland migration of intertidal and beach species during large wave events. This disruption will prevent intertidal habitats, saltmarshes, beaches, and other low-lying habitats from advancing landward as sea levels rise over the long-term.

Photo 5-1. Impact of Coastal Armoring. With sand (top), and without sand (bottom). Photo J. Nakagawa.

It is important to note that shoreline protection devices such as seawalls and revetments have several inevitable secondary impacts:

Placement loss – Wherever a hard structure is built, there is a footprint of the structure. The footprint of this structure results in a loss of coastal area known as placement loss. This inevitable impact can bury the beach beneath the structure and reduce the usable beach for recreation or habitat purposes. For example a 20' high revetment may cover up to 40' of dry sand beach. A vertical seawall or sheet pile groin typically has a smaller placement loss than a revetment or rubble mound groin. In some cases, the structures in IB, particularly the newer ones are located on private land, however some of the structures particularly at the south end of Seacoast are encroaching on the public beach.

Passive erosion - Wherever a hard structure is built along a shoreline undergoing long-term net erosion, the shoreline will eventually migrate landward to (and potentially beyond) the structure. The effect of this migration will be the gradual loss of beach in front of the seawall or revetment as the water deepens and the shore face moves landward. While private structures may be temporarily saved, the public beach is lost. This process of passive erosion is a generally agreed-upon result of fixing the position of the shoreline on an otherwise eroding stretch of coast, and is independent of the type of seawall constructed. Passive erosion will eventually destroy the recreational and habitat beach area unless this area is continually replenished. Excessive passive erosion may impact the beach profile such that shallow areas required to create breaking waves for surfing are lost.

Limits on beach access – Depending on the type of structure, impacts to beach access vary. Typically vertical beach access (ability to get to the beach) can be impacted unless there are special features integrated into the engineering design, however as passive erosion occurs (see #2 above), lateral (along) beach access is usually impacted.

Active erosion - Refers to the interrelationship between wall and beach whereby due to wave reflection, wave scouring, "end effects" and other coastal processes the wall may actually increase the rate of loss of beach in front of the structure, and escalates the erosion rates along adjacent unarmored sections of the coast. Active erosion is typically site-specific and dependent on sand input, wave climate, specific design characteristics and other local factors.

Economic issues – Potential use of local, state or federal subsidies to construction and protect private property, or obtain subsidized insurance coverage. This can create environmental justice issues. Construction may be performed on State or Municipal land although the IB armoring conditions require it to be entirely on private property. However, if it is on the public property, then the public is typically not compensated for this loss of valuable property.

Ecological impacts - Scientific studies have documented a loss of ecosystem services, loss of habitat and reduction in biodiversity when seawall-impacted beaches were compared to natural beaches.

Given the negative impacts of hard solutions, more attention is being focused on the implementation and resulting effectiveness of soft solutions. Soft options often include sediment management aspects such as sand dunes, cobble placement and/or beach nourishment. Often maintenance costs can be higher than the hard solutions. Some soft options are considered, living shorelines or natural infrastructure (e.g., dune restoration), as they restore or enhance existing habitat and if done correctly should be self-sustaining, meaning minimal maintenance costs. These "soft", "green" solutions tend to mimic natural processes and can help lessen erosion and flooding while also providing habitat, water filtration and recreational opportunities.

The potential economic impacts of a seawall, which should be considered in the impact assessment, include:

- Changes to property values;
- Capital costs from seawall construction and recurrent costs associated with seawall maintenance and managing any off-site erosion impacts;
- Erosion impacts on adjacent properties; and
- Visual amenity and beach access impacts.

In some circumstances permitting of coastal armoring by the Coastal Commission has added to the life of structure and monitoring requirements. Once this time has elapsed, or certain conditions are met (e.g. there is no usable beach in front of the structure for 12 months), then the structure must be removed, typically at the owners expense.

Sediment management is another option to combat erosion by building wider beaches and higher sand dunes, or increasing wetland accretion. However, sediment management can be costly, and ongoing sand supplies for large projects can become scarcer. Due to the lack of a suitable dredge with capacity to handle the conditions on the U.S. West coast, there are often extremely high mobilization costs which may continue to escalate. Secondary impacts from sediment management vary depending on the volume, frequency and method of placing, but typically include substantially degrading sandy beach ecosystems, temporary changes to flooding, changes to surfing resources, and limiting recreational use.

Horizontal Levees is a form of natural green infrastructure that has been applied elsewhere most notably San Francisco Bay. The concept is part of a marsh restoration strategy in which the marsh slope is increased to provide higher elevations near the back of the marsh. This provides a natural levee while also providing marshes room to migrate vertically in elevation up the slope.

6. Analysis of Select Adaptation Strategies

The following 5 adaptation strategies were selected for further analysis by the Steering committee to represent a wide range of potentially feasible alternatives to address open ocean coastal hazards:

- Hardening and armoring of the entire IB coastline
- Managed retreat or phased relocation
- “Business-as-usual” sand nourishment
- Hybrid dune and cobble approach
- Five groins with associated sand nourishment

For purposes of the following analysis, it is assumed that the strategy would be applied uniformly to the entire urbanized portion of the City from the Coronado city limits down to South end of Seacoast Drive a total distance of about 1.5 miles. This assumption allows for a more uniform comparison between each option. However, as explained in the previous section, there are a wide variety of “hybrid” options and there a numerous different combinations in which strategies can be combined along different portions of IB's shoreline. This is a starting point from which the community can begin to identify what combination of strategies- including those analyzed in this report and those yet to be analyzed- may be implemented.

6.1 Methodology and Assumptions

The economic analysis completed for this study, described in more detail in section 6.1.2, estimates the benefits and costs of various adaptation strategies focusing on recreational and ecological benefits of the City's beach and coastal ecosystems, and the value of structures and infrastructure inland.

The economic analysis looks at the forecasted impacts of sea level rise and coastal storms on the City of Imperial Beach over a time horizon extending to 2100.

6.1.1 Physical Methods

A quantified conceptual model was developed to track beach width changes and upland property changes over time under the five various adaptation strategies. The model was evaluated at 5-year time steps that were later interpolated to yearly beach width values through 2100.

The model calculates beach width (at each 5-year time step) resulting from the physical interaction between coastal erosion (accelerated with SLR), and each adaptation strategy. The numerical and visual representation allows us to evaluate the tradeoffs between the different adaptation alternatives based on their performance, number of treatments, costs, etc.

Model Inputs:

For all adaptation alternatives, the following common model inputs were used:

- Upland extent (which represents the extend of development potentially affected by coastal erosion and was assumed at 600ft.);
- Accelerated erosion rate for beach nourishment (which was assumed to be 10% per year, or 50% every 5 years);
- Beach nourishment width (fixed at 100ft based on historic nourishments); and
- Beach width threshold, at which a new adaptation treatment should be implemented.

Additionally, the following additional inputs were required for the Hybrid Dune approach:

- Width of cobble nourishment (assumed 50 ft.);
- Beach width at which the cobbles start to erode (assumed at 175ft.);
- Cobble erosion rates (assumed at 90% of background accelerated erosion rate);
- Dune length (assumed at 30ft); ix) Dune erosion rates (same as background erosion rates); x) cobble width at which the dune starts to erode (assumed at 40ft.); and xi) Dune width at which a new complete treatment (beach nourishment, cobble replacement and dune) is triggered (assumed at dune width of 25ft.).

Model outputs include beach, cobble and dune width at each time step, as well as graphical representations of beach and upland development widths.

6.1.2 Economic Methods

The economic analysis prepared for this project is designed to identify the potential costs and benefits of adaptation to the City. This analysis will also include changes in transient occupancy taxes and sales taxes (from tourist spending) which result from altering the beach profile at Imperial Beach.

In evaluating these benefits and costs, the key factors to be considered are the following:

- Changes in beach recreation;
- Changes in coastal ecology;
- Erosion and flood losses to private residences and businesses including land and structures; and
- Losses to public property and infrastructure.

Recreation

Data on recreation came from two sources: (1) interviews with lifeguards and other public safety officials; (2) survey data and counts from previous studies prepared for SANDAG. Lifeguards at Imperial Beach generously provided us with their count data. In addition, Dr. King has prepared two studies for SANDAG on the economics of its nourishment program, including Imperial Beach. The survey data contains information on the residence and preferences for Imperial Beaches' visitors. Our data indicate that 25% of beach visitors currently come from out of town with the remaining visitors being local residents. As Imperial Beach's amenities and hotel rooms grow, it is very likely that beach visitation from non-residents will increase over time. Unlike many other beaches in San Diego County, Imperial Beach has adequate parking and good access.

Although beach spending is a useful metric, economists measure the (non-market) value of beach recreation not by how much people spend, often referred to as economic impact, but by their willingness to pay to recreate at a beach. Since beaches in California are free, economists have developed various techniques to elicit how much a beach trip is worth, based on a visitor's willingness to pay for the beach experience. Our estimates for the economic value of beach recreation are based on attendance estimates and an economic valuation model developed by Dr. King for the State of California and the U.S. Army Corps of engineers, the California Sediment Benefits Analysis Tool (CSBAT) a benefits transfer model. The CSBAT model allows one to estimate the gain or loss in recreational value as beach width decreases (e.g., due to erosion) or increases (e.g., due to nourishment). For a fuller discussion, see King and Symes (2004). The model was calibrated for beach width using SANDAG survey data.

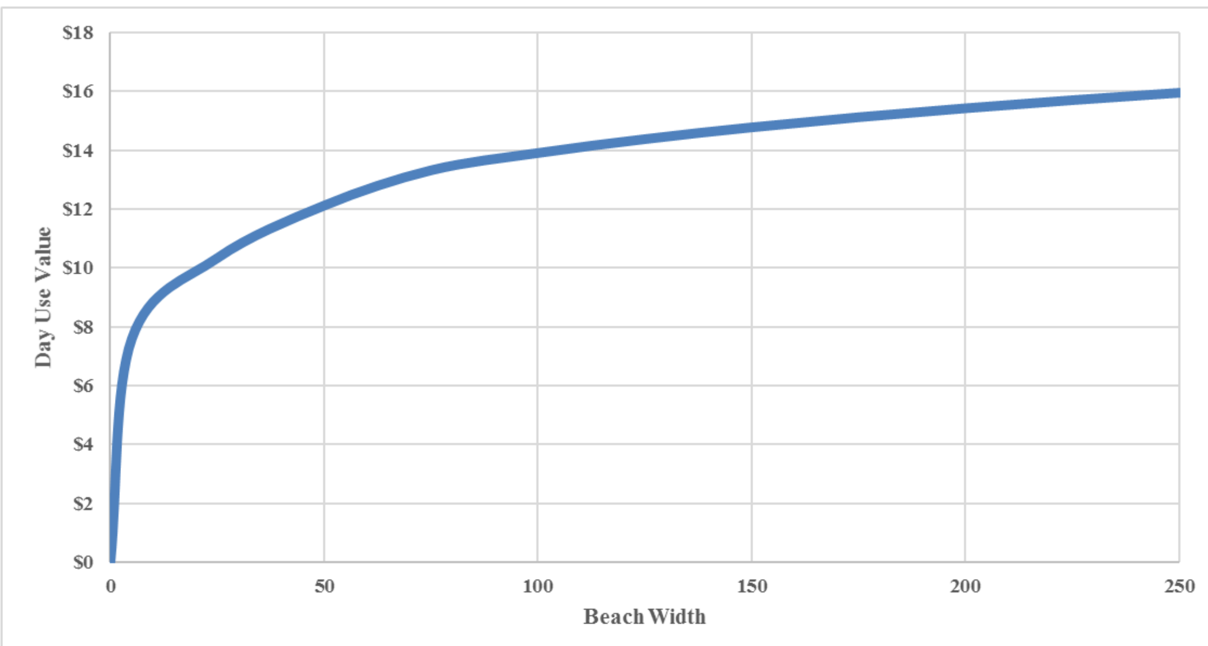

Figure 6-1. Day Use Value as a Function of Beach Width

Figure 6-1 above demonstrates the relationship between beach width and the value of a day at the beach for an average visitor. We used a maximum value of $16 per day, which is quite conservative. As beach width narrows, the day use value is reduced. Note that the relationship is not linear (straight-line)—even a relatively narrow beach can give significant recreational value. Numerous studies (e.g., Landry et. Al. 2011) demonstrate that most visitors prefer wider beaches up to 250/300 feet. Consequently, our model, which was calibrated by SANDAG survey data, accounts for this fact.

Our analysis from SANDAG also indicates that beach width also increases attendance, both because visitors prefer wider beaches (and hence are more likely to go) and because wider beaches create more "towel space" for visitors. This analysis only looked at "dry beach"—beach up to the mean high tide line.

Property

This study identified existing land, buildings, and infrastructure (roads, waterlines, etc.) within the erosion and flood zones for 0.5 meters of sea level rise (forecast for 2047), 1.0 meters of SLR (2069) and 2.0 meters of SLR (2100). In order to estimate the costs of replacement or mitigation, this analysis relied on various sources discussed in more detail below.

For land and structures subject to property tax (generally land/structures not owned by a governmental entity), this report used a Parcel Database obtained from the City of Imperial Beach, which contains detailed information on the size of the parcel (in square feet) as well as the size of the structure (also in square feet). In California, Proposition 13 caps any increase in the assessed value of the land/structure at 2 percent a year, until the parcel is resold.

The cost of infrastructure replacement was estimated based on interviews with experts/engineers. Where this information was not available, reasonable metrics (e.g., the cost of replacing overhead power lines) were found from reputable sources, generally in Southern California.

Private Property

Coastal flooding and erosion are existing risks to public and private land, structures and other facilities in Imperial Beach. Economists and engineers have developed and refined a number of methodologies to assess these risks. Our analysis began with property tax data provided by the City of Imperial Beach. This data contains detailed information for each parcel subject to property tax. This "parcel data" contains detailed information about the size of the parcel, the size of the structure, the type of structure, (e.g., single family dwelling, multiple family dwelling), and the elevation of the parcel. This data was provided to us in a GIS file and the relevant economic data was exported to an Excel file, where it is easier to manipulate.

Before our economic analysis could begin, we needed to address a number of inconsistencies and inaccuracies in the data. First and foremost, the parcel data contains information on the assessed value of the property—that is, the value that is placed on the property for tax purposes. Proposition 13 limits increases in the assessed value to 2% a year. However, over the past 30-50 years, the rate of increase has been substantially higher than 2% in many years. Thus a property purchased in the 1970s would have an assessed value substantially smaller than the true market value. To correct for this flaw, we used the last sale prices for the property and updated this value using the Case-Shiller Real Estate Index for San Diego, which contains housing inflation rates for the San Diego area. This method allowed us to properly value each parcel using current market rates. The structures on the parcels (e.g., houses) were valued using standard Federal Emergency Management Agency (FEMA) techniques. These techniques value a structure by size, number of stories, type of dwelling and type of construction.

Another important consideration in measuring damages to assets at risk is to define the thresholds at which damages are triggered by high tide, chronic flooding and erosion. Just because an asset intersects with a hazard zone does not necessarily mean that economic damages will occur. Consider again the example of residential property that is subject to erosion. Erosion may only expose a small fraction of the property and not infringe on the footprint of the structure. In this scenario only a small amount of the land is subject to damage, thereby leaving intact a majority of the land's utility and, by extension, the value of the property. On the other hand, if a majority of the property is exposed to erosion it would be reasonable to assume that a significant portion of the property value is compromised. Damage functions to account for these dynamics were established with consideration of the physical extent of the exposure and its potential effect on the economic use of the asset.

Public Property

Public property such as schools, libraries and other buildings owned by various government entities is not subject to property tax. In these cases the parcel data does not contain assessed value and often contains very little information other than the size of the parcel. In these cases, parcel were identified on a case-by-case basis and values to the property/structure were assigned from other sources. In most cases, the City or other government agency (e.g., the school district) provided detailed information on the replacement cost of the structure.

Infrastructure

The two most important types of infrastructure estimated in this project are roads and water pumps. We assumed that all roads/infrastructure would need to be replaced when threatened by erosion and these assets were valued at the estimated replacement cost at the time of failure. Our team determined the timeline and “trigger points” where replacement would occur. Our analysis does not include the additional costs of finding a new site for rebuilding.

Engineering Cost Assumptions

All of the strategies below imply engineering costs for replacement, removal or maintenance. Table 6-1 presents the assumptions for seawall removal and construction, groin construction, cobble, dune construction as well as the costs of removal for managed retreat scenarios.

Table 6-1. Engineering Costs of Construction/Removal

Structure	Initial cost/unit	Units	Total Cost	Maintenance
Seawall Removal	$1,000 per ft.	7,920 ft.	$7,920,000	
Old Seawall	-	-	-	5% every 10 years, 8% if beach width < 60 ft.
Nourishment	$20 per cy	1,000,000 cy.	$20,000,000	Cost growth 1%
New Seawall	$4,500 per ft.	7,920 ft.	$35,640,000	2% every 10 years, 5% if beach width < 60 ft.
New Groin	$4,000 per ft.	3,720 ft.	$14,880,000	5% every 10 years
Cobble	$3,000 per ft.	7,920 ft.	$23,760,000	
Dune Sand	$1,000 per ft.	7,920 ft.	$7,920,000	
House Removal	$10 per sq. ft.			
Condo Removal	$20 per sq. ft.			
Road Removal	$4 per sq. ft.			
Pipe Removal	$20 per ft.			
Pump Station	$200 per sq. ft.			
Dune Restoration	$77,000 per acre	11.8 acres	$910,000	

Economic Impacts

The analysis above discusses the costs and benefits of various adaptation strategies. In addition, policy makers are often interested in the economic *impacts* of these measures. Economists measure economic impacts by measuring changes in spending for various strategies.

Our analysis incorporates estimated changes in beach recreational spending with various adaptation strategies. As discussed above, beach visitation varies with beach width.

Consequently, strategies that maintain or enhance beach width, such as nourishment, create positive economic impacts and also generate more in State and local taxes (see next section). On the other hand, armoring strategies often lead to diminished beach width, which not only lowers the non-market recreational benefits that visitors get from a day at the beach, but also lowers total spending in Imperial Beach, since fewer visitors go to narrower beaches.

Tax Revenue Impacts

The economic impacts/spending discussed in the previous section also implies increased tax revenues. Our analysis focused on two primary sources of local tax revenues that would be seriously influenced by the adaptation strategies discussed in this study: sales taxes and transient occupancy taxes (TOTs). As with economic impacts, the tax revenue impacts vary by beach width—wider beaches increase visitation.

Ecological Benefits of Coastal Habitat

Although beaches are recognized primarily for their recreational and cultural/aesthetic value, they also provide a significant array of ecological services, which are often underappreciated (Dugan et al. 2008,). In fact, California's beaches provide habitat/spawning area for a number of species, including threatened and endangered species. In addition, beaches generate many of the ecological services provided by wetlands, such as stopping-off grounds for migratory birds, water filtration, etc. Beaches also act as a buffer against storm damage; this aspect of beach ecosystem services has already been modeled elsewhere in this study.

Consequently, preserving healthy beaches is critical to maintain healthy coastal ecosystems. Ecologists typically divide beaches into three distinct ecological zones (McLachlan and Jaramillo 1995): (a) the relatively dry sand above the high tide line, (b) the damp sand in the intertidal zone, (c) the saturated sand on the seaward side of the intertidal zone. Although these zones are ecologically distinct, many biota in this zone move back and forth with the changing tides and use the back beach as a refuge against storms and overpowering waves. These zones generally correspond to the relatively dry sand around and above the high tide strand line or drift line, the damp to wet sand of the middle intertidal and the saturated sand of the lower and swash intertidal zone (Figure 6-2 below) (Dugan et al. 2006). The challenge for a study such as this one is placing a dollar value on the ecological functions, goods and services (EFGS) that beaches provide other than recreation and storm damage prevention.

Although economists and ecologists have developed a literature attempting to place a dollar value on the EFGS provided by wetlands, beaches and other critical habitat, this literature is in its infancy and there is no recognized consensus. Further, our scientific understanding of the EFGS provided by beaches is limited; thus it's hard to quantify the dollar value of a beach's EFGS without knowing exactly the scope of magnitude of these goods and services (e.g., see Barbier, 2011). An alternative approach, developed by Dr. King and others for the California Coastal Commission (2015), is to view California's beaches as critical natural capital. This approach assumes that any beach ecosystems which are damaged or destroyed need to be replaced, ideally in the same littoral cell. In California, a number of beach ecosystems have been restored. For this study, we used this restoration cost as a metric to value coastal ecosystems. In many ways, this approach is analogous to the valuation metrics used elsewhere in the study, where we used the replacement cost of physical capital (residential, public and commercial buildings roads, etc.)

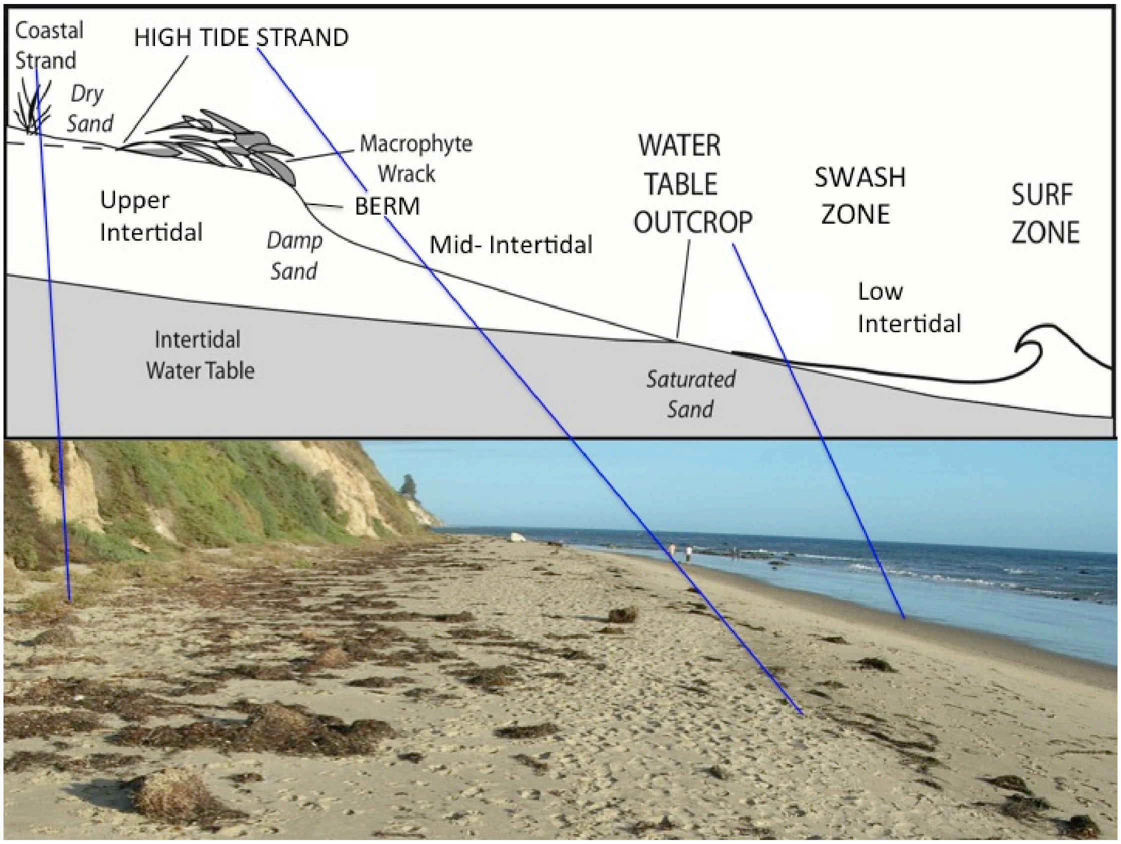

Figure 6-2. Ecological Zones of Sandy Beaches Top: Diagram of a California beach at low tide showing zones and features. Bottom: Photograph of a bluff-backed beach with the features shown in the diagram (Arroyo Burro Beach, Santa Barbara County) Photo: Jenny Dugan, from Coastal Commission (2015)). Note that while this is for a location other than Imperial Beach the concepts of ecological beach zonation and function are the same.

Table 6-2 summarizes these costs and provides uniform metrics that could be applied: cost per linear foot and cost per square foot. For this project, we decided to use cost per square foot. Since beach widths vary over time due to erosion, sea level rise, and various policies such as nourishment and coastal armoring, our approach can account for these impacts on beach ecosystems.

The analysis above yields quite significant values for the ecological value of beaches. A cost per square foot of $58 implies an acre of beach is worth $2.5 million. One potential issue with using the replacement cost analysis is double counting. The analysis contained in this study also estimates the economic benefits of recreation and storm damage prevention. If we also include the costs of restoration, these benefits may be counted twice. However, beaches and other coastal ecosystems have value beyond their important roles as storm buffers and towel-space for tourists. Barbier et. al. (2011) discusses the various ecological functions, goods and services of coastal ecosystems. In addition to buffering against storms and tourism, beaches and other coastal ecosystems provide the following EFGS:.

Table 6-2. Examples of costs for restoration of beach ecosystems in California[1]

Beach	Linear Feet	Area (acres)	Cost ($2015)	Project Elements
Pacifica State Beach	2,000	4	$6,960,000	·Removal of parking lot, revetment ·Nourishment ·Dune restoration
Surfer's Point	1,100	2.1	$4,670,000	·Removal of paving ·Beach/dune restoration ·New road, parking lot ·New storm drains
Ocean Beach	4,000	13.5	$200,000,000	·Removal of fill, revetment, roadway, parking, native vegetation. ·Construction of public facilities farther inland
Goleta Beach	700	1	$3,650,000	·Protection of sewer outfall ·Removal of parking, revetment ·Relocation of utilities, bike path
Average	**1,950**	**4.03**	**$53,820,000**	
Avg. w/o Ocean Beach	**1,267**	**2.37**	**$5,093,333**	

- Water purification;
- Nesting, foraging and spawning ground for a rich and unique set of flora and fauna;
- Carbon sequestration;
- Support for fish, crabs, clams and other seafood; and
- Nutrient cycling for species on and offshore.

With the exception of commercial fishing, where the link with beaches is not well understood, economists and ecologists do not yet understand the role or economic value of all of these EFGS. For example, Breaux (1995) estimates that the value of one of these services, water purification, ranges from $785 to $15,000 in EFGS per acre per year in 1995 dollars. Given the uncertainty here, it is difficult to establish a precise economic value and it is unlikely that ecologists and economists will fully understand all of these EFGS with any certainty in the near future. To be conservative, in this study, we assume that the EFGS other than for recreation/tourism and for storm buffering account for only a small portion of the restoration value, equivalent to $30,000 per acre per year of EFGS other than recreation or storm buffering. This amounts to only 25% of

[1] Source: Memo from ESA on Beach Restoration costs, April 23, 2015. Note that costs for acquisition or permission, easements, permitting, planning, monitoring etc., are not included in these estimates

the total ecological services if valued at replacement cost.

It should also be noted that the above restoration costs are all on public land and hence do not include the cost of land acquisition, which would add considerably to the expense given the high cost of coastal property in California.

Ecological Impact of Nourishment

Although nourishment projects enhance beach width and hence recreation, nourishment is also detrimental to beach/coastal ecology. The process of pumping sand on a beach and (typically) bulldozing the sand in place disrupts the foraging, nesting functions of beaches and buries many creatures who live in the sand (e.g., sand crabs). The result is generally a significant loss in EFGS for a time. However, beach ecosystems typically recover within a period of 5-10 years,[2] as is assumed in this study. Our analysis of ecosystem services assumed that the EFGS was reduced by 50% immediately after nourishment, and recovered at a rate of 15% per year until reaching our threshold of $30,000 in EFGS per acre per year.

Benefit/Cost Analysis

The ultimate purpose of the economic analysis is to compare the relative benefits and costs of various adaptation strategies. These results will be presented in section 6.7. Our benefit/cost analysis simply sums up all of the costs and benefits related to each strategy.

The costs of adaptation strategies include the costs of implementation (e.g., nourishment) as well as the costs in terms of losses to public and private property from flooding and erosion. The primary benefits to these strategies comes from the recreational and ecological benefits provided by Imperial Beach's beach and other coastal ecosystems.

Discount Rate

Since our analysis extends to 2100, future costs and benefits must be discounted at the appropriate rate. When considering benefits and costs that are incurred over a number of years, the dollar values must be adjusted to reflect the fact that a dollar received today is considered more valuable than a dollar received in the future. One important reason for this is the fact that a dollar received today could be invested to produce additional wealth. To do this, it is important to identify the period of time that will account for most of the relevant benefits and costs and to select a discount rate that will account for the diminishing value of benefits received in the future.

The choice of an appropriate discount rate is generally even more critical in the analysis since a higher discount rate implies that future benefits and costs are weighted lower. For most private projects the choice of a discount rate is relatively simple—whatever the appropriate market rate is. For example, if a private company is considering a $100 million dollar investment in a new factory that would yield a future stream of returns (profit), the firm would use their cost of capital. If they can borrow money at a 5% rate of interest, then 5% would be the discount rate.

A number of economists have argued that using market interest rates when analyzing social costs and benefits is inappropriate for a variety of reasons. First, the social rate of time preference— that is the rate at which society values present consumption over future consumption—is not necessarily given by the market interest rate (Zhuang, Liang, Lin, &

[2] The recovery of a sandy beach ecosystem depends on a variety of factors, size and scale of construction impacts, and species being monitored for recovery. One study following the 2012 regional sand replenishment program showed reduced levels of beach invertebrates 15 months after placement (Wooldridge et al 2014). Our assumption is based on research and discussions with Dr. Jenny Dugan over the last several years.

Guzman, 2007). A number of economists have conducted empirical studies of the social rate of discount and have found rates ranging from 0.1% to 3% (Liang, Lin, & Guzman, p.6).

Standard discounting practices face another critical problem in that the rates that are typically used discount goods and services to future generations to such an extent that future generation's preferences can become irrelevant. Applying a discount rate of 3%, for example, implies that benefits or costs born in 100 years are only weighted at 5% (1/20) of current costs and benefits; if one uses a 2% rate, the weighting changes to (a still low) 14%. Even applying a rate as low as 1%, as used in this study, implies that benefits/costs 100 years from now are only weighted at 37% of today's benefits.

Given the potentially enormous costs of climate change to future generations and the longer time scale, many environmental economists have proposed applying lower discount rates when analyzing the economic impacts of climate change. One of the most widely cited reports, the Stern report (2007), applied a 1.4 % discount rate. Arrow et. al. (2014) point out that climate change modeling presents a unique set of issues given the uncertainty involved and the potential for catastrophic outcomes (even if the probability of such outcomes is low). Consequently, many climate change models use a declining discount rate over time—implying that a longer time horizon should receive a lower discount rate. A number of European countries have already adopted such an approach. For example, Great Britain has adopted a declining rate formula for climate change projects where the discount rate can reach 0.75% after 300 years (Arrow et. al., 2014). In a widely cited paper, Weitzman (2001) posits a 1% discount rate for periods exceeding 75 years and 0 for periods exceeding 300 years.

We followed Weitzman (2001) in this paper and applied a 1% discount rate, which implies that consumption and expenditures by future generations are relatively more important than implied by a higher discount rate. However, our sensitivity analysis, discussed later, examined benefits and costs using differing discount rates.

Real vs. Nominal

In this report, we have generally assumed that the real costs and benefits of various adaptation strategies are constant. Put simply, once corrected for inflation, the prices/costs of most property and engineering solutions will stay constant. However, for beach recreation, this assumption is quite limiting since existing demographic/population projections by the State of California indicate that both the state and county will experience population growth. We have assumed that recreational demand for beaches will grow with population and real income.

6.2 Armoring

The armoring strategy focuses on the protection of the upland property and continues to rely on the existing mix of coastal armoring structures through 2030. At that point in time, the coastal armoring structures are all upgraded to a uniform vertical recurved seawall. As erosion of the beach continues the beach is lost while the upland remains protected. The implementation and evolution of this strategy can be seen in (Figure 6-3: Coastal Armoring).

In Imperial Beach, the current coastal armoring policy requires that any new or substantive repairs to coastal armoring is in the form of a vertical seawall located on the private property. This analysis did not consider the precise location of the structure and the private/ public boundary, only the size of the encroachment over the beach.

Specific Assumptions

Physical –

- In 2030 when the revetment is removed then placement loss decreases from 25 feet under a revetment to a 5 feet wide with a seawall.

Economic –

- Our engineering/economic analysis assumes that existing seawalls will be built to the same specifications and will have a thirty-year lifespan. Table 6-3 below lists the study's estimates for maintenance costs.
- 2. The economic methodology for armoring follows the methods outlined in section 6.1.2. In addition to the costs of constructing and maintaining a seawall, the study estimated the change in recreational and ecological value associated with armoring. Since armoring results in a narrowing of the beach, this loss of beach area was factored into our analysis. On the other hand, armoring strategies typically reduce erosion to upland property and this savings is also factored into the benefit/cost analysis.

Table 6-3. Maintenance Costs of Strategies.

	Groins	Retreat	Nourish	Dunes	Armor
Narrow Beach					
2047 (0.5 m)	$8,300,000	$3,800,000	$5,500,000	$3,100,000	$5,600,000
2069 (1.0 m)	$12,500,000	$3,800,000	$7,800,000	$3,100,000	$9,100,000
2100 (2.0 m)	$21,700,000	$3,800,000	$13,300,000	$3,100,000	$16,300,000
Wide Beach					
2047 (0.5 m)	$7,500,000	$2,400,000	$4,800,000	$2,400,000	$3,100,000
2069 (1.0 m)	$11,800,000	$2,400,000	$7,100,000	$2,400,000	$4,500,000
2100 (2.0 m)	$20,300,000	$2,400,000	$11,900,000	$2,400,000	$11,600,000

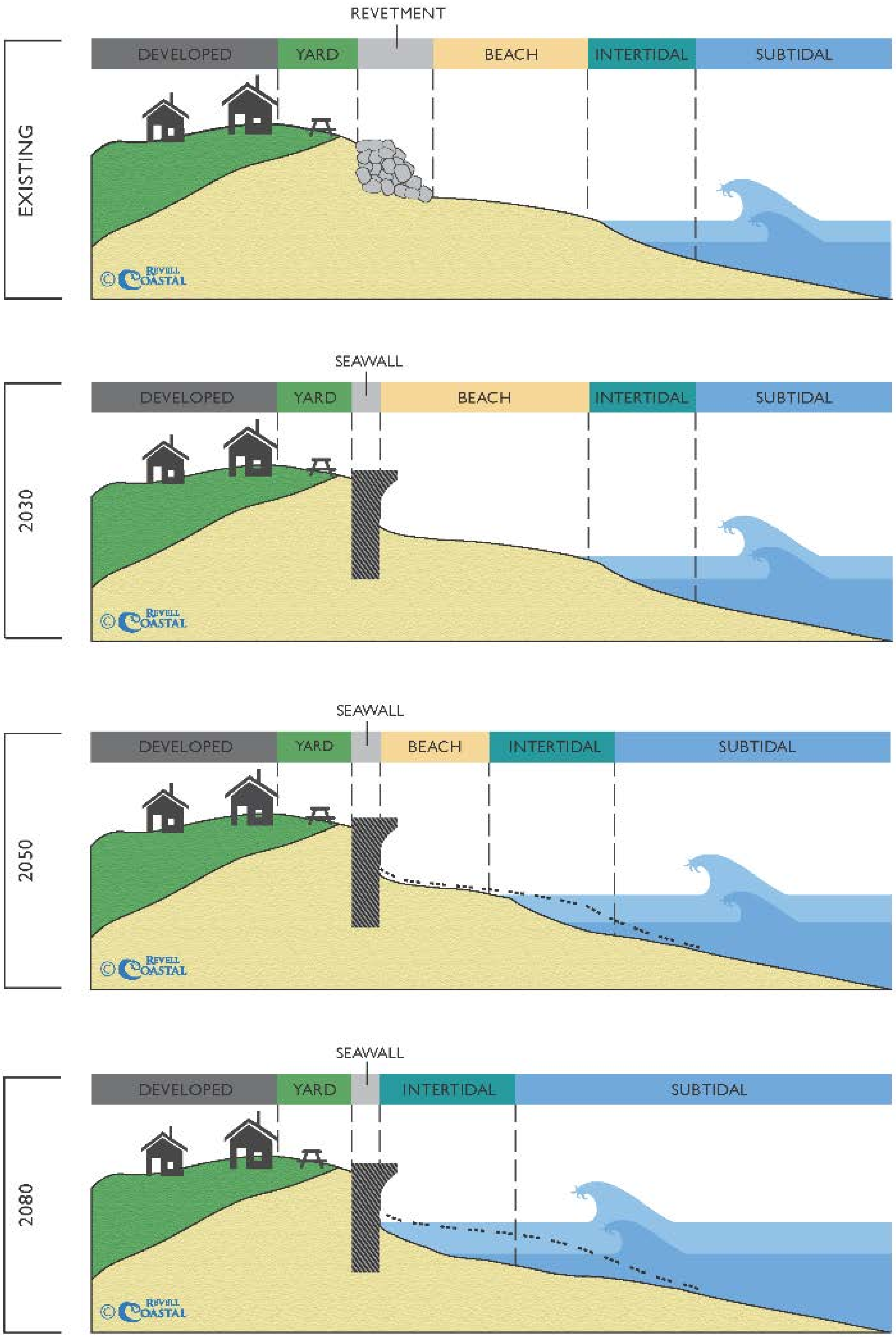

Figure 6-3 Evolution of the Armoring adaptation strategy

The economic analysis also accounts for the fact that maintenance costs for armoring solutions will increase when beach widths narrow, creating more wave energy.

6.2.1 Physical Results

Results from the physical analysis of beach width versus upland property show that under both of the beach width conditions, that upland property would be maintained into the future.

For the narrow beach condition, dry sand beaches would likely completely disappear by 2050, and damp sand beaches (those that are only accessible at low tide) would disappear by 2060

For the wide condition, typically seen following a nourishment, the dry sand beach disappears by 2065 and the damp sand beach disappears by 2075.

For both of these findings, it is important to note that this modeling did not include the impact of any major storm events which from historic observations can erode the beach 100+ feet in any given major storm event.

6.3 Managed Retreat

The managed retreat alternative prioritizes preservation of the beach and its associated recreation and ecological benefits above property protection. The intent of this alternative is to remove the shoreline armoring in 2030 and then to allow the coast to erode inland. As buildings and infrastructure are damaged there are removal costs and dune restoration costs associated. The implementation and evolution of this strategy can be seen in (Figure 6-4: Managed retreat).

While there are many ways to implement managed retreat from both a policy and acquisition stand point, (see section 7.3 for more discussion), this alternative was selected to look at a public acquisition of the properties with a lease back option so that the City could recover a portion of the investment before the structures would have to be removed. Thus this would likely require a financing of the acquisition and a development of a lease agreement. The lease-back option is discussed in more detail in section 8.

Specific Assumptions

Physical

- Structures removed in 2030 regain placement loss (25') then initiate managed retreat into upland.
- After removal of structure and development, the beach reaches an equilibrium width of 75 (narrow) to 175ft (wide).

Economic

- The methods used here are as described in section 6.1.2. In addition, our analysis factored in the costs of removing structures, roads, pipes and water pumps, which is required for managed retreat.

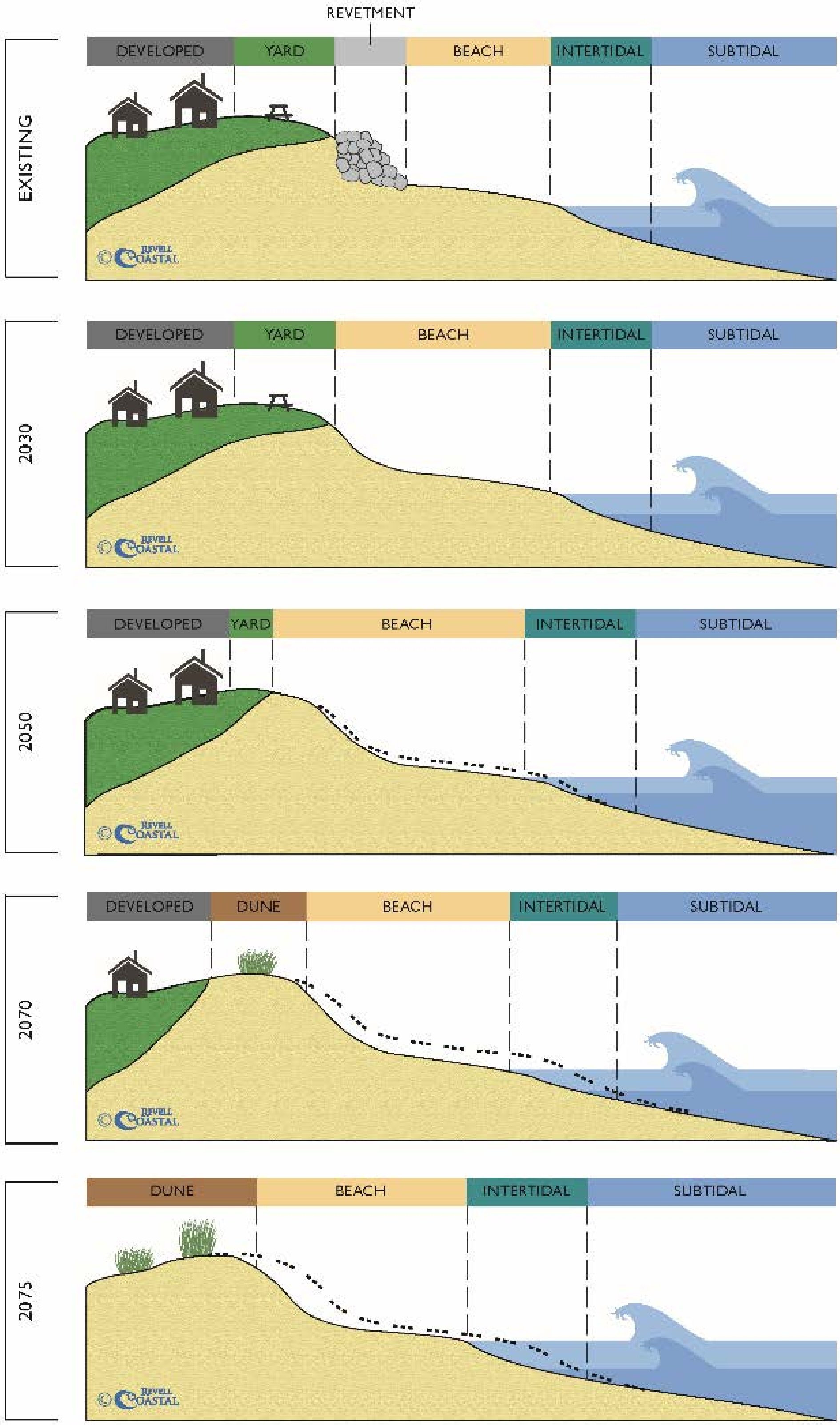

Figure 6-4. Evolution of the Managed retreat adaptation strategy

6.3.1 Physical Results

Results from the physical analysis of beach width versus upland property show that under both of the beach width conditions, that dry sand beaches would be maintained into the future in either a narrow condition (~75 feet wide, or a wide condition ~175 feet wide). Erosion of the upland development could reach on average up to 3 parcels inland (~300 feet) which is on the inland side of Seacoast Drive.

For both of these findings, it is important to note that this modeling did not include the impact of any major storm events which from historic observations can erode the beach 100+ feet in any given major storm event.

6.4 Nourishment

This "business as usual" nourishment alternative was selected to emulate what has been the most common practice in Imperial Beach, namely to periodically nourish the beaches while maintaining the existing structures. The intent of this alternative is to protect the existing upland and maintain a beach. The implementation and evolution of this strategy can be seen in (Figure 6-5: Nourishment).

Specific Assumptions

Physical –

- Size tied to historic nourishment volume and size (~100' by 1.5 mile)
- Placed sand decreases 50% every 5 years
- Renourishment triggered before upland property damages occur
- Upland eroded protected by existing armoring (with maintenance costs)

Economic

- Our engineering/economic analysis used recent data from the SANDAG nourishment project to estimate the costs (in cubic yards) of nourishment. Since there may be significant economies of scale in larger nourishment projects (e.g., mobilization costs for a hopper dredge may be large).
- The recreational benefits of nourishment are substantial. The CSBAT model was developed specifically for the State of California to estimate the economic benefits of increased beach width due to nourishment. More detail on this method are provided in section 6.1.2 and in our technical report.
- The impacts of nourishment on beach ecology are mixed. Typically, nourishment projects involve burying existing ecosystems under tons of sand including bulldozing. Numerous studies (cited earlier) have found detrimental environmental impacts from nourishment. To account for this detrimental impact, this study assumed that the value of ecosystem services would be diminished by 50% in the first year after nourishment and gradually recover at a rate of 15% a year until full ecological capacity is reached (typically in 5-7 years).

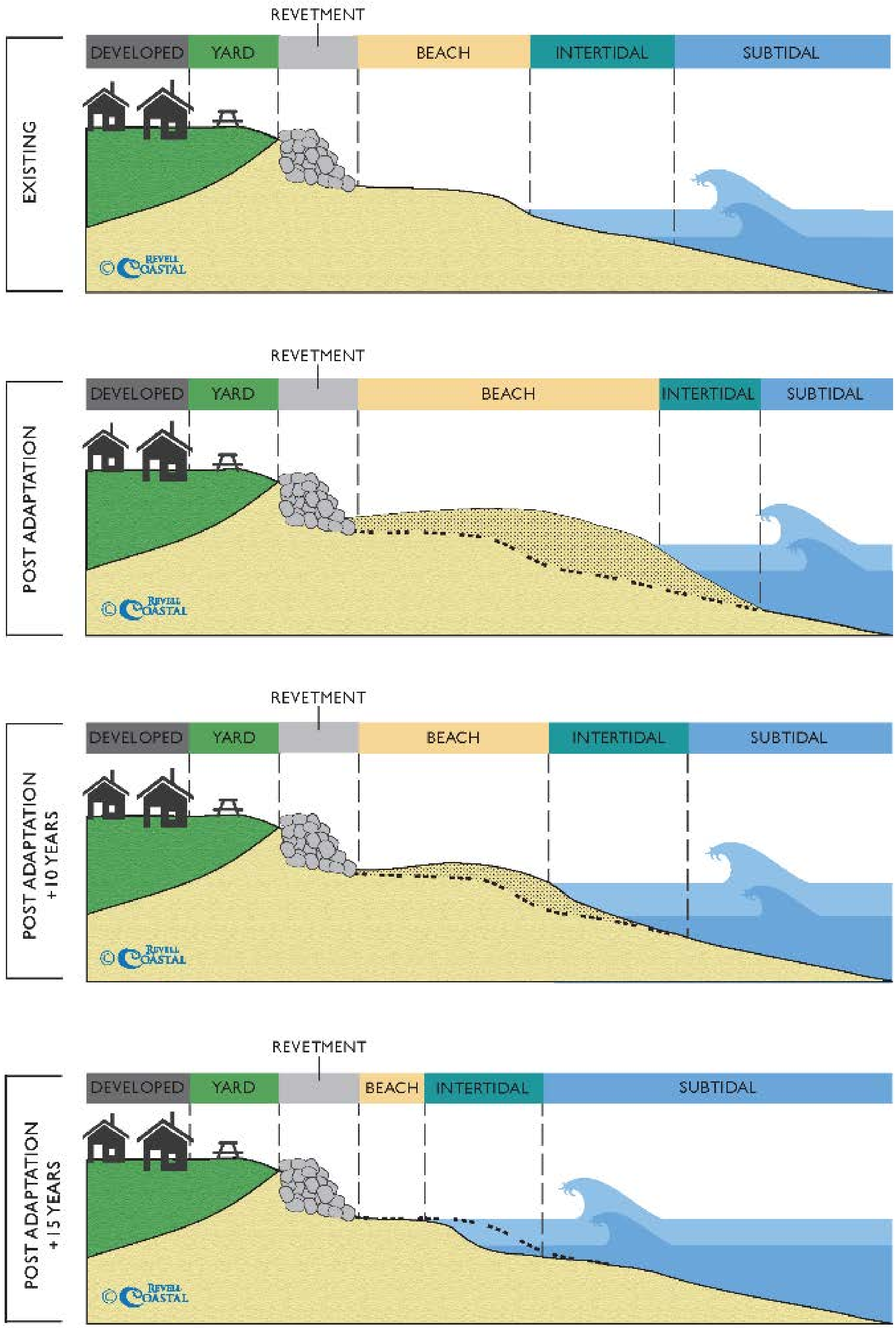

Figure 6-5. Evolution of the Business as usual nourishment strategy.

6.4.1 Physical Results

Results from the physical analysis of beach width versus upland property show that both the upland can be protected while maintaining a sandy beach with enough nourishment placements. To maintain a recreational beach to accommodate 6.5 feet of sea level rise, model results project that between 9 (wide) and 11 (narrow) times must be placed by 2100 to maintain beach width and protect upland property. As sea level rises and erosion rates increase the frequency of nourishment increases. In the near future nourishments tend to occur every 15 years or so, but by the end of century, it is projected that the nourishment cycle would have to occur about every 5 years.

For both of these findings, it is important to note that this modeling did not include the impact of any major storm events which from historic observations can erode the beach 100+ feet in any given major storm event.

6.5 Hybrid Dune Approach

This hybrid dune approach alternative was selected to emulate what was likely the natural form and function of the coastal landscape prior to substantial human influence and development. Based on the documented understanding of the historic condition with natural dunes and wide sandy beaches underlain by cobbles, this alternative is the closest to the green protection approach (See Section 2 for more discussion)

The intent of this alternative is to protect the existing upland with a combination of beach sand nourishment, cobble placement and dune creation. The resulting strategy then allows erosion of the beach which triggers a reduced rate of erosion in the cobbles which eventually leads to dune erosion. Once the dune is eroded then by 1/3 with the crest elevation still intact, a new hybrid dune is implemented. The implementation and evolution of this strategy can be seen in (Figure 6-6: Hybrid Dune Approach).

Specific Assumptions

Physical

- Size tied to historic nourishment volume and size (~100' by 1.5 mile).
- Cobble volume estimated based on historic observations, assumed 50 feet.
- Dune crest placed at 100 year TWL (Everest 2001 - ~20 feet NAVD).
- The nourishment experiences an accelerated erosion rate of 50% of the nourishment length every 5 years. We assume this accelerated rate to be constant throughout the 5 years (I.e. 10% loss per year).
- Once beach width is reduced to 175ft. Cobbles erode at a reduced rate of 90% of the background erosion rate.
- Once the cobbles width reaches 25ft, Dune erodes occurs at the background erosion rate accelerated with sea level rise.
- Reconstruction is triggered once the dune is eroded by 1/3.

Economic

- The economic assumptions for a hybrid dune are similar to nourishment.
- We assumed that dunes have recreational value similar to beach width.

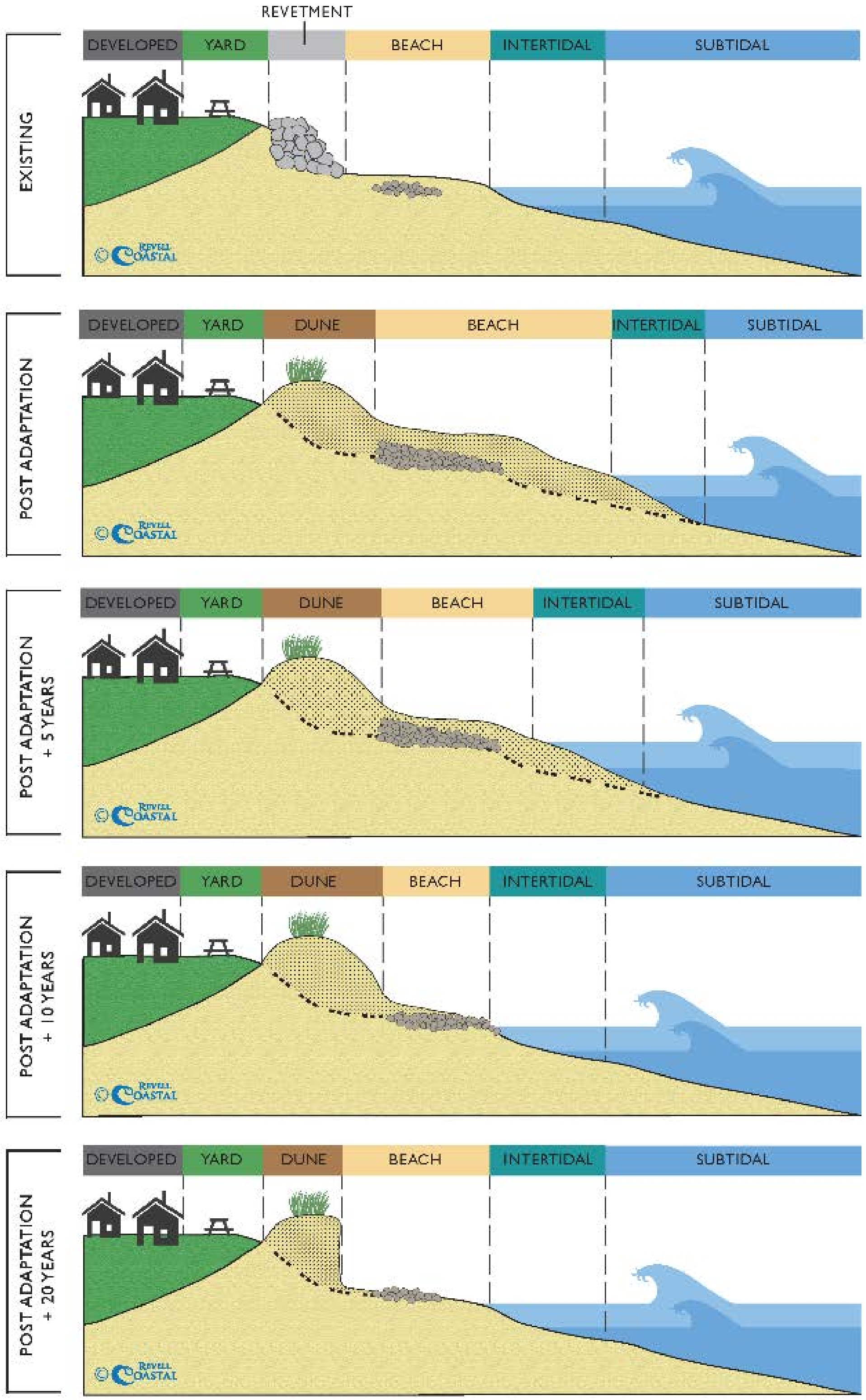

Figure 6-6. Evolution of the Hybrid Dune Approach nourishment strategy.

6.5.1 Physical Results

Results from the physical analysis of beach width versus upland property show that both the upland can be protected while maintaining a sandy beach with enough hybrid dune nourishment placements. To maintain a recreational beach to accommodate 6.5 feet of sea level rise, model results project 8 (wide) and 9 (narrow) times by 2100 to maintain beach width and protect upland property. The key difference between the wide and narrow beach is that under the narrow condition, there must be a double nourishment in the beginning to provide enough space to construct the entire strategy and then it is maintained the same as the wide beach.

As sea level rises and erosion rates increase the frequency of the hybrid nourishment placements increases. In the near future nourishments tend to occur every 15 years or so, but by the end of century, it is projected that the nourishment cycle would have to occur about every 5 years.

For both of these findings, it is important to note that this modeling did not include the impact of any major storm events which from historic observations can erode the beach 100+ feet in any given major storm event.

6.6 Groins

The intent of this alternative is to protect the existing upland with a completion of the original Army Corp of Engineers 5 groin concept, with some extension of the existing two groins and the construction of 3 new groins to a length of 930 feet. The construction of the groins as a sediment retention structure is coupled with a nourishment which fills the groin compartments and reduces the likelihood of downcoast erosion impacts to the City of Coronado and Silver Strand State Beach. This charging of the groin field is akin to filling up a leaky barrel (aka filling with sand) and should mitigate the downcoast erosion commonly associated as the primary downside of groins. It is also assumed that the existing coastal armoring structures remain and the widen beach from the nourishment reduces the armoring maintenance costs.

The resulting strategy constructs the groins and nourishment with additional nourishment triggered once the beach reaches a certain threshold beach width. The implementation and evolution of this strategy can be seen in (Figure 6-7: Groin).

Specific Assumptions

Physical

- Five groins with initial nourishment completion of 4 additional groins (each of 930') for a total of 5 groins
- Existing groin included a 350 foot extension as per Joe Ellis recommendations
- Groin retains sand for some equilibrium distance downcoast (based on San Diego Beach Retention Strategy
- Nourishment of 100 feet to avoid downcoast impacts
- Nourished sand retained with 25% loss every 5 years
- Background erosion accelerated with Sea Level Rise
- Wide Beach is re-nourished when it narrows below 150ft
- Narrow Beach is re-nourished when it narrows below 75ft

Economic

- In this study we assumed that groins did not have a positive or negative impact on recreational experiences.

- Groins can increase the recreational experience for fishermen or possible surfers, but can also detract from the aesthetics of a beach. Groins do inhibit the movement of some biota on the beach, but this was also not factored into our analysis.

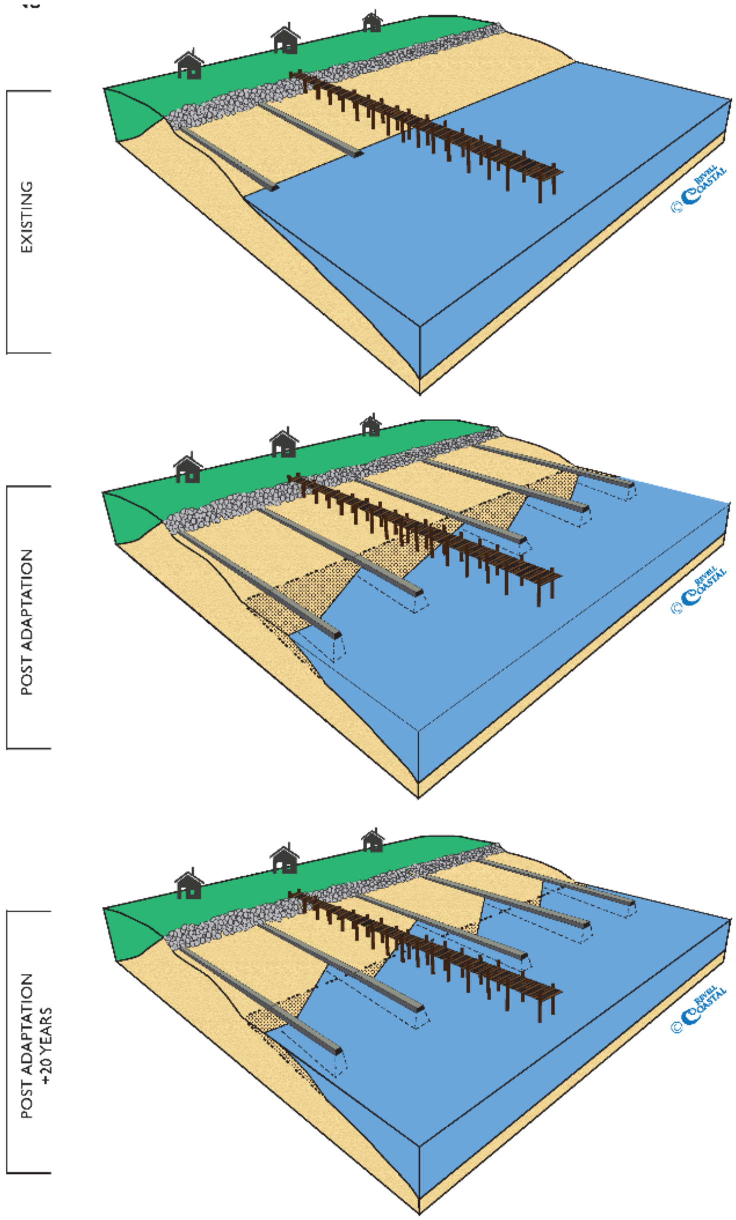

Figure 6-7. Sand retention with groins adaptation strategy implementation over time.

6.6.1 Physical Results

Results from the physical analysis of beach width versus upland property show that both the upland can be protected while maintaining a sandy beach retained with groins. To maintain a recreational beach to accommodate 6.5 feet of sea level rise, model results project 6 (wide) or 7 (narrow) nourishment placements by 2100 to maintain beach width and protect upland property.

As sea level rises and erosion rates increase the frequency of the nourishment placements increases. In the near future nourishments tend to occur every 25 years or so, but by the end of century, it is projected that the nourishment cycle would have to occur about every 10 years.

For both of these findings, it is important to note that this modeling did not include the impact of any major storm events which from historic observations can erode the beach 100+ feet in any given major storm event.

6.7 Results of Economic Analysis of Adaptation

This section will present an analysis of the benefits and costs of each adaptation strategy based on the methods and assumptions described earlier in this section. Table 6-4 below summarizes the total initial costs for each adaptation strategy.

Table 6-4. Immediate Costs of Implementation (No nourishments, maintenance or removal costs)

Scenario	Component	Cost
Groins	New Groin (5 total: 3 new and 2 halves)	$14,880,000
	Beach Sand Nourishment	$20,000,000
	Total:	**$34,880,000**
Retreat	2030 Seawall Removal	$7,920,000
	Total:	**$7,920,000**
Nourish	Beach Sand Nourishment	$20,000,000
	Total:	**$20,000,000**
Dunes	Cobble	$23,760,000
	Dune Sand Nourishment	$7,920,000
	Beach Sand Nourishment	$20,000,000
	Dune Restoration	$910,000
	Total:	**$52,590,000**
Armor	2030 Seawall Removal	$7,920,000
	New Seawall Construction	$35,640,000
	Total:	**$43,560,000**

Our analysis assumed that the property/structures are completely lost after erosion reaches the edge of the structure, and that the property is also lost once chronic flooding hits any structure on the land. In the case of event flooding (modeled as a 100 year storm) the analysis applied flood damage curves as discussed above and the losses

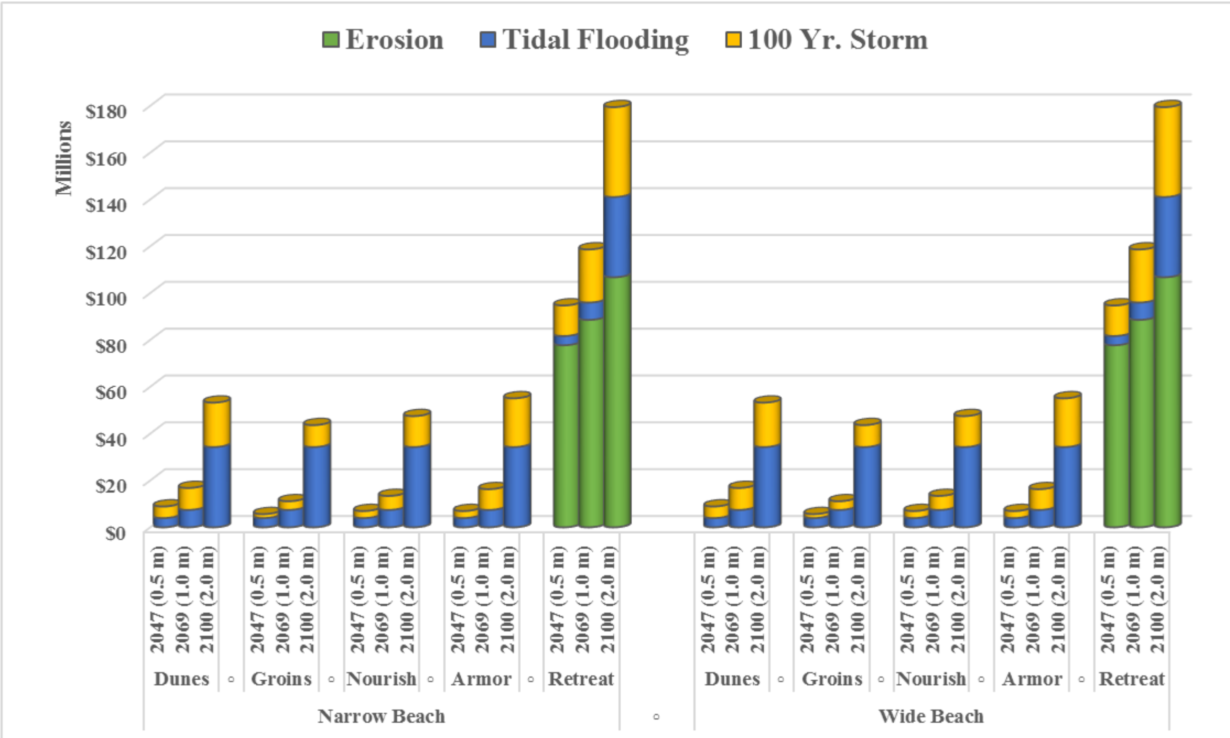

Figure 6-8. Vulnerability of Private and Public Parcels to Erosion, Tidal Flooding and a 100 Yr. Storm Event.

represent the replacement/repair costs to structures from event flooding.

For retreat, the largest losses are due to erosion, which is not surprising. All strategies are equally vulnerable to tidal flooding. The vulnerability to event flooding varies with adaptation strategy. As expected, the retreat strategy is the most vulnerable to event flooding; armoring provides the greatest protection against event flooding, and nourishment, with and without groins, is in between.

Figure 6-9 includes the estimates from Figure 6-8 on the losses due to erosion and flooding for both public and private assets, including infrastructure. "Public Assets" includes publicly owned parcels, roads, sewer pipes and pumps.

Figure 6-9 also incorporates the costs of implementing these strategies (e.g., the costs of nourishment). As one can see in, the costs of implementing many of these strategies is often greater than the value of the assets being protected. The costs of dunes are especially large given the large volume of sand required. The costs of groins, however, are less than regular nourishment since they do not require as frequent of nourishments.

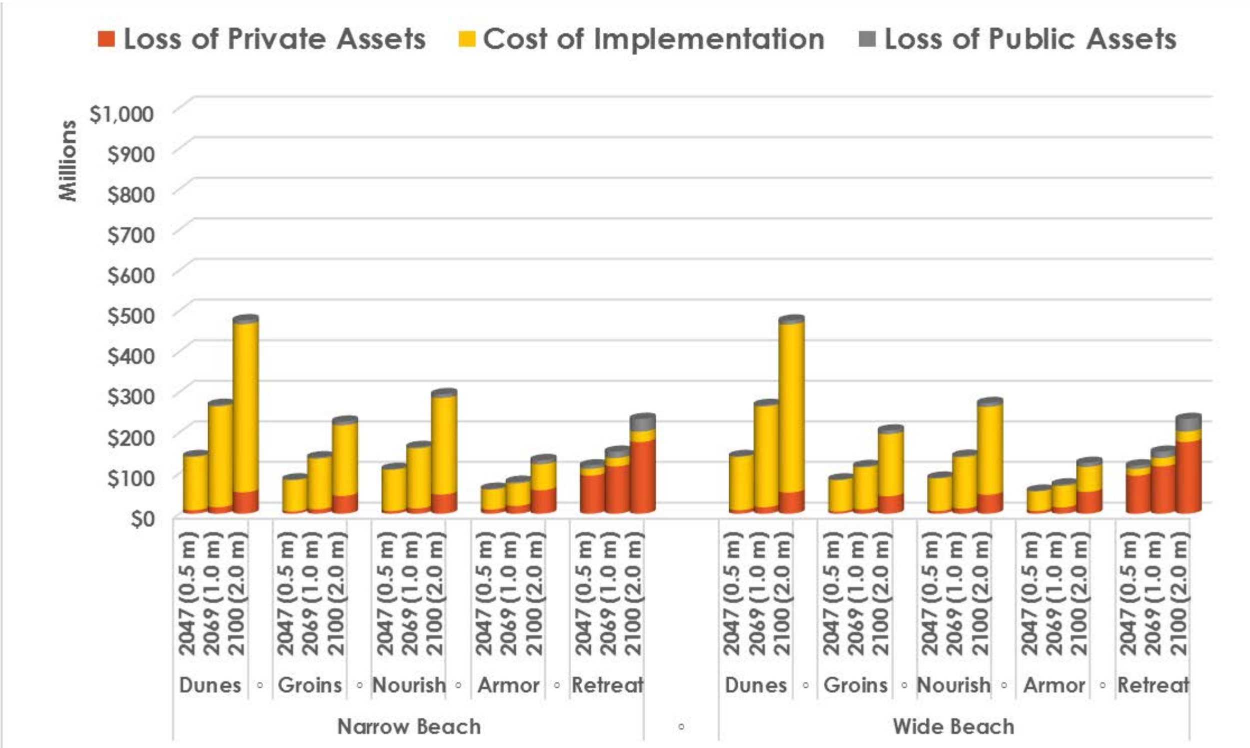

Figure 6-9 Total Costs as a Sum of Losses of Private Assets, Losses of Public Assets and Costs of Implementing the Adaptation Strategies.

The implementation costs of armoring are lower. However, as demonstrated below, armoring reduces the beach's recreational and ecological value significantly.

Figures 6-10 and 6-11 show the evolution of beach widths modeled through time as managed for the wide and narrow beach conditions. The zig zag, sawtooth pattern illustrates the nourishment cycles or how frequently a new nourishment will be required to maintain the desired wide or narrow beach condition. The comparison for the nourishment strategies are the managed retreat/phased relocation which maintains a stable beach through time contrasted with the armoring condition which results in a loss of beach in the future. The frequency of these nourishment cycles directly impacts the total cost of implementing the strategy through time and the frequency also reflects in the ecological impacts.

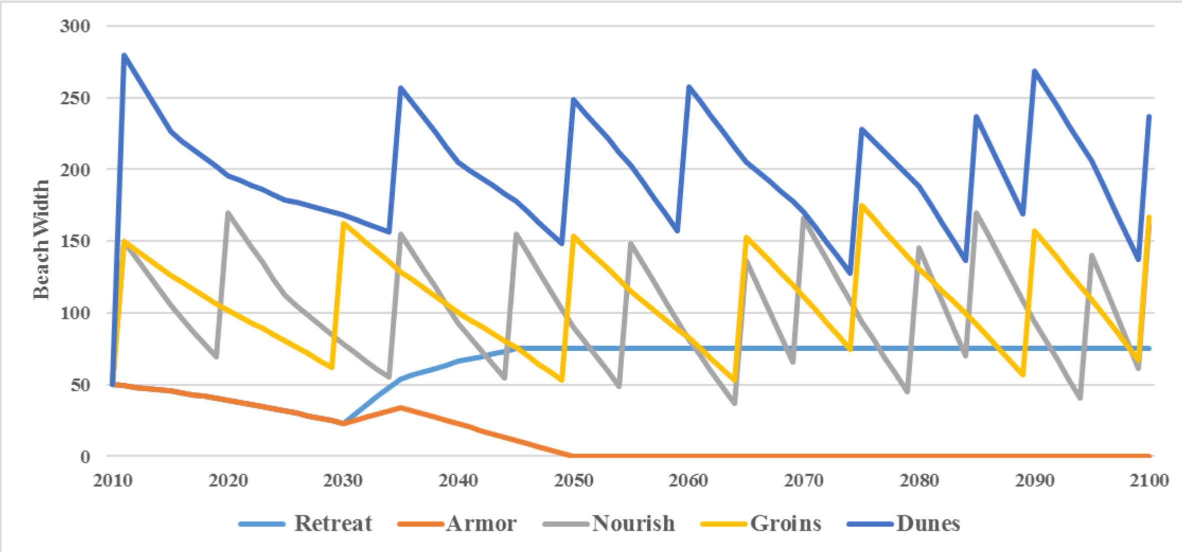

Figure 6-10. Beach Width over Time – Narrow Beach.

Figure 6-11. Beach Width over Time – Wide Beach

Summary of Wide and Narrow Beach Results

- The Dunes strategy is exactly the same, regardless of whether the beach is naturally wide or narrow. In other words, we assume that we can re-engineer the natural equilibrium toward which the beach will tend.
- Under the narrow beach, armoring loses a sandy beach much faster than in the wider beach.
- The pivot point at year 2030 corresponds to the removal of the armoring that is currently in place. It is at this point that the city becomes vulnerable to large amounts of erosion.

- In general, those beaches that maintain a larger beach width will produce larger Recreational Benefits, Ecological Benefits and tax revenue (See section 6.8 for more details). This is the major difference between the Wide and Narrow beach results.

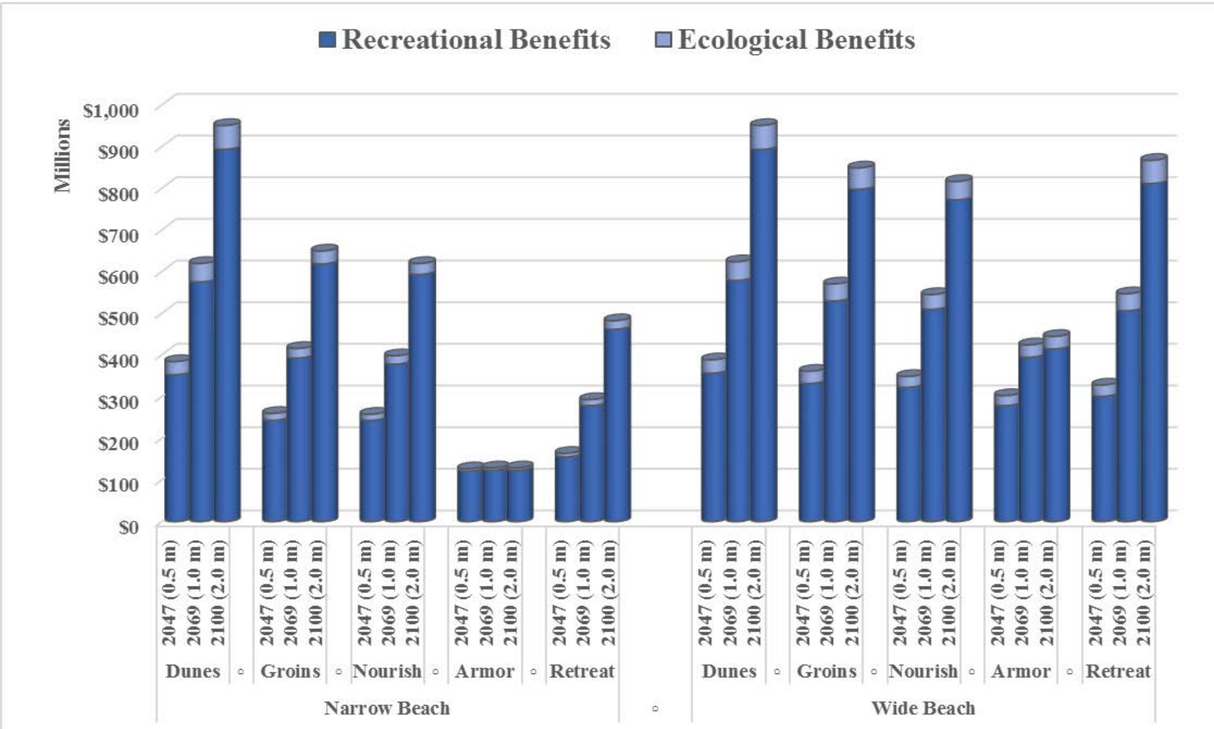

Figure 6-12. Total Benefits as a Sum of Recreational Benefits and Ecological Benefits

Figure 6-12 above summarizes the recreational and ecological benefits provided by various strategies. Not surprisingly, armoring provides the lowest recreational and ecological benefits, since armoring leads to reduced beach width. As discussed previously, armoring also reduces ecological value since it creates a barrier for many fauna who are adapted to retreat to dry land during storm surges.

As expected, retreat has much higher recreational and ecological value than armoring since it preserves the beach and coast. Although nourishment does degrade ecological value initially, the increased beach width from nourishment does provide additional habitat over time. In particular, dunes provide additional habitat and ecological value. Some key highlights from Figure 6-12:

- Ecological value is far smaller (about 5%) than recreational value.
- The differences between the wide and narrow beaches are clearly illustrated in the armoring scenario. In the narrow beach, armoring destroys the dry beach quicker, thus blocking any further increase in benefits.
- The Dune strategy does very well in the narrow beach because it maintains a MUCH wider beach than the other strategies.
- A retreat strategy looks relatively better with a narrow beach.

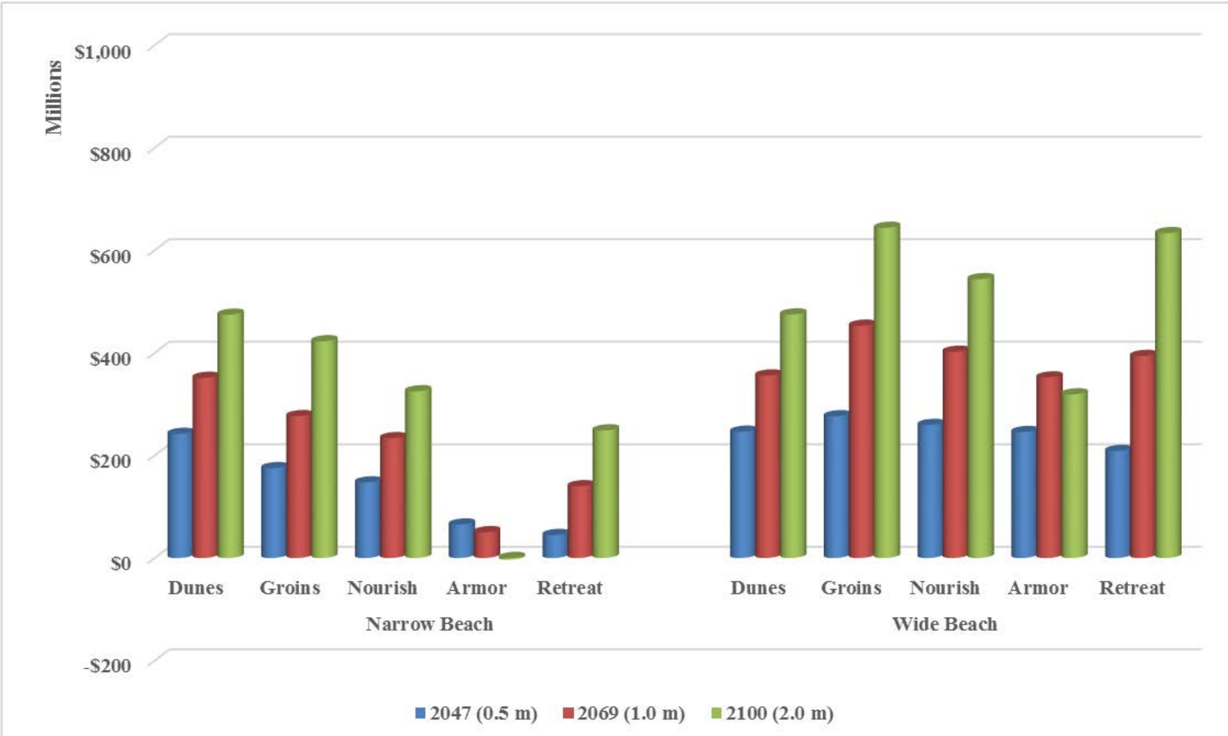

Figure 6-13. Net Benefits of each Adaptation Strategy

Figure 6-13 above provides a summary of the net benefits (benefits minus costs) for each adaptation strategy. For a wide beach over the long term, the net benefits for two strategies, groins and retreat are the highest. Although groins yield a slightly higher value, this is well within the margin of error. Nourishment and dunes provide somewhat lower net benefits over time (groins maintain the beach width). In contrast, the net benefits of armoring for a wide beach diminish over time as beach width is eroding, reducing both recreational and ecological value.

For a narrow beach, nourishment strategies dominate and armoring yields much lower net benefits over time since the beach is lost. Retreat provides higher benefits than armoring but lower benefits than nourishment.

A few other highlights from Figure 6-13:

- In the Wide Beach, the large benefits of the Dunes are offset by the large costs of implementing the strategy.
- Groins are more cost-effective than nourishment (without groins) because the higher frequency of nourishments makes the Net Benefits of nourishment significantly lower than those of groins.

6.8 Sensitivity Analysis

As with any economic modeling, the results presented above are based on certain assumptions. To understand the role of each of these assumptions in our analysis, we conducted a sensitivity analysis, which involves applying running the model using a range of values for key parameters to determine how sensitive the model is to changes in that parameter. We focused on the parameters that we believed were the most uncertain or where experts could disagree. We determined these were the key parameters:

- Recreational Value
- Preferences Concerning Beach Width
- The Future Costs of Nourishment

A full analysis of our sensitivity analysis is contained in the technical appendix C. In this section we only present the sensitivity analysis for one key variable: the cost of nourishment.

For recreational value, our results generally indicate that changing the recreational value does not change the rank ordering of our results. The exception occurs with dunes, which are sensitive to assumptions about changes in recreational value. As we assume higher recreational values (either because of higher attendance or higher day use value), the dune based adaptation strategies increase in net present value.

For beach width preferences (whether one prefers a wider beach or not) our results are also quite robust—the rank orderings do not change—except for, once again, dunes. As people prefer wider beaches, dunes become more preferable. Our final, and perhaps most important sensitivity analysis was on the cost of sand/nourishment. Our model assumed that the cost of sand /nourishment increases by 1% a year in real (inflation corrected) terms. However, it's possible that sand costs could rise much more rapidly if offshore sand supplies are difficult to find OR if environmental permitting makes it difficult to nourish. On the other hand, it's also possible that nourishment could become cheaper if there are economies of scale to conducting nourishment on a regular basis (e.g., SANDAG or the State of California could contract for a long-term lease for dredging/nourishment).

Not surprisingly, the three nourishment strategies yield significantly worse net present values over time as sand/nourishment costs go up. This is particularly true in 2100. As the costs of nourishment increases retreat becomes a more viable policy and as increases in nourishment costs become greater than 1% a year, retreat becomes the most viable strategy, at least in terms of yielding higher net present value.

The costs of sand for nourishment over time depend upon two key issues. First, the availability of sand near shore is critical. The farther the "borrow sites" with available and compatible sand are away from Imperial Beach, the higher the costs of nourishment. The costs of hiring a hopper or other dredge are also quite high and depend on a number of factors including current demand. For the SANDAG project, the "mobilization" costs—the fixed costs of moving a hopper dredge to Imperial Beach—are quite high. Thus it may make sense for Imperial Beach to continue to work with regional agencies such as SANDAG or State agencies in order to gain economies of scale (more projects lower the cost) which will lower nourishment costs.

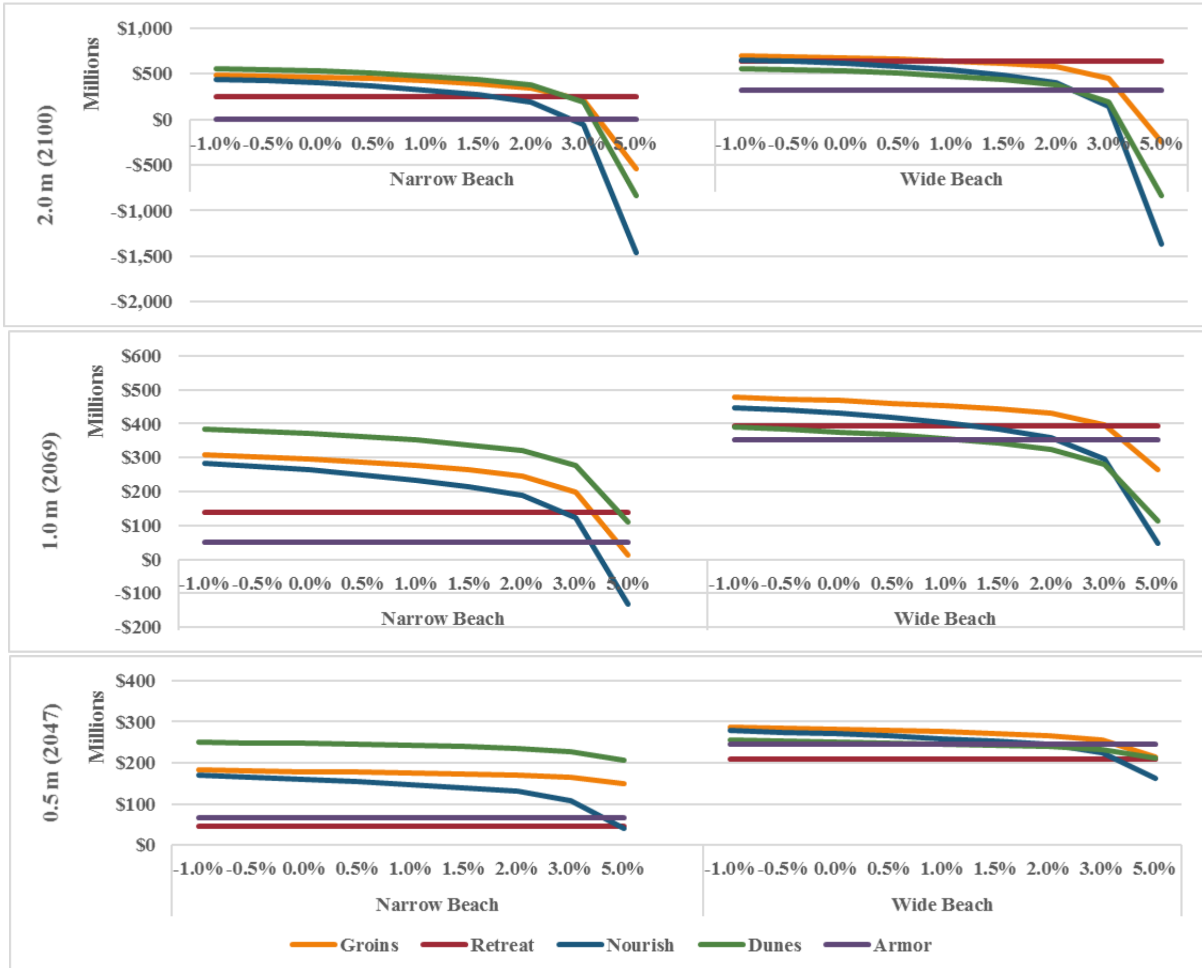

Figure 6-14. Sensitivity to Increasing Costs of Nourishment

6.9 Tax Revenue Impacts to the City

Imperial Beach's beach tourism provides substantial revenues to the city. The analysis conducted for this study was limited to sales taxes and transient occupancy taxes (TOTs). In addition to measuring economic benefits, this study also measured some tax revenue impacts for the City—notably Transient Occupancy Taxes, and Sales taxes.

A survey conducted by Dr. King for SANDAG, indicates that approximately 25% of Imperial Beach's beach visitors are from out of town and the remaining 75% are local. As Imperial Beach builds out its tourist infrastructure, we expect that the percentage of out-of-town visitors will increase.

The SANDAG survey also asked respondents how much they spend on gas, food, lodging, etc. We used these figures to estimate total spending per visitor. For TOT's we simply estimated total spending on lodging and applied the 10% TOT rate. We assumed that 90% of all visitors to Imperial Beach stayed overnight in Imperial Beach and applied the average spending rate per night ($25.25 per person per night). (Although $25 per person per night sounds low, keep in mind that most people stay in groups and that

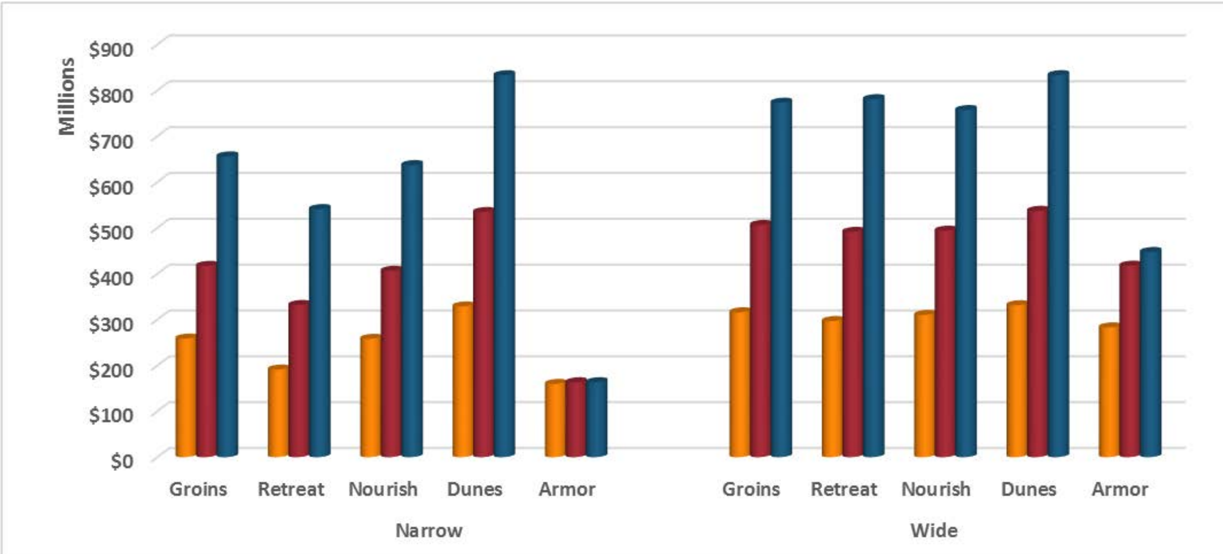

Figure 6-15. Beach Related Spending over Time

many people stay overnight at family and/or friends and spend nothing per night.)

For sales taxes we estimated the spending on items subject to sales tax. Most grocery spending is not subject to sales tax; this study assumed only 30% of grocery spending is subject to sales tax, which is an industry average. The total sales tax in Imperial Beach is 8%. However, only 1% (one-eighth) of the sales tax goes to the City's general fund.

Further, not all spending occurs within the City of Imperial Beach. Tables 6-5 and 6-6 below list the study's assumptions about spending within the City.

Table 6-5. Percent of Purchases made within Imperial Beach (as opposed to San Diego County)

Expenditure	% in Imperial Beach
Lodging	90%
Gas	50%
Restaurants	90%
Spirits	70%
Sundries	60%
Groceries	60%

Table 6-6. Beach Expenditures per Person Per Day

Expenditure	Overnight	Day
% of Visitors	25.4%	74.6%
Lodging	$25.25	$0.00
Gas	$2.41	$1.25
Restaurants	$7.96	$1.64
Spirits	$2.10	$0.21
Sundries	$0.48	$0.66
Groceries	$3.99	$1.01
Total	**$42.19**	**$4.78**

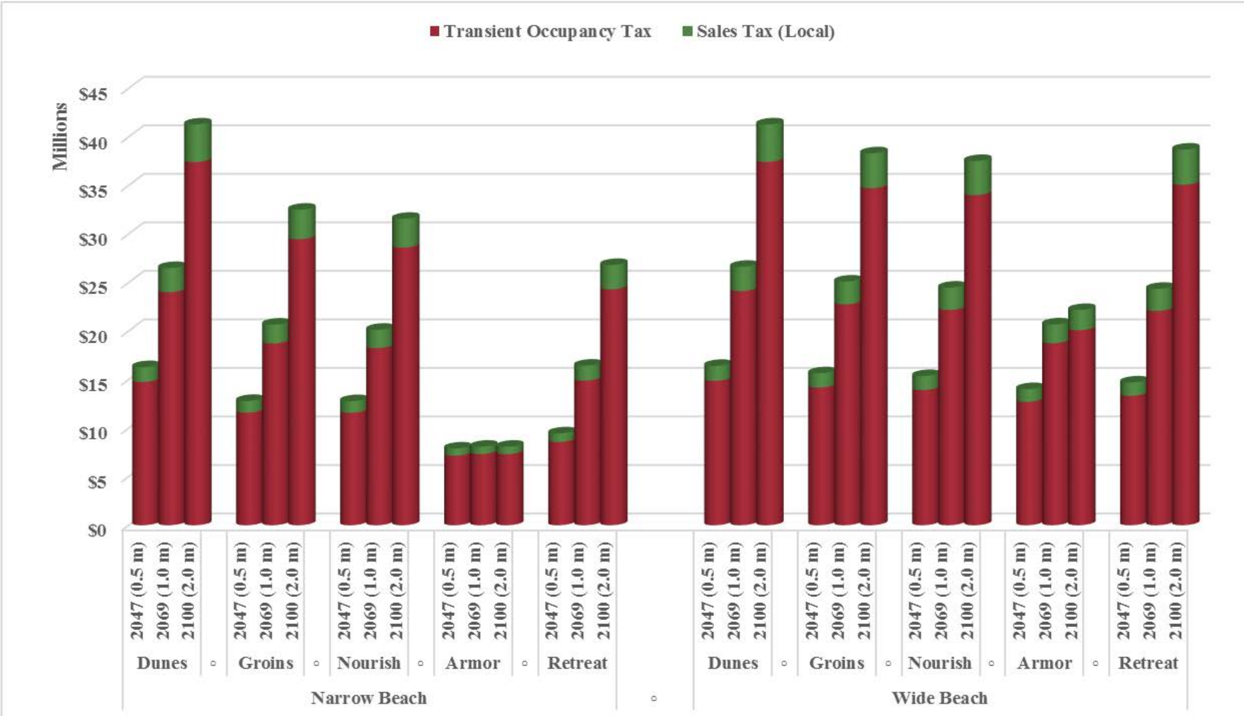

Figure 6-16. Estimated (Local) Sales Tax and Transient Occupancy Tax Revenues

Figure 6-16 presents our estimates of sales and transient occupancy taxes under various adaptation strategies. As expected, the nourishment strategies, which lead to wider beaches and increased tourism, yield the highest tax revenues. Armoring yields the lowest TOT and sales tax revenues.

theoretical 20-year Bluff Retreat Area. The Coastal Commission may be considering a relatively new ecosystem damage fee. The ecosystem damage fee is intended to provide mitigation funds to restore damages to coastal habitats from the development. These could be to restore rocky intertidal habitat, sandy beach and dune habitat, or wetland habitats.

Rental Surcharge Fees

A new type of fee would be a rental surcharge fee for property owners with armoring and coastal structures that occupy a portion of the public trust beach below MHW. For these structures, there would be an annual lease or rent for the ability to have a structure occupy the public trust resource (i.e., beaches). This rent would increase each time the tidal epoch was updated and MHW moved farther landward as more of the structure occupied more of the beach.

Increase Taxes

The City could also use more traditional mechanisms such as raising the sales tax and devoting a portion to these costs. The City ToT rate is currently at 10 percent. This could be raised to 12 percent with a portion of the increase to pay for adaptation.

7. Conclusion

This study identifies potential impacts to land uses, infrastructure and resources, based on the four coastal process hazards, as the foundation for the vulnerability assessment. Based on the characteristics of the City's coastline and input from the City and steering committee, seven sectors were analyzed in the vulnerability assessment. The sector profiles (Appendix A) summarize the key impacts and a range of potentially appropriate adaptation strategies to the various sectors identified for analyses.

A. Land Use

B. Roads

C. Public Transportation

D. Wastewater

E. Stormwater

F. Schools

G. Hazardous Materials

Vulnerability Approach

Coastal hazard projections available from USGS and Department of Defense provided projections for existing conditions, 0.5, 1.0, and 2.0 meters of sea level rise for a suite of coastal hazards.

Existing conditions mapping of hazards was based on a 2010 LiDAR topographic survey of the region. Coastal hazards are presented and include the following:

- Coastal Flooding from a 100 year wave event
- Coastal Erosion
- Tidal Inundation
- Nuisance Stormwater Flooding

Key Findings

The following are key findings identified as a result of analyses in this report:

Vulnerabilities

- All of the beach accesses and oceanfront properties are in existing coastal erosion and coastal flood hazard zones associated with a 100-year wave event. From historic storm observations beach erosion of 50 to 150 feet in a single storm event is possible.
- Four primary neighborhoods face coastal and tidal flooding impacts: the South Seacoast neighborhood; the Carnation Ave neighborhood located just north of Palm Avenue; Seaside Point just north of NOLF and the neighborhood around Bayside Elementary on San Diego Bay.
- Coastal erosion will likely accelerate above historic erosion rates as sea level rises. Accelerating historic erosion rates based on 6.5 feet of sea level rise escalates erosion from 7.4 ***inches*** per year to 6.2 ***feet*** per year.
- Storm water and nuisance flooding associated with high tides will increase in frequency and duration as tidal elevations decrease the stormwater conveyance capacity.
- Land use impacts primarily impact residential properties and with 6.5 feet (2 meters) of approximately 30 percent of all structures and parcels in the City could be impacted during coastal flood events. The City's property tax base is at escalating risk as a result of these increasing exposure to coastal hazards and sea level rise.

- Tidal inundation has a very small impact under existing conditions, but impacts escalate dramatically between 1 and 2 meters of sea level rise.
- Coastal hazards on top of 6.5 feet of sea level rise could potentially impact about 40% of all roads inside the City.
- Most of the hazardous materials storage tanks and potential exposure to hazardous materials come from military related issues. The Tijuana River Estuary may reconnect with San Diego Bay through Imperial Beach in the event of a 100-yr storm with 6.5 feet or more of sea level rise. This increases the coastal flooding impacts and sector vulnerabilities along the 8th Street north/south road alignment, which was the former Tijuana River channel that used to flow into the San Diego Bay.

Adaptation

- Armoring leads to loss of beach recreation and ecological value.
- Nourishment options are a potentially viable long-term choice, depending upon availability of sand, the cost of nourishment, environmental degradation, and community values.
- Short term, sand retention groins are slightly better than other options although part of this depends on the assumptions made on the width of the beach.
- In the medium term (through 2069), managed retreat and groins have similar net benefits in strict economic terms.
- Over the long run, managed retreat and groins yielded the highest net benefits with current (wide) beach width. With a narrower beach width, nourishment options yield higher net benefits.
- Armoring yields the lowest net benefits over the medium (2069) and long-term (2100) time horizons.
- The public benefits of recreation, the ecosystem services provided by beaches, as well as avoided construction costs, offset losses to infrastructure and private property.
- Public acquisition of vulnerable oceanfront parcels coupled with a lease back or rental option reaches a break even return on investment point after about 30 years.

Vulnerabilities by Planning Horizon

This vulnerability assessment is advisory and is not a regulatory or legal standard of review for actions that the City or the CCC may take under the California Coastal Act. This assessment provides the best available science, and is part of an ongoing process to understand and prepare for coastal hazards and climate change. ***It should be noted that these vulnerabilities assume that NO adaptation strategies have been implemented.***

The following is a summary of the resulting vulnerabilities organized by Planning Horizons for purposes of planning, implementation, monitoring, and adaptation:

2010 (Existing) Vulnerabilities

- Under existing conditions, only one of the hazardous material locations is within City's regulatory authority and the other is associated with the Naval Outlying Landing Field.
- No school buildings are susceptible to coastal erosion.
- Tidal Inundation already impacts many of the key storm water outlets that drain into the Bay and Estuary particularly during high tides.
- Nearly 800 feet of wastewater pipe is currently exposed to existing erosion hazards.

- 5 pump stations are currently vulnerable to coastal flooding.
- Presently, 1.7 miles of roads are potentially subject to coastal erosion from a 100-year wave erosion event.
- All of the beach accesses and oceanfront properties are in existing coastal erosion and coastal flood hazard zones associated with a 100-year wave event. From historic storm observations beach erosion of 50 to 150 feet in a single storm event is possible.

2047 Vulnerabilities

(~1.6 feet or 0.5 meter of sea level rise)

- The Carnation neighborhood north of Palm Avenue and the Seaside Point neighborhood becomes substantially more exposed to coastal flooding.
- Coastal erosion with 0.5 m of sea level rise could impact most of Seacoast Drive without adaptation measures.
- Six buildings associated with two of the elementary schools – West View and Bayside - become exposed to tidal inundation and coastal flooding.
- Significant increases in public transportation related vulnerabilities along bus routes along Seacoast Drive and the Bayshore bike path occur with 0.5 meters of sea level rise due to the expansion of potential erosion and flooding impacts.
- Potential erosion impact to oceanfront stormwater outfalls doubles from existing conditions.
- The stormwater pump station at Palm Avenue is exposed to potential coastal erosion.
- Erosion hazards potentially expose 1.2 miles of wastewater pipe and a sewage pump station.

2069 Vulnerabilities

(~ 3.3 feet or 1 meter of sea level rise)

- With 1 meter of sea level rise more than half of the stormwater drainages are impacted by tides at least 50 percent of the time.
- Nearly 20 miles of roads could be closed temporarily from coastal flooding impacts and 4.3 miles of road could be destroyed by coastal erosion. About 1.2 miles could be exposed to routine coastal flooding along the low-lying parts of town.

2100 Vulnerabilities

(~ 6.5 feet or 2.0 meters of sea level rise)

- Approximately 30% of all parcels could be exposed to coastal hazards with over 1500 parcels subject to episodic coastal flooding and 450 parcels subject to periodic tidal inundation. Combined damages from these two hazards are estimated at $72.6M.
- 594 parcels could be exposed to coastal erosion creating an estimated $106.8M in losses to public and private development.
- Approximately ~40% of the City roads could be vulnerable to coastal storm flooding. Coastal Erosion could destroy up to 5.4 miles of roads, virtually the entire length of Seacoast Drive. Tidal flooding exposes 4.3 miles of roads to routine flooding.
- Approximately 68 percent of the City bike paths, one-third of the bus stops, and 35 percent of the bus routes could be vulnerable to coastal storm flooding. Coastal erosion could potentially result in permanent loss closure of the bus and bike routes along Seacoast Drive. Tidal inundation will routinely close about a mile of bike path along the Bayshore bike path.
- All school buildings at West View and Bayside Elementary schools become exposed to periodic coastal flooding.
- The majority of the stormwater drainages will be impacted for the entire tide cycle, which in turn significantly increasing flood

depths and frequency as well as potentially introducing additional sources of flooding across the City through the drainage network.

- Coastal flooding affects 4.5 miles of the stormwater system and impacts more than half of the inlets. Coastal erosion could destroy over 1 mile of the stormwater system.
- Nearly 2.7 miles of wastewater pipe could be exposed to erosion hazards threatening the viability of the entire infrastructure and potentially exposing the community to raw sewage spills.
- 45 sewer manholes will be inundated by tides and 311 manholes subject to coastal flooding which would introduce additional water into the sewer system as well as posing risk to emergency responders during flood events.
- One of the wastewater pump stations becomes subject to routine tidal inundation.

Adaptation Strategies

None of the impacts identified in the vulnerability assessment considered the effect of adaptation strategies on reducing the extents of coastal hazards on the sector vulnerabilities.

The following are considerations and a list of policy and project specific adaptation strategies that the City could consider and implement to address the climate-induced hazards and related vulnerabilities.

Policy Approaches

The following represents the overall policy approaches based on the analyses completed in this report:

- Update the LCP policies and implementing ordinances and zoning. This effort should integrate Climate Action Planning, results from CURRV and the SD Bay Adaptation plan, and results of the Ecotourism Study into an overall set of policies and implementing ordinances that set a long term vision for the City.
- Recognizing the interrelated jurisdictional boundaries, it will be essential that the City participate in continuing regional dialogs related to coastal management, and climate change adaptation. The City can't adapt to climate change alone. The State, the County, SANDAG, the Port, City of Coronado, the Army Corps of Engineers, and the Navy must be partners.
- Adopt Hazard Zone Overlays based on the completed hazard mapping. The Hazard Zone Overlay would trigger the following:
  - Real estate disclosures for coastal and climate-induced hazards.
  - Triggers for a site-specific hazard report.
  - Building code revisions such as movable foundations.
  - Changes to building heights to accommodate additional freeboard elevation.
- Develop a Repetitive Loss Clause Program to allow properties to be downzoned over time to accommodate increased coastal flooding and related impacts.
- Revised the floodplain ordinance to name both a planner and an public works staffer as co-floodplain managers so that both perspectives are included in hazard reduction efforts.
- Develop a beach management plan to reduce hazards in the short term and accumulate sand on the beach using natural processes of wind transport.
- Promote outreach and education by providing signage depicting historic flooding depths and elevations.

Adaptation Project Approaches

These suggested approaches are based on the results of the economic and physical process analyses and provide some insights on the effectiveness of different approaches over time. The reality is that there are a wide variety of hybrid options that combine various aspects of various adaptation strategies into an overarching Adaptation Plan.

- The study's economic analysis indicates that armoring generally yields lower net benefits than other strategies, particularly in later time horizons. As sea level rise increases coastal erosion and other hazards, the beach is lost and armoring becomes a much less economically viable strategy.
- Over the midterm, the three strategies based on nourishment (including those with sand retaining groins and hybrid dunes) yielded the highest net benefits in many cases. The critical issue here is the availability of sand and the costs of dredging and placing sand on the beach. The ecological costs of nourishment were considered as part of this study, but a more detailed analysis is probably necessary before the City commits to a long-term nourishment strategy.
- In the midterm, managed retreat generally yielded significantly higher net benefits than armoring. If nourishment costs are high, managed retreat is a much more cost effective strategy.
- Over the long term, either nourishment or managed retreat is the most economically viable solution. The results depend on the viability and availability of sand for nourishment as well as the natural width of the sandy beach.
- Our analysis indicated that if the City wishes to construct a lease-back option, where it purchase property at risk and leases it back to the original owners (or someone else) the payback time is approximately 30-35 years. If the City decides to pursue such a strategy, more research on implementation mechanisms and community acceptance is needed.
- All of these strategies will require financing to administer. This study examined the lease-back option. It also examined changes in transient occupancy taxes and sales taxes. Our results indicate that armoring will substantially reduce the City's ability to finance these options since it leads to lower sales and transient occupancy taxes.

Potential Sector Specific Adaptation Approaches

The following section identifies adaptation strategies for additional consideration and are divided into potential Policy and Projects. For each sector adaptation strategy prioritized, there will be a need to be a higher level evaluation to make sure that individual adaptation measures work in a comprehensive manner to reduce vulnerabilities and not maladaptive, merely prioritizing one sector risk reduction at the expense of another.

Land Use

Policy

- Codify an increase to base floor elevation or movable foundation standards for new development.
- Develop real estate disclosure requirements to inform homebuyers of the risk of coastal hazards and sea level rise associated with living adjacent to the Pacific Ocean.

Projects

- Develop a phased long-term managed retreat plan.
- Require any abandonment or retreat to remove derelict or threatened structures.

Hazardous Materials

Policy

- Establish more stringent policies for timing associated with cleanup. The timing should be based upon projected exposure to coastal flooding and tidal inundation.
- Strengthen policies regarding storage for hazardous materials that would require additional elevation and containment.

Projects

- Cleanup or retrofit storage tanks prior to when coastal flooding impacts are projected to occur.

Public Transportation

Policy

- Develop alternative bike and bus routes further inland.
- Coordinate with SANDAG and San Diego Metropolitan Transit System to avoid vulnerable areas through the Regional Transportation Plan.

Projects

- Elevate critical roads including Seacoast Drive, Palm Ave, Imperial Beach Boulevard as well as the Bayshore bike path.
- Amend the City's Capital Improvement Plan to add additional inches to the lift in street resurfacing to gain elevation at the pace of sea level rise or greater.

Schools

Policy

- Evaluate alternative school locations for the West View and Bayside Elementary schools.
- Include language in policy updates to consider sea level rise and flood hazards in the renewal of any future school leases.

Projects

- Remediate contaminated soils at Bayside Elementary.
- Evaluate a horizontal levee[3] option to increase flood protection capacity at both schools and provide some vertical habitat transgression opportunities for areas exposed to bay and estuary side flooding.

Stormwater

Policy

- Increase base floor elevation of new development to reduce potential stormwater flood impacts.
- Revise stormwater policies in the LCP, Capital Improvements Plan, and General Plan addressing sea level rise and future decline in conveyance.

Projects

- Conduct a stormwater system analysis that examines alternative pump locations, capacity, and expanded conveyance.
- Add flap gates after expanding capacity.
- Develop stormwater retention basins that allow for reuse or release once tides drop to levels less restrictive to discharging stormwater.

Transportation

Policy

- Develop alternative major roads.
- Work with Caltrans and SANDAG on SR-75 exposure and vulnerability issues.
- Investigate phased long term abandonment of South Seacoast Dr.

Projects

- During the short to medium term Consider elevating critical sections of roads including Seacoast Dr., Palm Ave, Imperial Beach Blvd.
- Amend Capital Improvement Plan to add additional inches to the lift in street

[3] See discussion on page 5-8

resurfacing to gain elevation at the pace of sea level rise or greater.

Wastewater

Policy

- Encourage regional dialog about the future location of the sewer network or possible tie into to an upgraded TJ plant.
- Add policy language to require relocation or avoidance of wastewater hazards to the extent possible.

Projects

- Relocate pump stations and pipe segments susceptible to coastal erosion. Prioritize sections by timing of impact.
- Conduct advanced maintenance to keep pipes clear.
- Recommend flood proofing pump stations.
- Retrofit manholes to reduce flood waters into sewer system.

Monitoring

The City would benefit from working with researchers, SANDAG and regional adaptation partners to monitor the coast. As appropriate, development projects, coastal development permits, LCPs, and other planning updates should incorporate an adaptive management framework with regular monitoring, reassessments, and dynamic adjustment in order to account for uncertainty. Examples include monitoring the following:

- Monitor physical environment to identify when the City is nearing thresholds.
- Monitor inland extent, duration and depth of inundation and coastal flooding at key low lying areas around the City particularly along South Seacoast Drive, Carnation Avenue, Seaside Point, the impacted elementary schools and the Bayshore bike path.
- Collect and study beach profiles to understand variability in sand supply, alongshore sediment transport and erosion.
- Monitor beach elevations and widths around coastal armoring structures to determine impacts on elevations and the narrower beaches. Compare with elevations and beach widths at nearby or adjacent unarmored control sites such as the beach fronting the TRNERR or those few unarmored parcels. This monitoring will help to identify when there is an impact on beach elevations (and thus ecology and ESHA) and lateral access.
- Conduct structural monitoring to understand the condition of existing structures and when maintenance or replacement will be required.
- Monitor sea level rise trends from local tide stations.
- Stay current on climate science related to sea level rise, wave climate, precipitation, wildfire, and temperature.
- Monitor pre-and post-storm monitoring—erosion extents, high water marks, and inland locations of flooding.
- Develop a routine monitoring of underground tanks testing for elevated groundwater and salinity that may increase the corrosion of the tanks and spread the hazardous materials beyond the parcel boundaries.
- Monitor the groundwater levels and salinity levels to understand the impact of both on sewer capacity.

Positive Findings

Although climate change and its related impacts present challenges for the future, it is not without hope. Some positive findings are as follows:

- Tidal inundation has a very small impact under existing conditions, but impacts escalate dramatically between 1 and 2 meters of sea level rise.

- No tanks or hazardous material storage sites are exposed to coastal erosion hazards, even with 2 meters of sea level rise.
- Emergency services except for the Lifeguard headquarters are outside of the coastal hazards zones.

8. Discussion – What's next?

Next steps for the City include a variety of actions, including integrating this information into LCP revisions and continued coordination with regional adaptation partners and research institutions, such as TRNERR, Cities of Coronado, Chula Vista, the Port of San Diego, SANDAG, the Navy, regional utility providers, the San Diego Regional Climate Collaborative and others based on the discussion of favorable adaptation strategies and implementation mechanisms contained in this report.

At the City level, there are many adaptation pathways through which the City can successfully adapt over time and reduce vulnerabilities including the implementation of various policies, plans, programs, and projects.

One of the best tools for the City to begin developing and implementing adaptation strategies is to certify policy and regulatory language within the LCP. This process with the Coastal Commission, which applies the California Coastal Act at the local level, allows the City greater flexibility in decision making. The City recently received grant funding from the CCC to develop revised policies and regulations.

Implementation of adaptation strategies in the LCP typically involve policy modifications for land use plans and regulatory permit conditions that focus on avoidance or minimization of risks and the protection of coastal resources. Example strategies may include:

- Requiring proposed projects to anticipate longer-term impacts in design;
- Consideration of whether critical infrastructure will be able to withstand the increased exposure to floods, waves, erosion, and/ or storms; and/ or
- Rezoning hazardous areas as open space.

It's important that all strategies are adaptive so that future changes in hazard risks can be effectively incorporated into long-term resource protection. In most cases, especially for LCP land use and implementation plans, multiple adaptation strategies will need to be employed. This section provides an overview of general categories of adaptation planning measures, ranging from soft "nature-based" or "green" measures to "hard" or "gray" engineering measures.

Implementation of adaptation strategies can occur many different ways and are discussed in the following sections. Below is a list of the pathways to implementation but is not an exhaustive list, as there are numerous vehicles for implementation that should be explored as the City moves forward with adaptation planning. Using this list of adaptation strategies as a foundation for discussion, the City of IB will now need to determine what adaptation strategies to implement by evaluating what actions: (1) support the community's vision for the future, (2) address the specific risks outlined in the vulnerability assessment; and (3) align with California Coastal Act requirements.

Note: Where applicable, the corresponding California Coastal Act Sections have been referenced. The actual implementation of these policies and regulations may vary based on a variety of factors, including applicable policies and location or project-specific factors that may affect feasibility.

8.1 Policies, Plans, & Programs

City of Imperial Beach Local Coastal Program

The City's LCP has an important role to play in adaptation planning. The Land Use Plan lays out the policy framework for addressing all planning and permitting that occurs within the coastal zone. Updating the LCP would enable climate change, adaptation, climate action planning, ecotourism priorities to be programmed into the guiding principles and policies whereas the Implementation Plan provides site-specific regulatory implementation language upon which permit decisions are reviewed against. The policies, along with implementing language, can influence the level of consequence from climate change impacts and guide the approach to reducing vulnerabilities over time into the future.

Example: Require new development to avoid coastal flood hazards in the Local Coastal Program.

In order to minimize the adverse effects of sea level rise, flooding, and storms, it is important to carefully consider decisions regarding areas vulnerable to flooding, inundation, and erosion.

It is important to avoid permitting any significant new structures or infrastructure that will require new coastal armoring or flood protection from sea level rise, coastal flooding, or coastal erosion during the expected life of the structure. This should include careful long-term consideration of extending routine maintenance of existing levees or other protective measures.

In some instances it may be better to rezone or acquire properties that are in hazardous areas. If the City permits development that will require new protection during the expected life of the new project, the City should consider requiring that the project proponent:

- Minimizes risks through siting, design and engineering.
- Requires viable funding sources for building, monitoring, and maintaining the new sea level rise protections. This should include a performance bond to repair, maintain, or remove the structures if they become public nuisances.
- Requires that any new development must consider how risk changes over time.
- Requires that actions to reduce risk in the short-term do not increase risk in the long-term (no maladaptation).
- Designs protection in a manner that maximizes conservation of natural resources and public access.

Example: Provide policy and regulatory triggers for relocation and removal of structures in the Local Coastal Program.

As part of a LCP update, it is beneficial that policies incentivize early adopters of adaptation strategies as well as identify triggers for implementing additional safeguards for elevating new or redevelopment structures, or for relocation and removing structures once they are threatened or suffer repetitive losses.

Example: Develop and adopt a Transfer of Development Rights Program within the Local Coastal Program.

An LCP may establish policies to implement a Transfer of Development Rights (TDR) program to restrict development in areas vulnerable to sea level rise and allow for transfer of development rights to parcels with less vulnerability to hazards. A TDR program can encourage the relocation of development away from at-risk locations, and it may be used in combination with a buy-out program. A TDR program could also be used to promote other smart planning principles such as infill development and mixed uses.

City of Imperial Beach Capital Improvement Program

The Capital Improvement Program (CIP) allows the City to identify the needs of the community and to prepare a roughly 5-year funding strategy to meet those needs. The CIP includes any project that involves needed repairs or improvements to existing infrastructure (streets, parks, city facilities, etc.) and the acquisition or construction of new infrastructure. It is intended to address infrastructure needs associated with both existing and future development identified in the General Plan. The CIP is intended to address infrastructure needs associated with both existing and future development identified in the General Plan. Currently, the CIP does not have any discussion of climate change impacts, which limits the City's ability to proactively fund adaptation measures before the City experiences the consequences of climate change.

Example: Protect critical infrastructure contained in the Capital Improvement Program.

It's beneficial to set aside General Fund funding through the CIP for an on-going program to address the most critical infrastructure issues. Then an annual list outlining infrastructure improvement projects would ensure that the most critical needs are funded.

Within the CIP, a Critical Infrastructure Protection Plan should be developed, which is a strategy to make critical infrastructure more resilient. It can include both buildings (e.g., schools, town halls, etc), and also physical facilities such as roads, storm drains, potable water pipes, or a sewer collection system. Critical infrastructure must be designed, located, and sufficiently protected to remain operational during hazard events and emergencies, including floods, wildfires, high winds, and severe weather. A diminished or vulnerable critical infrastructure system will greatly impede a whole community's ability to withstand or recover sooner from hazard events.

To make these facilities more resilient requires taking actions that remove risk to physical infrastructure. In terms of buildings, examples include: relocation; elevation of the building above the base flood elevation; dry proofing and wet flood proofing; fire-resistant building materials; and, in some cases, engineered solutions such as levees and floodwalls.

In terms of hardening capital facilities, examples include:

- Double sleeving water pipes,
- Elevating roadways prone to flooding,
- Expanding the capacity of stormwater culverts,
- Removing physical impediments that restrict water flow in rivers and floodplains, and

Elevating key electrical equipment and generators.

2016 (in prep) San Diego County Multi-Jurisdictional Hazard Mitigation Plan

The 2016 San Diego County Multi-Jurisdictional Hazard Mitigation Plan (HMP) update was led by the County Office of Emergency Services. The HMP was prepared with input from the City, and with the support of the State of California

Governor's Office of Emergency Services and FEMA. It is the HMP's intent that the plan will be used as a tool for stakeholders to increase awareness of local hazards and risks, while at the same time providing information about options and resources available to reduce those risks. The City involvement and input into the HMP provides an opportunity to identify flood risk reduction projects and approaches which would then qualify the City for federal funding should a natural disaster occur.

This is an important pathway through which the City can fund adaptation on the local level but requires multiple City departments to partake in the updating of the HMP. City involvement in the HMP is codified in the floodplain ordinances in the City Zoning and LCP. One option that may help link local adaptation to the HMP would be if the City floodplain ordinance required both a public works staff member and a planner to engage in the HMP update process.

Beach Management Plan

A beach management plan is typically a certified plan that outlines certain management actions and allows specific activities on the beach. Such management actions can include beach contouring, beach wrack (kelp) management, bonfire management, woody debris management, sand fencing, and storm berm grading. Currently the City doesn't have a beach management plan, although the public works staff and the tidelands maintenance staff do implement many of these actions independently. A Beach Management Plan would help the City to leverage ongoing management actions and ensure that they are strategically considering adaptation.

Sediment Management Plan

A sediment management plan would provide the City with a systems approach to deliberately manage sediments in a manner that maximizes natural and economic efficiencies for shoreline maintenance. This Program would accomplish the following:

- Recognize sediment as a valuable resource;
- Outline implementation strategies across multiple projects and business lines to guide investments to achieve long-term economic, environmental, and social value and benefits; and
- Enhance relationships with stakeholders and partners to better manage sediments across a region (local actions with regional benefits).

Imperial Beach is participating as a SANDAG member agency in the development of the first Regional Coastal Sediment Management Plan. The Management Plan builds upon what has been developed for the California Coastal Sediment Management Master Plan, which has a goal of developing a process that facilitates the management of sand on a regional basis. The Regional Management Plan is a guidance and policy document that will discuss how management of sediment targeted at coastal erosion can be implemented in an expeditious, cost-effective, and resource-protective manner throughout the San Diego region.

It is also recommended that the City coordinate with TRNERR. Given that the beach is ecologically and economically important to the City, developing a Sediment Management Plan (SMP) in partnership with TRNERR may help both jurisdictions identify opportunities for how sediment in the River Valley can be managed in a mutually beneficial way. A plan of this nature will ensure beneficial reuse of excess sediment entering the River Valley from Mexico providing the City a pathway to enhance ecosystem services provided by living shorelines and ensure resilient beaches into the future

Opportunistic Sand Placement Plan

The City in concert with SANDAG should participate in another Sand Compatibility and Opportunistic Use Plan for implementing opportunistic beach replenishment. The Plan should contain beach fill processes of receiver site selection, material identification, testing protocols, implementation, and monitoring. The goals of the Plan should be:

- Improve protection to coastal structures, and enhance beach recreation opportunities and environmental habitats;
- Establish a process approved by regulatory agencies for environmentally-responsible use of opportunistic materials to nourish a pre-established receiver site(s) when those materials become available;
- Promote a clear vision of the type of testing and monitoring needed before, during and after construction; and
- Develop standardized methodologies for establishing compatibility between potential sources and receiver sites and the use of optimum and less-than-optimum source sands.

8.2 Policy Implementation

Real Estate Disclosures for Coastal Hazards

This policy strategy requires that upon any real estate transaction, buyers of properties in the coastal hazards zones are made aware of the potential hazards to their property. This disclosure informs buyers that they may face such hazards as erosion, coastal flooding, inundation, wildfire, or flooding as a result of climate-induced impacts, such as sea level rise. This type of real estate disclosure would be similar to the flood insurance disclosure which is already part of hazard disclosures if a property within a creek flood hazard zone is bought or sold. The education of landowners and potential buyers is important to understanding the risk of owning property in a hazardous area and provides some liability protections for the local jurisdiction.

Zoning and Building Code Revisions

This approach involves agencies incorporating flexibility into building codes to help adapt to changes in climate. This may include:

- Limiting development in flood or erosion-prone areas;
- Using movable foundations;
- Requiring materials and foundations that are resistant to hazards such as wave velocity, fires or extreme wind;
- Updating height restrictions by freeboard elevation, which would allow buildings to be raised for flood protection purposes; or
- Revising the grading ordinance to reflect sea level rise projections.

Coastal Hazard Zoning Overlays

This policy measure identifies areas that are vulnerable to a set of specific hazards, perhaps using the hazard maps generated by this report. Within each hazard zone, there can be a restriction on the types of development (e.g., residential, or commercial), a basis for setback lines, and/ or triggers for site-specific technical analyses or studies (e.g., geologic report triggers, slope stability analysis).

The mapped Coastal Flood Hazard Zones from this report can help inform an LCP update, and, more specifically, ensure updated land use and zoning requirements are designed to minimize risks from sea level rise in the identified coastal flood hazard zones. If adopted, Coastal Flood Hazard Zones can trigger the following:

- Real Estate disclosures for coastal and climate-induced hazards;
- Triggers for a site-specific hazard report;
- Building code revisions, such as movable foundations; and
- Changes to building heights to accommodate additional freeboard elevation.

Example: Require redevelopment strategies to reflect sea level rise/coastal flood hazards.

This would require modifying the applicable building codes to enable structures to withstand higher water levels within the City's Coastal Flood Hazard Zones. For example, development and redevelopment in the City's

Coastal Flood Hazard Zones may require:

- Additional setbacks,
- Increased base floor elevations,
- Limited first floor habitable space,
- Innovative stormwater management systems,
- Special flood protection measures,
- Mitigation measures for unavoidable impacts, and
- Relocation and removal triggers and methodologies.

Some of these changes may require a change in the maximum building height.

Downzoning for Coastal Hazards

Downzoning is the process by which an area of land is rezoned to a usage that is less intense than its previous usage. This is typically done to limit sprawl and overgrowth of cities; however, it can also be applied in cases where hazards are present in order to lessen the amount of damage during a flood or similar event. However, the downzoning strategy cannot be considered in conjunction with the managed retreat option per AB 2292 (Dutra – Government Code Section 65863).

A federal program that is being currently offered is the FEMA Repetitive Loss Program. Through the Flood Insurance Reform Act of 2004 (FIRA 2004) residential property owners are given insurance premium reductions for mitigation projects that reduce future flood losses through:

- Acquisition or relocation of at-risk structures, and conversion of the property to open space;
- Elevation of existing structures; or
- Dry flood proofing of historic properties.

From 1968 to 2010, the City of Imperial Beach had 3 properties that have filed 7 claims against the National Flood Insurance Program.

By developing a Repetitive Loss Clause Program as part of an LCP update, properties would be rezoned over time to accommodate increased coastal flooding and related impacts. If a building has been severely damaged or repeatedly flooded, a City can designate the property as "substantially damaged" or a "repetitive loss property." The property owner is then required to rebuild it in a flood-safe way, which usually means elevating or moving the structure.

Through the Flood Insurance Reform Act of 2004, Congress directed FEMA to develop a program to reduce future flood losses. The Severe Repetitive Loss Grant Program makes funding available for a variety of flood mitigation activities. Under this program, FEMA provides funds to state and local governments to make offers of assistance to the National Flood Insurance Program–insured repetitive loss residential property owners for mitigation projects that reduce future flood losses through:

- Acquisition or relocation of at-risk structures and conversion of the property to open space;
- Elevation of existing structures; or
- Dry flood proofing of historic properties.

8.3 Projects: Protect, Accommodate, or Relocate

Protect

Seawalls or Revetments

A seawall or revetment is a structure separating land and water areas, primarily designed to prevent erosion and other damages caused by wave action. A seawall is usually a vertical structure made of wood or concrete, while a revetment is a pile of rock built at a stable angle with enough weight of the armor stone to withstand erosive wave forces (Photo 5-1) he City LCP currently allows the construction of vertical seawalls on private property. As revetment maintenance costs escalate in time, removal of nuisance structures should be considered or a timeline for replacement of a revetment with a seawall should be specified.

Groins

Groins are structures built perpendicular to the beach with the objective of capturing or retaining sand (Photo 2-5). Sand capture occurs as sand is transported alongshore by the waves. When the sediment being transported alongshore encounters the groin, the currents and sediment are diverted offshore into deeper water where the currents slow down, depositing much of their sediment load. Existing groins in the City appear to be undersized to retain the sand, and the current alignment due west, causes some issues with cross shore transport occurring during west swells that mobilize sand and move it offshore and out of the groin containment area.

Artificial Reefs/Submergent Breakwaters

The artificial reef (submerged breakwater) is a variation of the common shore-parallel emergent breakwater in which the structure crest is below the surface. The artificial reefs can cause waves to break offshore, dissipating the wave energy. While they have some benefits because of their low aesthetic impact, enhanced water exchange, and recreational benefits (e.g., fishing, surfing, diving), they become less effective when the water over the crest deepens. Unfortunately, this is a result of storm wave events and sea level rise. This is not likely to be an effective long term solution.

Beach Nourishment & Sediment Management

Sediment is nature's natural defense resource. This form of protection management uses different types of sediment to mitigate the impacts of rising seas. This form of soft protection either augments or alters where sediment accumulates. By replenishing or mimicking natural buffers or elevating land, habitats are less vulnerable to flooding, King Tides, and erosion. Sediment management can occur at a variety of scales, including changes in dredged sediment disposal, opportunistic sand placement from upland sources, and/ or offshore mining from the seafloor.

Nourishment can also differ based on where the sediment is placed. Historically in Imperial Beach sand has been placed directly on the beach and shaped by a bulldozer before allowing the natural wave processes to equilibrate the sand. Another option would be to place the sediment into nearshore sand bars just offshore of the beach where wave action can sort the sand and during long period wave energy move the sand back onshore.

Other placement options such as the nearshore placement may avoid some of the previously observed complications with backshore ponding and seepage flooding. Placement of sand farther north in Imperial Beach may also reduce the role that the nourished sand may have had in contributing to a closure of the Tijuana River mouth in 2016.

Our analysis in section 6 indicates that the net benefits of nourishment depend critically on the cost and availability of sand over time. In the SANDAG nourishment projects a hopper dredge was hired to pump sand on a number of beaches. The costs of dredging sand depend on how close a "borrow" site for sand is from the beach. If the dredge needs to go farther to obtain sand, costs increase. Even if sand is available, environmental and permitting issues may raise the costs of obtaining sand. Finally, the "mobilization" costs of moving a hopper dredge (often from the Gulf of Mexico) are quite high and it's typically more cost-effective if numerous nourishment sites are lumped together, as in the SANDAG nourishment projects. The City may want to consider opportunities for regional cooperation, such as the SANDAG project, in its future plans.

Accommodation

Elevation or Structural Adaptation

Structural adaptation is the modification of the design, construction, and placement of structures sited in or near coastal hazardous areas to improve their durability and/or facilitate their eventual retreat, relocation, or removal. This is often done through the elevation of structures, specific site placement, and innovative foundation construction. These can be implemented through revisions to the Building Code.

As part of this analysis we assumed that the retrofit costs of elevation is $250 per sq. ft. for structures (ESA, 2015). As indicated in Table 7-1 below, the total retrofit cost of elevating is quite high, ranging from $198 million in 2047 to $385 million in 2100. However, our analysis of the total losses from tidal and event flooding are significantly lower (less than $100 million) in all time horizons, indicating that retrofitting structures is not cost effective. However, there are a variety of other means to improve construction standards and building codes to encourage elevation of structures in hazardous areas.

Table 7-1 Retrofit Costs of Elevating Structures in Flood Zones

	Elevated Sq. Ft.	Total Cost
2047 (0.5 m)	791,630	$197,907,500
2069 (1.0 m)	1,039,031	$259,757,750
2100 (2.0 m)	1,539,025	$384,756,250

Example: Retrofit existing transportation infrastructure as necessary and in consistency with the Capital Improvement Program.

Transportation infrastructure is essential for both people and commerce, in daily life as well as in times of emergency: a city's transportation system is often inextricably linked with the effectiveness of its emergency response. Capital investment adaptation consists of measures such as:

- Retrofitting existing infrastructure that is susceptible to climate change (e.g., installing pumps to reduce flooding of vulnerable facilities), and
- Construction of permanent barriers to lessen the exposure of transport systems to water and wind.

During construction, the City can "build once" to a higher standard, rather than to build to lower standards initially and then be forced to retrofit later. Examples of this include the following:

- Increasing bridge clearances to accommodate higher water levels; and
- Increasing design specifications for culvert diameters;

These approaches can be combined with non-motorized transportation options, such as bicycle paths and pedestrian walkways, to reduce greenhouse gas emissions and achieve public health benefits.

Example: Retrofit or relocate sections of the California Coastal Trail and Bayshore Bikeway

This can be accomplished through the use of boardwalks, bridges, and/or other design features to maintain continuity of the California Coastal Trail and Bayshore bike path in sections that are vulnerable to coastal hazards. Some sections will need to be relocated or elevated over time. The maps in Appendix 1 identify vulnerable sections of the California Coastal Trail and the City through its LCP or other policies should establish a phased approach to relocate or elevate sections of the trail in such a way that is consistent with provisions of the Coastal Act and requires that the trail remains within sight, sound, or smell of the sea.

Example: Incorporate sea level rise into calculations of the Base Floor Elevation

As part of updating of the building codes, adding in additional freeboard that is related to the projected sea level rise for the determined life of the structure, or adding more stringent and stable foundations will allow near ocean front properties to be elevated above future coastal flood exposure and more resilient to wave velocity impacts on the foundations.

Example: Maintain public access at street ends

In terms of implementing the Coastal Act, there are two basic types of public access: vertical access (i.e., access to the shoreline), and lateral access (i.e., access along the shoreline). Imperial Beach has developed an extensive system of access points to the ocean beaches and the San Diego Bay.

Virtually all of the Pacific Ocean shoreline beaches are public and the bay is accessible via public beaches, parks, shoreline trails, walkways and boardwalks. The City is dedicated to ensuring new development, causing or contributing to adverse public access impacts, provides easements or dedications in areas where public access is inadequate.

As part of an LCP update, it would be beneficial for the City to conduct an extensive review of its Shoreline Street Ends and, in consultation with the Port of San Diego and the California Coastal Commission draft a work plan to help the City achieve the following goals:

- Improve shoreline access and enjoyment;
- Protect views;
- Maintain and enhance shoreline habitat;
- Encourage community stewardship;
- Support maritime and other related coastal-dependent industry; and
- Manage private permits.

Throughout this process, it would be beneficial for the City to examine restricting the nature and extent of improvements that may be installed over public rights of way on the oceanside of beachfront residences and to preserve the City's right to utilize oceanfront street easements for public projects.

Natural Infrastructure

Also called "living shorelines," natural infrastructure reduces vulnerabilities by supporting the physical processes that support habitat creation, including coastal habitats such as dunes and wetlands. The maintenance of these physical processes allows habitats to evolve and is compatible with anticipated climatic and environmental changes. This measure and related policies are intended to maintain landscape connectivity, which can provide habitats room to transgress and evolve. Examples include sediment management that mimics natural sedimentary processes and vegetation restoration. Often natural infrastructure will be integrated into the design of "grey" infrastructure (e.g., seawalls, revetments) to maximize the benefits of and minimize the cons of both "grey" and "green" adaptation approaches when installed independently (e.g., horizontal levee). As with many options there are hybrid versions of these types of adaptation strategies that warrant consideration and additional investigation.

Passive Beach Dewatering

Passive beach dewatering involves the use of tubes placed in the beach, which help to lower the beach groundwater and increase natural sediment accretion. It works on the premise that when waves run up a dry beach, the ocean waves carrying sand will infiltrate into the sand and deposit the sand on the beach. During dropping tides this deposition does not work because the beach is saturated, so the sand is picked up off the beach and carried offshore. By drying the beach, natural deposition is increased. This has never been tried in California and thus is a rather scientifically uncertain approach, but it has been successful in other international locations. The characteristics for successful experiments elsewhere have included a high tide range, mixed sand grain sizes, and high sediment transport. Imperial Beach has all of these geomorphic characteristics. As a low cost adaptation option, it may be worth experimenting and monitoring in the near future.

Relocation

Phased relocation refers to the gradual removal or relocation of structures and infrastructure away from unstable erosion or flood -prone areas. This allows shore migration and mitigates coastal hazards by limiting, altering, or removing development in hazardous areas. This measure can be implemented in a number of ways through policy options and financial incentives.

Setbacks

Setbacks are commonly used to place development farther away from coastal hazards. This is typically done by calculating some average annual erosion rate into the future. Presently, Imperial Beach does not have any setback policies from the ocean. In absence of setbacks the Coastal Commission often utilizes a stringline policy in which development, decks, coastal armoring is placed in the same line so as to not further encroach on the beach or get closer to coastal hazards. Setbacks are often fraught with challenges since once development is permitted with setbacks, then after the setback distance is eroded through then the eventually threatened development typically applies for a coastal armoring permit under the "existing development" clause in the Coastal Act.

Transfer of Development Rights Program

This program involves transferring development rights from parcels near hazardous areas, such as the coast, to parcels that are further away from the hazard and can therefore accommodate development better, such as a more inland location. Often there is an incentive for this relocation such as increased density or relaxation of building heights. This strategy can be used to incentivize and encourage private property development away from hazardous areas.

Fee Simple Acquisition

Fee simple acquisition is the purchase of vacant or developed land in order to prevent or remove property from the danger of coastal hazards such as erosion or flooding. One such example of this adaptation strategy is to purchase properties at risk and to demolish structures and restore habitats and physical processes, as has been done in Pacifica, California. A hybridized version of this adaptation strategy may be a public acquisition program in which an entity purchases the hazardous property and then leases the land back to the previous landowner with the deed restriction and understanding that when the structure or parcel is damaged that the lease may expire.

Figure 7-1 below provides our estimate of the payback time for fee simple acquisition if the property is leased out to the existing owners—or a new tenant. Our analysis assumed that the City of Imperial Beach could finance a buyback using municipal bonds at a rate of 2.5% a year, which is in line with current market rates for California Municipal Bonds.

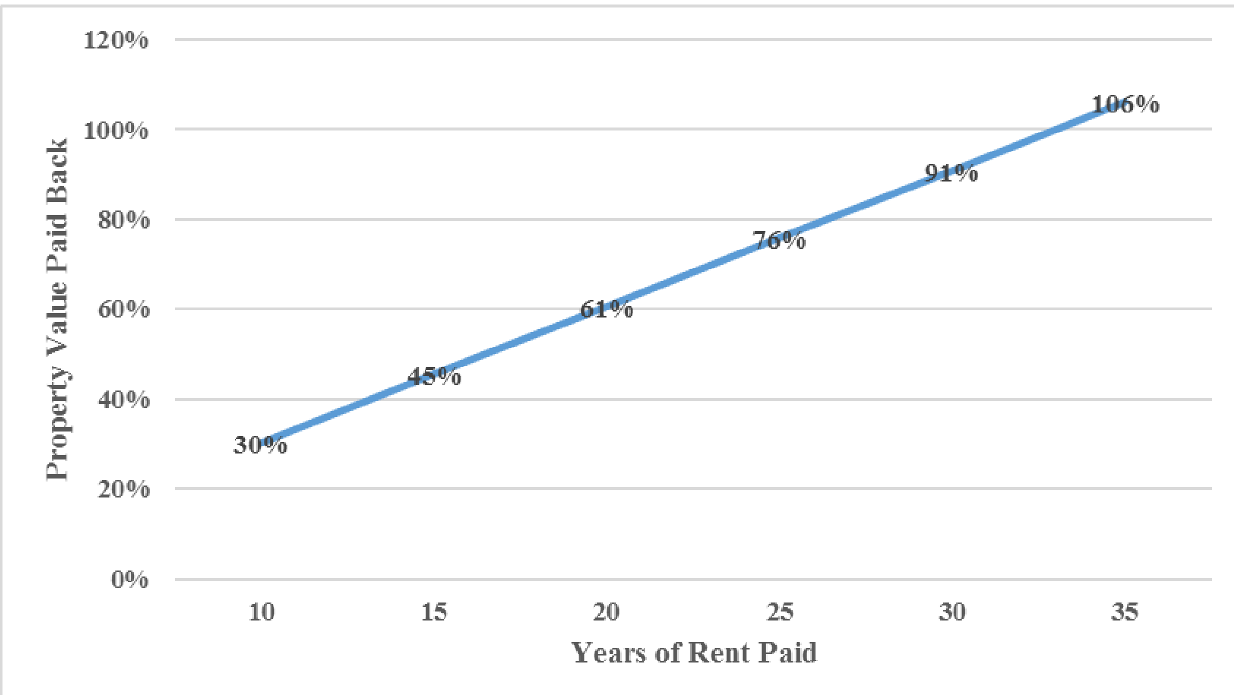

Figure 8-1. Length of Time for Rent to Pay Back the Property Value

In many ways figure 7-1 is analogous to a mortgage payback. The longer the leaseback period, the longer the period of time that the property can be paid off. Our analysis here uses a standard industry metric—the ratio of rents to the value of the residential property— to approximate the total revenue that one could obtain from leasing back these properties.

Our analysis indicates that if a lease-back period is long enough, in this case approximately thirty years, (same length of time as many mortgages) then the City of Imperial Beach may be able to finance a lease-back without burdening taxpayers (though the City may have to assume some liability if the bonds are not paid off).

Rolling Easements

The term "rolling easement" refers to a policy or policies intended to allow coastal lands and habitats, including beaches and wetlands, to migrate landward over time as the mean high tide line and public trust boundary moves inland with sea level rise. Such policies often restrict the use of shoreline protective structures, limit new development, and encourage the removal of structures that are seaward (or become seaward over time) of a designated boundary. This boundary may be designated based on such variables as the mean high tide line, dune vegetation line, or other dynamic line or legal requirement. In some cases, implementation of this can be through a permit condition (such as the "no future seawall" limitation) or purchased at a substantial discount (such as purchasing the land between the MHW boundary and the dune vegetation line or MHW boundary plus 5 feet so the policy can adjust with sea level rise).

Conservation Easements

A conservation easement is a legally enforceable agreement attached to the property deed between a landowner and a government agency or a non-profit organization that restricts development or certain uses "for perpetuity," but allows the landowner to retain ownership of the land. The allowable uses for this easement could be structured to allow flooding or erosion processes to occur.

8.4 Financing Implementation

FEMA's Hazard Mitigation Assistance

As there is overlap between LCP planning and Local Hazard Mitigation planning, FEMA's Hazard Mitigation Assistance grant programs provide significant opportunities to adapt by reducing or eliminating potential losses to the City's assets through hazard mitigation planning and project grant funding. Currently, there are three programs: the Hazard Mitigation Grant Program, Pre-Disaster Mitigation, and Flood Mitigation Assistance.

Coastal Hazard Abatement Districts

Coastal Hazard Abatement Districts (CHADs) provide a potential means for future renovations or improvements to flood control structures, including future alterations that may be necessary because of sea level rise. By accumulating a funding reserve for future maintenance and rehabilitation, a CHAD can provide the financial resources necessary for potential future expansion, maintenance or repairs of flood or erosion control structures. Further, because of the relative safety of CHAD revenues (CHADs are typically financed through the collection of supplemental tax assessments), CHADs can borrow from lenders or issue bonds with very attractive credit terms.

Infrastructure Financing Districts

California has recently passed a bill in September 2014 allowing cities and other entities to create enhanced infrastructure financing districts; this allows incremental property tax revenues to be devoted to a specified purpose such as a fund for cleanup, or infrastructure, parks and open space, transportation, things that could be applied to a variety of adaptation approaches. With the passage of Assembly Bill 313 and Senate Bill 628, the requirements for establishing these districts have been streamlined. The intent of this bill was to fill the local funding void left by the dissolution of the redevelopment agencies. Basically an Economic Infrastructure Financing District is set up, develops a business plan with priority projects (e.g. infrastructure, adaptation, etc), then can draw funds from changes in local tax revenues occurring as part of a redevelopment or rezone or apply for grant funds. For more information see http://www.eifdistricts.com/

Innovative Structured Fees

Certain structured fees could be established to generate revenues for 1) covering the necessary planning of, technical studies for, design of, and implementation of adaptation strategies or 2) developing an emergency cleanup fund to be able to respond quickly and opportunistically following disasters. Disasters, through a different lens, are opportunities to implement changes.

Sand Mitigation Fees, Public Recreation Impact Fees and Ecosystem Damage Fees

There are two structured fees that the CCC currently uses to address the impacts of coastal armoring—sand mitigation fees and a Public Recreation fee that the Coastal Commission is considering on a pilot program basis for the City of Solana Beach (City of Solana Beach LCP Amendment No. LCP-6-SOL-16-0020-1 (Public Recreation Impact Fee Study). The sand mitigation fee is a fee intended to mitigate for the loss of sand supply and loss of recreational beaches in front of coastal armoring structures. The Public Recreation Fee addresses impacts to the loss of recreation based upon the loss of beach area described as (1) Initial Area and (2) theoretical 20-year Bluff Retreat Area. The Coastal Commission may be considering a relatively new ecosystem damage fee. The ecosystem damage fee is intended to provide mitigation funds to restore damages to coastal habitats from the development. These could be to restore rocky intertidal habitat, sandy beach and dune habitat, or wetland habitats.

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Appendix A. Sector Profile Results

This appendix contains sector profiles that summarize the findings and recommendations that can be used in future decision-making. Each sector has its own profile, complete with a vulnerability map and 2-page description of findings for ease of communication. The vulnerability maps contain a combination of the existing and the projected future coastal hazards.

They are as follows:

A. Land Use
B. Roads
C. Public Transportation
D. Wastewater
E. Stormwater
F. Schools
G. Hazardous Materials

Land Use and Structures

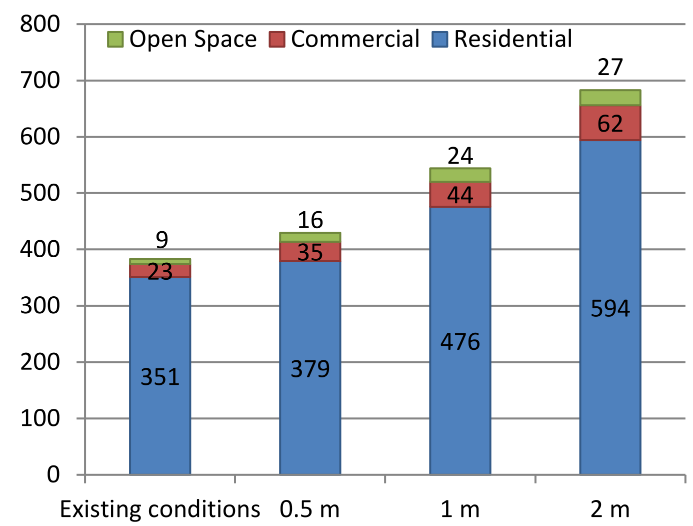
Overview

There are **14** land use categories within the City of Imperial Beach, which were categorized into **three (3)** distinct land use types. Land uses were categorized into (1) residential, (2) commercial, and (3) open space (and public facilities). (See Section 4.4 for more detail on hazard model assumptions).

The following measures of impacts were identified to quantify the impact of coastal hazards and climate change on land use and structures:

- Parcels by land use type;
- Number of structures and square footage.

Coastal Erosion (Number of Parcels)



Coastal erosion analysis consisted of a sea level rise and a 100-year wave erosion event. Note that the erosion model developed by the Dept. of Defense assumed that existing coastal armoring failed and did not stop erosion.

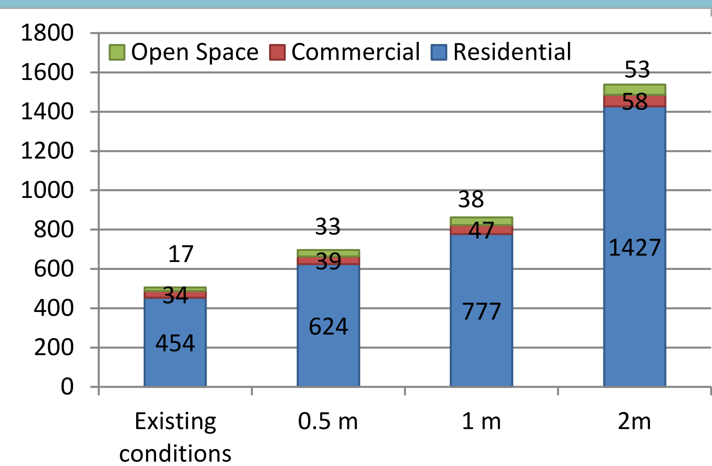
Erosion results show a steady increase in the number of parcel and structures impacted. The majority of impacts are to residential parcels located along Seacoast Drive. Commercial assets impacted include the businesses located along Sea Coast Drive, including the visitor-serving Pier South and other coastal tourism businesses. Many of the parks along the oceanfront are also impacted.

By 2100 with 2.0 meters of sea level rise, erosion could impact up to 3 parcels inland from the shoreline.

Economic Vulnerabilities:

2047 (0.5 m)	$77,745,256
2069 (1.0 m)	$88,575,388
2100 (2.0 m)	$106,775,246

Coastal Flooding (Number of Structures/Buildings)

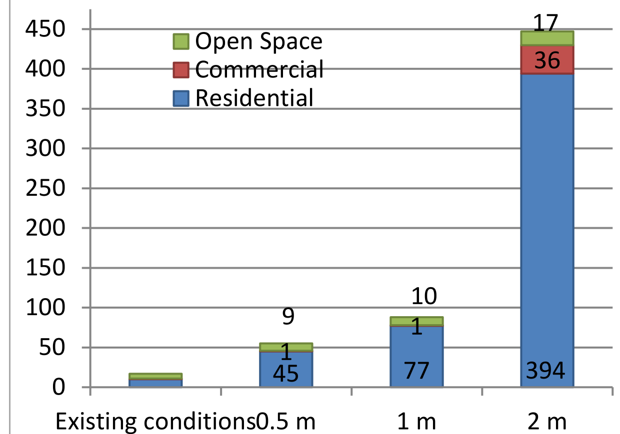


The majority of impacts for any coastal wave 100-yr flood are predominately to residential structures and buildings. Under existing conditions the South Seacoast neighborhood is impacted. With only 0.5m of sea level rise, the Carnation neighborhood north of Palm Ave becomes exposed. There is a marked increase in vulnerability with 2 m of sea level rise, and the associated 100 year storm, due to the projections of flooding with the Bay and Estuary connecting along the old remnant Tijuana River channel the backshore along 8th St. between Palm Ave and Imperial Beach.

Economic Vulnerabilities:

2047 (0.5 m)	$13,042,016
2069 (1.0 m)	$22,665,789
2100 (2.0 m)	$38,388,225

Tidal Inundation (Number of Parcels)



Tidal inundation consisted of impacts to parcels located along the Bay. Under existing conditions there is little risk from tidal inundation alone. Between 1.0m and 2.0m of sea level rise there are substantial escalating impacts. The majority of impacts are to residential parcels. However, Bayside Elementary and West View Elementary (counted as open space) are vulnerable to tidal inundation.

Economic Vulnerabilities:

2047 (0.5 m)	$3,943,381
2069 (1.0 m)	$7,412,742
2100 (2.0 m)	$34,267,250

Adaptation Strategies

Range of Strategies: Includes "No Action" and clean up, as well as retreat, accommodate and protection strategies.

Retreat - Includes policy and/or regulatory options (e.g. downzoning, transfer of development, FEMA repetitive loss, and rolling easements) as well as purchase of the vulnerable properties potentially with a lease back option. This will be the most effective strategy in the long term if steps are taken now.

Accommodate - Includes elevating structures and increasing setbacks. Elevating is expensive if completed as a retrofit, however building code changes would enable elevation to occur overtime with the bulk of the cost placed on developers and private property owners redeveloping their properties

Protect – Constructing levees and coastal armoring to reduce vulnerabilities is the "gray" protection approach.A "green" protection approach would contour slopes or "horizontal levees" on the Bay and the Estuary while a hybrid dune approach may be more feasible to protecting against future coastal hazards on the Pacific coast.

Secondary Impacts: Retreat strategies have secondary impacts due to the loss of structures and property and subsequent resulting impacts on the tax base revenues to the City. Gray protection options would result in a loss of ESHA wetlands and beaches over time. Green protection strategies may benefit wetlands by increasing wetland transition slopes.

Findings

Summary

- Residential parcels constitute the bulk of structures and parcels exposed to existing and future coastal hazards.
- Tidal inundation has very small impact under existing conditions, but impacts escalate dramatically between 1 and 2 meters of sea level rise.
- Coastal erosion hazards have the highest economic vulnerabilities than all other coastal hazards combined.

Thresholds:

- At 0.5 meters, coastal flooding impacts to the Carnation neighborhood increases.
- Between 1 and 2 meters, coastal flooding and tidal inundation vulnerabilities escalate substantially.

Potential Next Steps

Policy

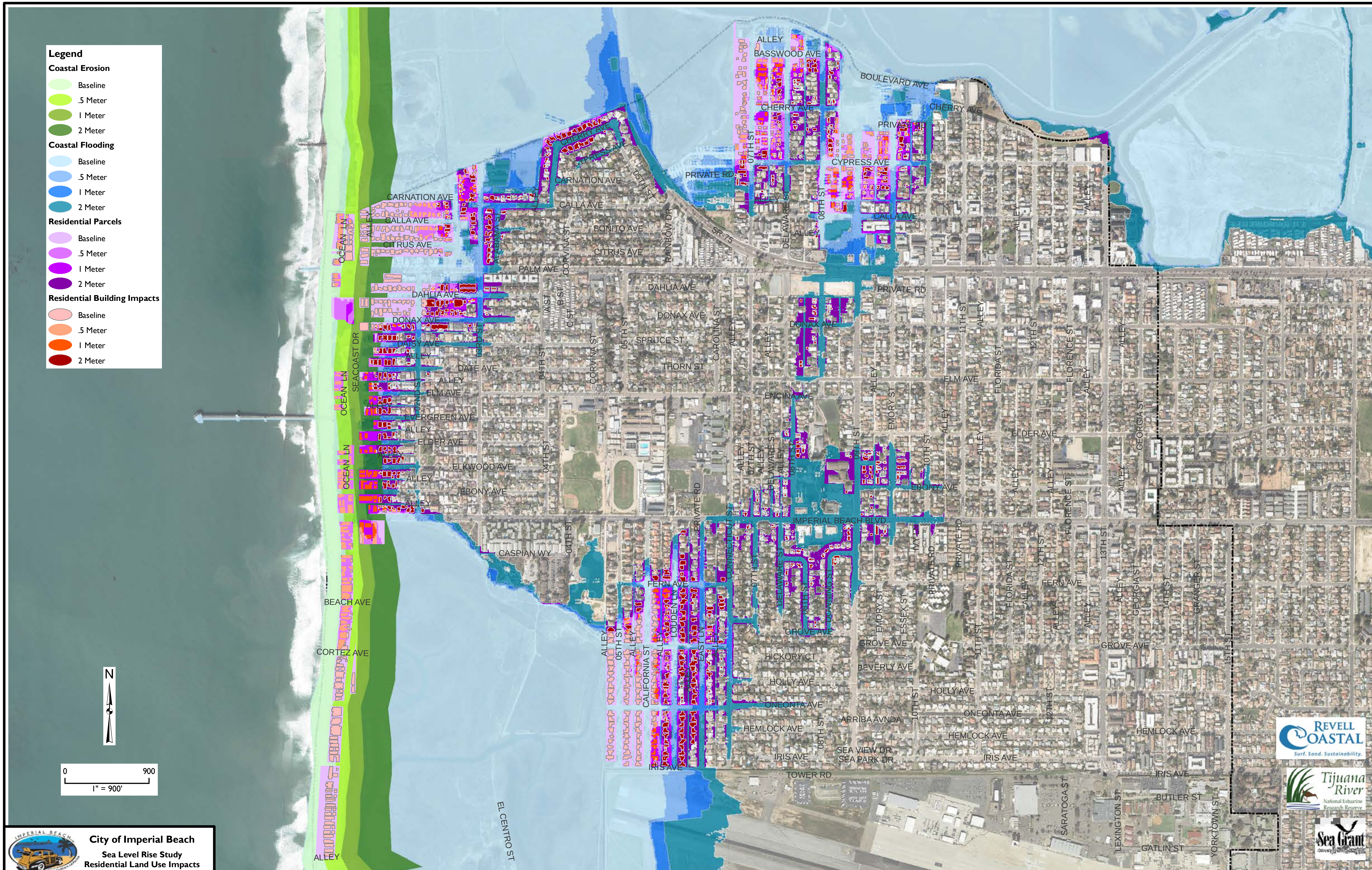
- Consider codifying an increase to base floor elevation or movable foundation standards for new development.
- Develop real estate disclosure requirements to inform homebuyers of the risk of living adjacent to the coast.

Projects

- Develop a phased long-term managed retreat plan
- Potentially require any abandonment or retreat to remove derelict or threatened structures.

Monitoring

- Monitor frequency, duration and depth of impacts at low lying areas around the City.


Legend
Coastal Erosion
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City of Imperial Beach
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Residential Land Use Impacts
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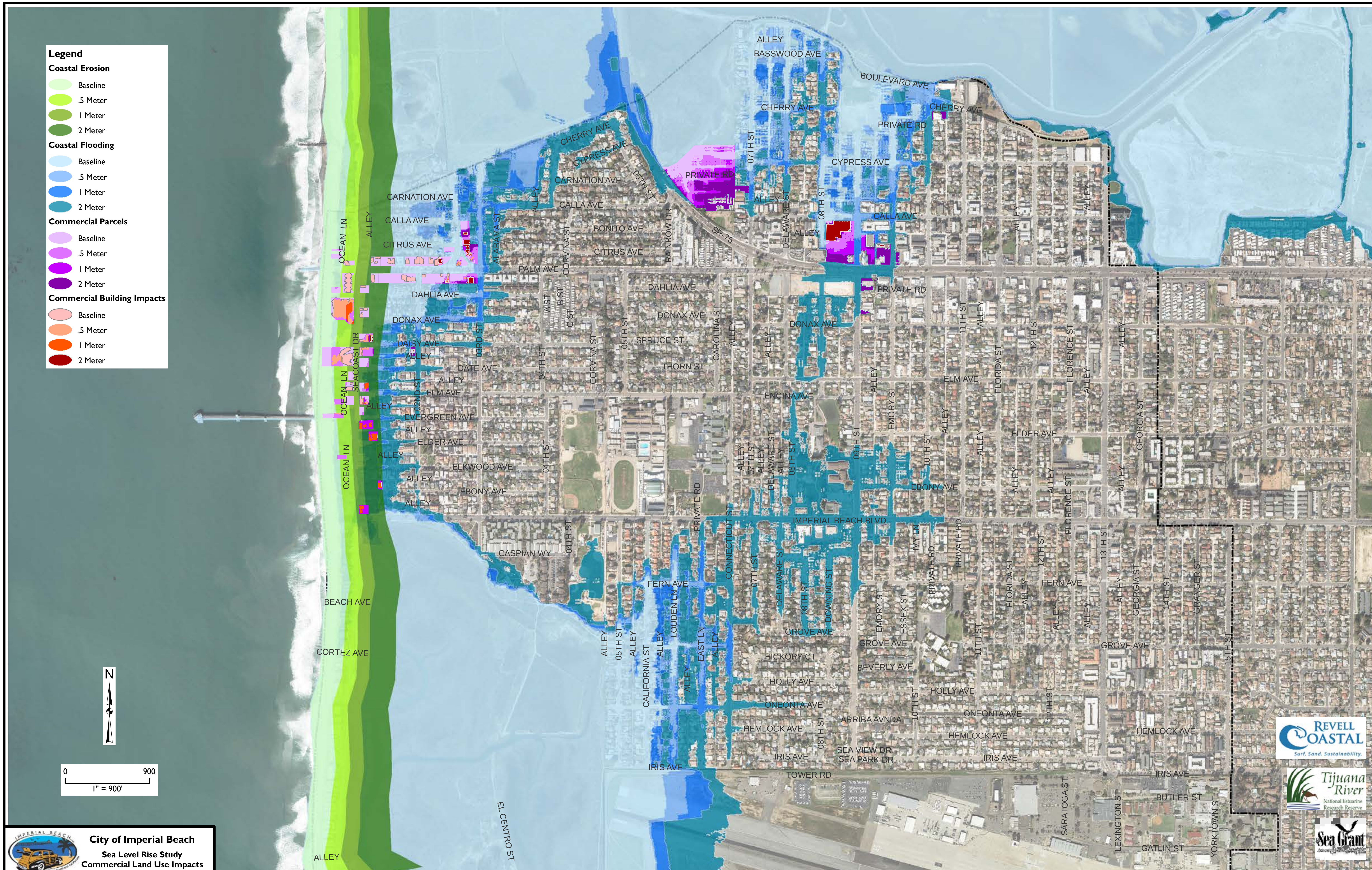
Surf. Sand. Sustainability.
Tijuana River
National Estuarine Research Reserve
Sea Grant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City of Imperial Beach
Sea Level Rise Study
Commercial Land Use Impacts
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National Estuarine Research Reserve
Sea Grant
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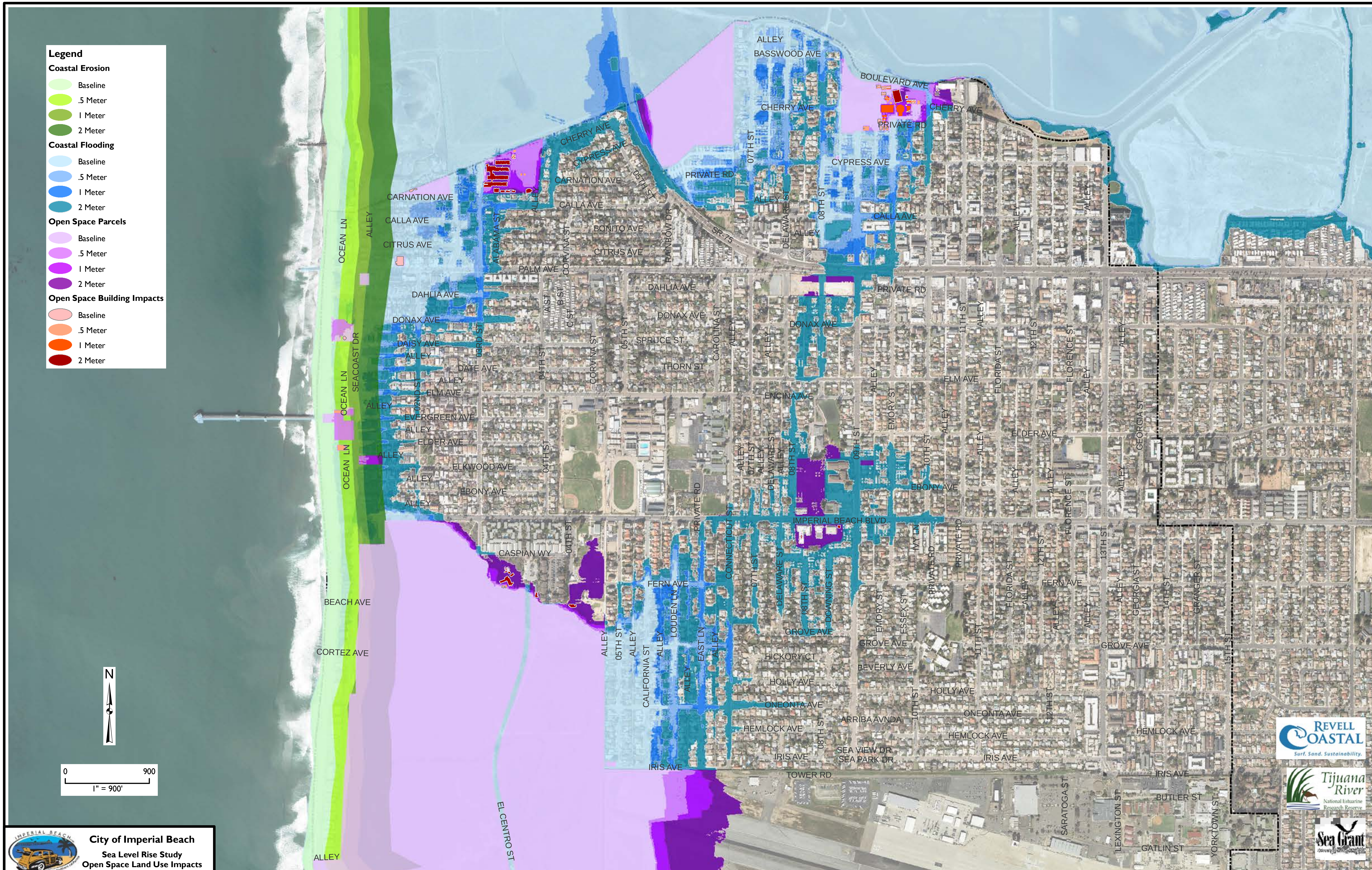
SR-75
OCEAN LN
SEACOAST DR
BEACH AVE
CORTEZ AVE
EL CENTRO ST
TOWER RD



Legend
Coastal Erosion
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Coastal Flooding
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Open Space Parcels
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Open Space Building Impacts
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City of Imperial Beach
Sea Level Rise Study
Open Space Land Use Impacts
REVELL COASTAL
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Tijuana River
National Estuarine Research Reserve
Sea Grant

Overview

Imperial Beach is served by an existing network of 73 miles of road within the City boundaries. While there are no major highways traversing the central portion of the City, there are two primary east-west roads (Palm Ave and Imperial Beach Boulevard) that serve as the major arteries for traffic in and out of the City. Both roads terminate at the coast and are vulnerable to coastal flooding during strong wave events in concert with high tides today.

To quantify the impact of coastal hazards and climate change on roads and public transportation, the following measures of impact have been identified:

- Length of roads (miles)

Existing Conditions

Tidal Inundation
- 0 miles

Coastal Erosion
- 1.7 miles

Coastal Flooding
- 13.7 miles

Open Coast: Under current conditions, with a 100-year storm, 13.7 miles of road are vulnerable to flooding. In the northern stretch of Imperial Beach, current impacts are most prominent between Ocean Lane to just shy of 3rd Street and between Carnation Avenue and Donax Avenue. To the south, impacts to Ocean Lane and Seacoast Drive commence again at Ebony Avenue and extend to their roads most southerly extents.

Bay: Impacts are along the Bayshore Bikeway (Silver Strand Bikeway), along 7th Street and Delaware, as well as along 8th Street and Cypress Avenue. There is slight vulnerability on Interstate 75, near the City's jurisdictional boundary.

Estuary: The main artery within the Estuary (El Centro Avenue) is vulnerable, as are stretches of trails along 5th Street and California Street between Fern Avenue and Iris Avenue.

Vulnerabilities

0.5 m (by ~2047)

Tidal Inundation
- 0.6 miles

Coastal Erosion
- 3.3 miles

Coastal Flooding
- 17.0 miles

Open Coast: The entire lengths of Ocean Lane and Seacoast Drive are now impacted. There is slight expansion of flooding eastward on the northern roads, from Carnation Avenue to 3rd Street.

Bay: There is an expansion of vulnerability to the bus route along interstate 75 reaching south just past Cypress Avenue. Slight expansion of vulnerability to the trails south along 7th Street, east along the Silver Strand Bikeway, and along Cypress between 8th and 10th Avenues.

Estuary: Very minimal eastward expansion of vulnerability along Iris Avenue.

1 m (by ~2069)

Tidal Inundation
- 1.2 miles

Coastal Erosion
- 4.3 miles

Coastal Flooding
- 19.9 miles

Open Coast: Increased eastward projected flooding along the central roads that intersect Seacoast Drive halfway up the block to 2nd Street, between Donax Avenue and Imperial Beach Boulevard.

Bay: Continued southeasterly expansion of existing and project vulnerabilities along Delaware, 7th, 8th and 9th Streets.

Estuary: Continued northeasterly expansion of projected flooding zones between 5th Street and Louden Lane.

2 m (by ~2100)

Tidal Inundation
- 4.3 miles

Coastal Erosion
- 5.4 miles

Coastal Flooding
- 29.6 miles

Open Coast: As coastal and bay flooding merge, there is considerable northeasterly increase in vulnerability in the northern section of Imperial Beach, now extending vulnerability to Alabama, Cherry Ave and Cypress. Further east between Donax and Imperial Beach Blvd, the flooding now extends to 2nd Street.

Bay: The alley between Delaware and 8th Street is now vulnerable to flooding, reaching flooding zones along Cypress Avenue. There is extension of flooding along 8th Street between Palm Avenue and Imperial Beach Boulevard.

Estuary: As flooding from the Bay and Estuary are projected to join, there are areas of flooding extending in all directions along Imperial Beach Boulevard from Ebony Avenue to Grove Avenue. There is also eastward expansion of flooding between Fern and Iris Avenue east to Connecticut Street.

Adaptation Strategies

Range of Strategies:

Retreat – relocate or remove roads from the hazardous areas. This would likely require a phased relocation of the central visitor serving portion of Seacoast Drive.

Accommodate – It is possible to elevate roads to accommodate higher flood water levels. This could be accomplished by elevating segments of road on causeways. Some of the low lying areas in the City located in the former Tijuana River Channels may be most applicable. Another option would be to incrementally elevate the road surface during routine repaving by adding an additional 2-3 inches of asphalt.

Protect – (Green) Contour additional elevation into a horizontal levee for vulnerable estuary and bayside areas.

(Gray) Construct levees and install pumps to flood proof the most vulnerable road segments.

Secondary Impacts:

Retreat strategies may negatively impact traffic and other resources of the City, depending on the realignment. Accommodation strategies may create additional storm water drainage issues. Protection strategies (green) could provide some room for habitat transgression for roads adjacent to wetlands. Gray protection strategies could negatively impact wetland habitat transgression as well as escalating maintenance costs.

Findings

Summary

- With 2 meters of sea level rise, approximately 40 percent of the City roads could be vulnerable to coastal storm flooding and 4.3 miles could be routinely inundated during high tides
- Coastal erosion with 0.5 meter of sea level rise could impact the majority of Seacoast Drive.

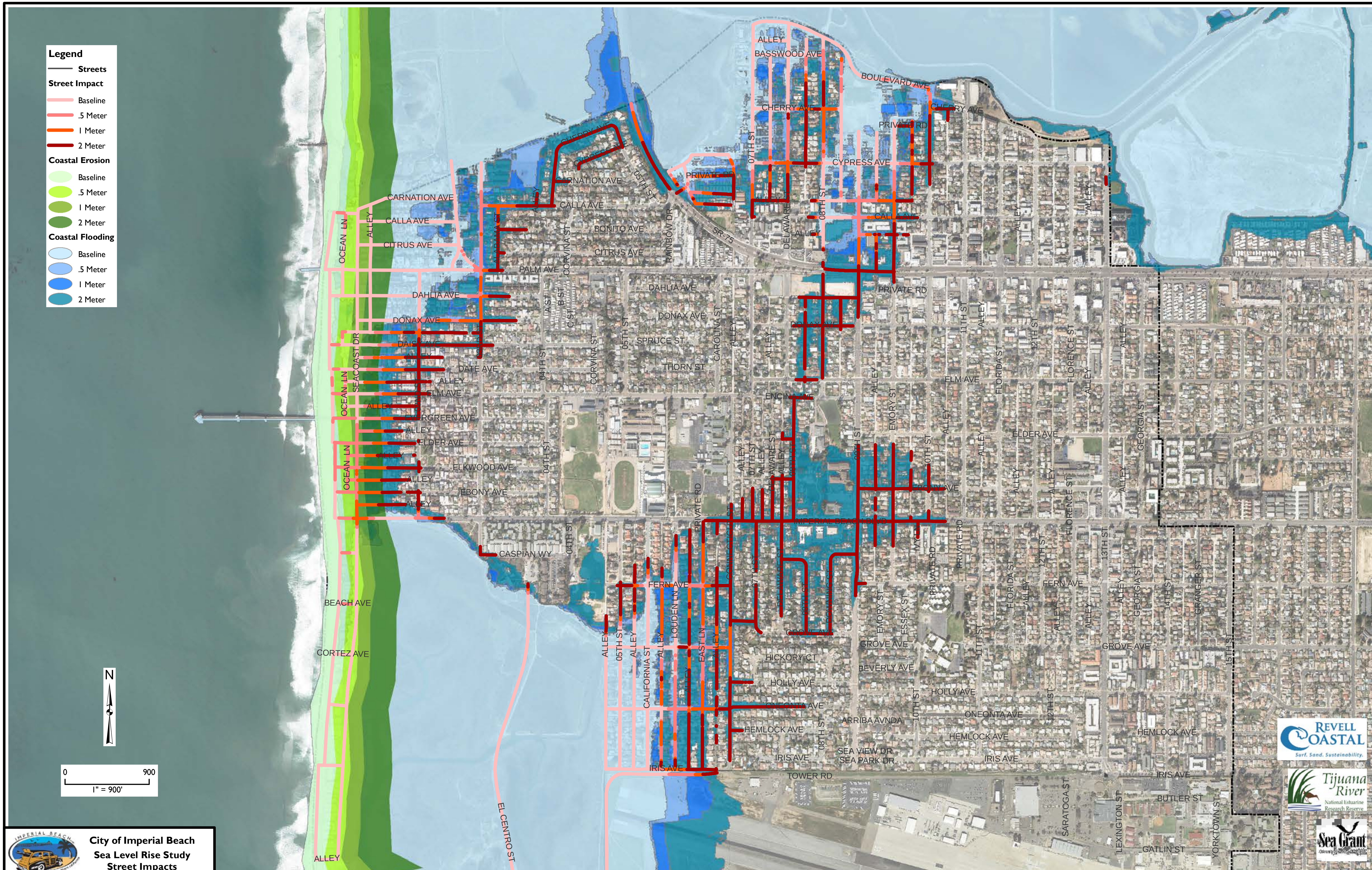
Thresholds: There are significant increases in vulnerability with the first 0.5 meter of sea level rise due to the expansion of potential erosion impacts. Between 1 and 2 meters of sea level rise, tidal flooding increases by a factor of approximately three, as water from the Bay and Estuary potentially join.

Potential Next Steps

Policy
- Work with Caltrans and SANDAG on SR 75 to ensure that regional connections remain intact.
- Investigate abandonment of South Seacoast Drive.

Projects
- Elevate critical roads including Seacoast Drive, Palm Avenue, and Imperial Beach Boulevard.
- Consider amending the City's Capital Improvement Plan to add additional inches for street resurfacing to gain elevation at the pace of sea level rise or greater.

Monitoring
- Monitor depth, extent and frequency of road flooding particularly along South Seacoast Drive and Carnation Ave.


Legend
Streets
Street Impact
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City of Imperial Beach
Sea Level Rise Study
Street Impacts
REVELL COASTAL
Surf. Sand. Sustainability.
Tijuana River
National Estuarine Research Reserve
Sea Grant
BOULEVARD AVE
CHERRY AVE
BASSWOOD AVE
CYPRESS AVE
CARNATION AVE
CALLA AVE
CITRUS AVE
PALM AVE
DAHLIA AVE
DONAX AVE
ELM AVE
ELDER AVE
IMPERIAL BEACH BLVD
FERN AVE
GROVE AVE
HOLLY AVE
ONEONTA AVE
HEMLOCK AVE
IRIS AVE
TOWER RD
SEACOAST DR
OCEAN LN
BEACH AVE
CORTEZ AVE
CASPIAN WY
EL CENTRO ST
SR-75
RAINBOW DR
FLORENCE ST
GEORGIA ST
SARATOGA ST
LEXINGTON ST
YORKTOWN ST
BUTLER ST
GATLIN ST

Overview & Measures of Impact

The bus system is operated by the San Diego Metropolitan Transit System. In recent years, Imperial Beach (IB) has strived to become recognized as an ideal spot for tourism and ecotourism – naming itself a classic Southern California city. Having multimodal forms of active transportation ranging from efficient and reliable public transportation, as well as bike trail accessibility, pedestrian paths will be critical to having IB attract tourists from within California, the U.S. and internationally.

Existing Conditions

Presently, there are 5.6 miles of bike paths, 11 miles of bus routes and 27 bus routes in the City. To quantify the impact of coastal hazards and climate change on roads and public transportation, the following measures of impacts have been identified:

- Number of bus stops; bus routes (miles)
- Walking/Biking trails (miles).

Existing Conditions

Tidal Inundation

- 0 bus stops / 0 miles (bus)
- 0.1 miles (bike)

Coastal Erosion

- 0 bus stops / 0 miles (bus)
- 0 miles (bike)

Coastal Flooding

- 4 bus stops / 1.3 miles (bus)
- 2.5 miles (bike)

Open Coast: 4 bus stops are impacted by flooding and 1.3 miles of bus routes. In the northern stretch of IB, the impact is to stops/routes along Seacoast Drive between Palm Ave and Evergreen Ave; Palm Ave between Seacoast Drive to 3rd St.

Bay: Bike routes are most impacted on the Bay side along the Bayshore Bikeway (Silver Strand Bikeway) and along 7th Street south to Cypress Ave. There begins to be a small impact to the bus route on Interstate 75 near Cherry Ave.

Estuary: Bike trails are impacted along the northern stretch of the Estuary along and down 5th Street to Iris Ave, as well as a block long stretch of Iris Ave between 5th Street and California Street There are pockets of vulnerability along Imperial Beach Boulevard between Seacoast Drive and 2nd Street.

Vulnerabilities

0.5 m (by ~2047)

Tidal Inundation

- 0.3 miles (bike)

Coastal Erosion

- 1 bus stops / 0 miles (bus)
- 0.7 miles (bike)

Coastal Flooding

- 5 bus stops / 1.7 miles (bus)
- 2.9 miles (bike)

Open Coast: The entire length of Seacoast Drive is now impacted.

Bay: The bus stop at 3rd Street and Palm Ave now becomes vulnerable. There is an expansion of vulnerability to the bus route along Interstate 75 reaching south just past Cypress Avenue. Slight expansion of vulnerability to the trails south along 7th Street and east along the Silver Strand Bikeway.

Estuary: Very minimal eastward expansion of vulnerability along Iris Avenue.

1 m (by ~2069)

Tidal Inundation

- 0.4 miles (bike)

Coastal Erosion

- 4 bus stops / 1.1 miles (bus)
- 1.2 miles (bike)

Coastal Flooding

- 6 bus stops / 1.9 miles (bus)
- 3.1 miles (bike)

Open Coast: There is minimal expansion of vulnerability along Imperial Beach Boulevard. However, the bus stop at Imperial Beach Boulevard and Seacoast Drive is now impacted.

Bay: Minimal expansion of vulnerability along 7th Street and Cypress Avenue to bike/walking trails.

Estuary: Expansion of vulnerability north on Iris Avenue.

2 m (by ~2100)

Tidal Inundation

- 1 bus stops / 0.3 miles (bus)
- 0.9 miles (bike)

Coastal Erosion

- 4 bus stops / 1.1 miles (bus)
- 1.2 miles (bike)

Coastal Flooding

- 9 bus stops / 3.9 miles (bus)
- 3.8 miles (bike)

Open Coast: There continues to be slight expansion of impacted trails along Palm Avenue and Imperial Beach Boulevard as well as the bus routes along these same arteries.

Bay: Impacts to Interstate 75 continue southeast now reaching Rainbow Drive There are also now pockets of impacted bus routes along Palm Ave between 8th Street and 9th Street as well as along 9th Street between Palm Ave and Donax Avenue and further south between Elder Avenue and Imperial Beach Boulevard.

Estuary: As flooding from the bay and estuary potentially join, the bus route along Imperial Beach Boulevard between East Lane and 10th Street, as well as along 9th Street as described above. Impacts to bike trails along Iris Avenue now reach as far east as Connecticut Street and up Connecticut Street to Imperial Beach Boulevard.

Adaptation Strategies

Range of Strategies:

Retreat – relocate or reroute bus routes and bike trails

Accommodate – Elevate roads and bike paths to accommodate higher flood water levels perhaps on causeways. Another option would be to add an additional 2-3 inches of asphalt during routine repaving of the road or bike paths.

Protect – (Green) Contour additional elevations into a horizontal levee for areas in and around open spaces.

(Gray) Construct levees and install pumps to flood proof the most road segments.

Secondary Impacts:

Retreat strategies may negatively impact traffic, other resources of the City, depending on the realignment. Accommodation strategies may create additional stormwater drainage issues. Protection strategies (green) could provide some room for habitat transgression for roads and bike paths adjacent to the Estuary and the Bay. Gray protection strategies could negatively impact habitats as well as escalating maintenance costs.

Findings

Summary

- With 2.0 meters of sea level rise, approximately 68 percent of the City bike paths, one-third of the bus stops, and 35 percent of the bus routes could be vulnerable to coastal storm flooding.
- Coastal erosion could result along permanent loss closure of the bus and bike routes along Seacoast Drive.
- Tidal inundation will routinely close about a mile of bike path with 2.0 meters of sea level rise.

Thresholds: There are significant increases in vulnerability with the first 0.5 meters of sea level rise due to the expansion of potential erosion impacts. Between 1 and 2 meters of sea level rise, tidal flooding impacts increases by a factor of approximately three, as water from the Bay and Estuary potentially join along 8th Avenue.

Potential Next Steps

Policy

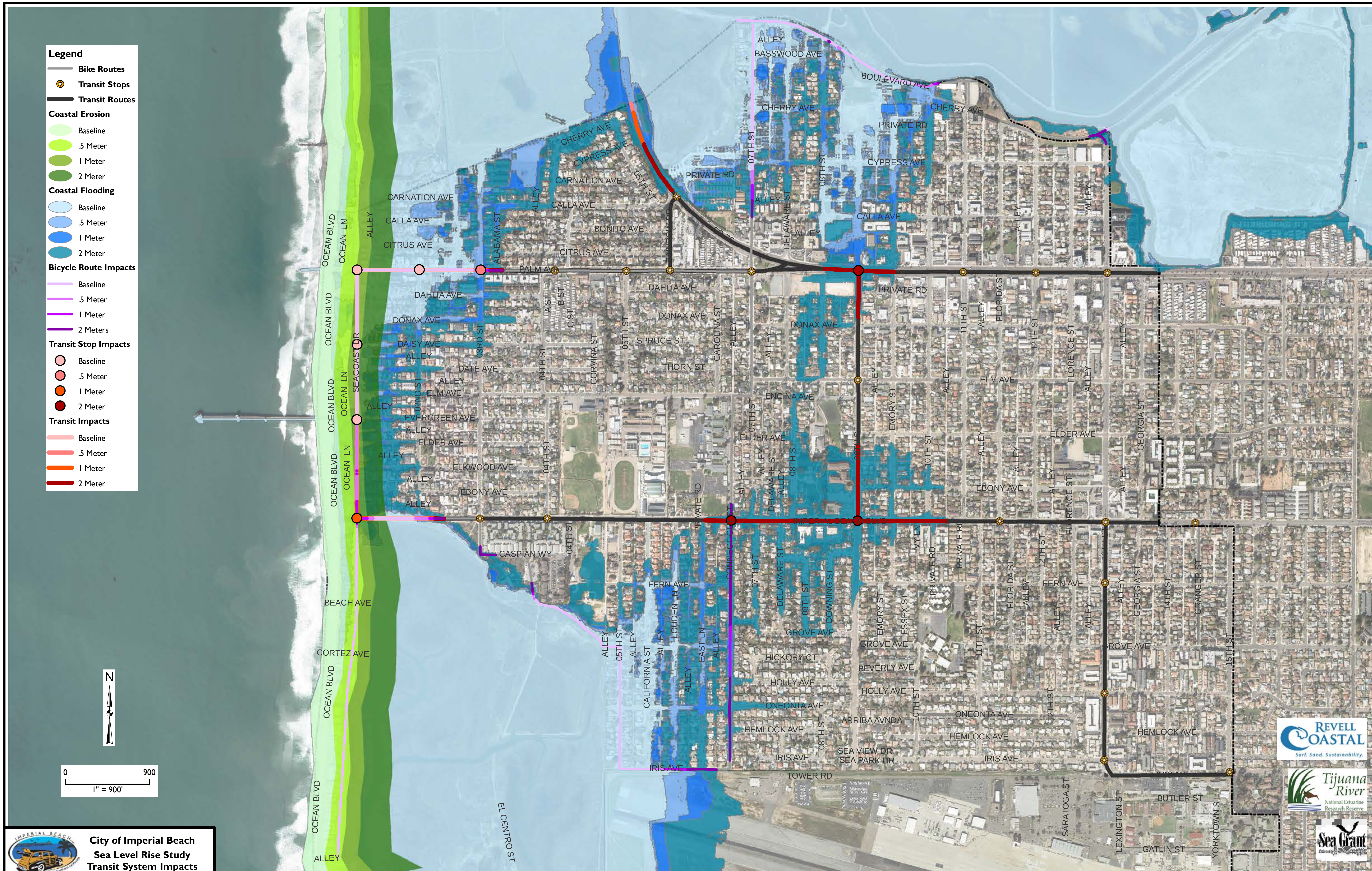
- Develop alternative bike and bus routes, further inland.
- Coordinate with SANDAG and San Diego Metropolitan Transit System to avoid vulnerable areas through the Regional Transportation Plan.

Projects

- Elevate critical roads including Seacoast Drive, Palm Ave, Imperial Beach Boulevard as well as the Bayshore bike path.
- Amend the City's Capital Improvement Plan to add additional inches to the lift in street resurfacing to gain elevation at the pace of sea level rise or greater.

Monitoring

Monitor depth, extent and frequency of road flooding with a focus along Bayshore bike path.


Legend
Bike Routes
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Coastal Flooding
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Overview

The City of Imperial Beach operates and maintains the wastewater collection system including approximately 41 miles of sewer lines and 10 pump stations. Currently, the wastewater is pumped to Point Loma Wastewater Treatment Plant. There are historic and current challenges with the infiltration of groundwater into the current wastewater system, potentially adding 30 – 50 percent more flow to the system.

To quantify the impact of coastal hazards and climate change on wastewater infrastructure, the following measures of impacts have been identified:

- Number of pump stations / Number of manholes
- Length of pipe (feet)

Existing Conditions

Tidal Inundation
- 0 pump stations / 0 manholes
- 0 feet of pipe

Coastal Erosion
- 0 pump stations / 4 manholes
- 799 feet of pipe

Coastal Flooding
- 5 pump stations / 106 manholes
- 26,309 feet of pipe

Open Coast: The most impacted areas along the coast include manholes, pump stations and pipes located along the northern stretch of Ocean Lane and Seacoast between Carnation and Evergreen, including the street ends at Palm, Date, and Dahlia Avenues. In the Northern stretch of town, the impacts extend eastward from Seacoast Drive between Carnation Avenue and Donax Avenue.

Bay: Assets located along 7th Street from the Bay south to Cypress Lane as well as assets along Cypress Ave between 8th Street and 9th Street are vulnerable to flooding impacts.

Estuary: Assets located in the alleys south of 5th Street and California Street between Iris Avenue and Grove Avenue are most vulnerable.

Vulnerabilities

0.5 m (by ~2047)

Tidal Inundation
- 0 pump stations / 7 manholes
- 1,479 feet of pipe

Coastal Erosion
- 1 pump stations / 30 manholes
- 6,279 feet of pipe

Coastal Flooding
- 5 pump stations / 135 manholes
- 35,714 feet of pipe

Open coast: Existing wastewater asset vulnerability spreads impacts the entire stretch of Seacoast Drive, now also including between Evergreen and Imperial Beach Boulevard.

Bay: Vulnerability expands to Delaware Street between Cherry Ave. & Cypress Ave.

Estuary: Projected impacts to assets in alleys west and east of 5th Street between Grove and Iris.

1 m (by ~2069)

Tidal Inundation
- 0 pump stations / 13 manholes
- 3,340 feet of pipe

Coastal Erosion
- 3 pump stations / 50 manholes
- 10,656 feet of pipe

Coastal Flooding
- 6 pump stations / 167 manholes
- 44,432 feet of pipe

Open coast: Vulnerabilities begin to move eastward and impact assets east of Seacoast between Daisy and Imperial Beach Boulevard.

Bay: Slight expansions of impacts along already impacted pipes.

Estuary: Slight expansions of impacts along already impacted pipes.

2 m (by ~2100)

Tidal Inundation
- 1 pump stations / 45 manholes
- 13,282 feet of pipe

Coastal Erosion
- 4 pump stations / 57 manholes
- 14,505 feet of pipe

Coastal Flooding
- 9 pump stations / 311 manholes
- 81,280 feet of pipe

Open coast: Continued expansion eastward along the same stretches, but now reaching 2nd Street. To the north, the vulnerability extends northeast to include assets located along Cherry Avenue and Cypress Avenue between 4th St and 5th Streets as well as along Alabama Street.

Bay and *Estuary:* Significant increase to impacted infrastructure now connected to the Estuary primarily along the alley between 8th and 9th Street between Donax and Encina Avenues; to 8th Street south of Encina to Imperial Beach Boulevard; and assets located along Imperial Beach Boulevard between East Lane and 10th Street, reaching as far south as Grove Avenue. Also considerable expansion of vulnerability to assets in the alleys near Louden Lane and Connecticut Street from Hickory Street to Tower Road as the coastal flooding connects the Bay and Estuary.

Adaptation Strategies

Range of Strategies: A range of strategies include retreat, elevating key vulnerable infrastructure, increasing conveyance and pumping capacity or flood proofing retrofits to protect existing system components.

Retreat: Phased relocation of the wastewater infrastructure must be tied to a community wide managed retreat strategy and coordinated regionally with the Point Loma Wastewater Treatment Plant and the City of San Diego

Accommodate: Elevating pump electrical and vulnerable components may accommodate several feet of sea level rise.

Protect: Flood proof retrofits to the vulnerable pump stations to protect electrical and pump system operations may provide a short term relatively low cost option to accommodate 0.5 meter of sea level rise. Seal the manholes to avoid coastal flood waters from overwhelming the sewage system. Coastal armoring (gray), additional Bayshore bike path levee elevation (gray) or horizontal levees (green) would provide protection from coastal erosion and Bay flooding.

Secondary Impacts: Vary based on approach and integration of adaptation measures to community adaptation planning, Failure in the system would cause pollution to spill in the City or into the Estuary or Bay.

Findings

Summary

- 5 pump stations are currently vulnerable to coastal flooding, with only 0.5 meter of sea level rise; the first pump station is exposed to coastal erosion now.
- Nearly 800 feet of wastewater pipe is currently exposed to existing erosion hazards, this vulnerability increases with 2 meters feet of sea level rise to 2.7 miles.
- By 2100, 45 manholes will be inundated by tides and 311 manholes subject to coastal flooding which would introduce additional water into the sewer system.
- With 2 meters of sea level rise, one of the pump stations is subject to tidal inundation.

Thresholds:

- With a 0.5 meter rise in sea level, erosion hazards potentially expose 1.2 miles of wastewater pipe and a pump station.

Potential Next Steps

Policy

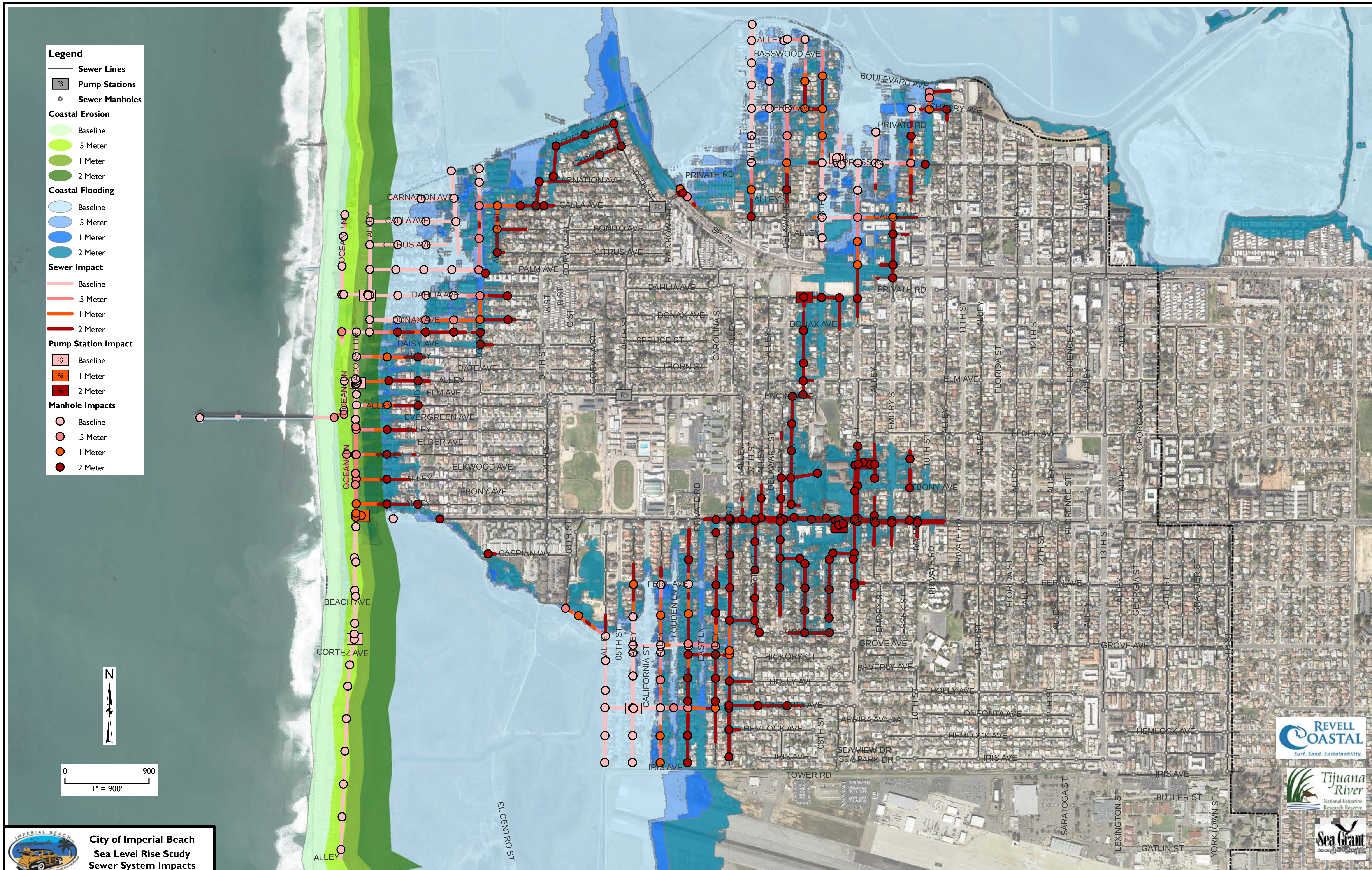
- Encourage regional dialog about the future location of the sewer network or possible tie into to an upgraded Tijuana treatment plant.
- Add policy language to require relocation or avoidance of wastewater hazards to the extent possible.

Projects

- Relocate pump stations and pipe segments susceptible to coastal erosion. Prioritize sections by timing of impact.
- Conduct advanced maintenance to keep lines clear.
- Recommend flood proofing the pump stations.
- Retrofit manholes to reduce flood waters into sewer system.

Monitoring

- Monitor the groundwater levels and salinity levels to understand the impact of both on sewer capacity.


Legend
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Pump Stations
Sewer Manholes
Coastal Erosion
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Coastal Flooding
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City of Imperial Beach
Sea Level Rise Study
Sewer System Impacts
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National Estuarine Research Reserve
Sea Grant

Overview

The City's stormwater system is managed by the Department of Public Works, which operates and maintains approximately 12 miles of storm drain pipes, 429 inlets, 50 outfalls and 10 pump stations. A large portion of the City's storm drain system is near current sea level and designed to accommodate a 5-10 year rain event. Most nuisance flooding occurs during precipitation events at high tides. Flap gates which used to be on the outlet side of the system have been removed to increase conveyance capacity at a cost of allowing tide water farther up into the pipe network. Storm drains have historically backed up at several locations: Carnation and Seacoast; Palm and Seacoast Date and Seacoast; Imperial Beach Boulevard, causing flooding at Bayside Elementary School. A pump station placed at Palm Avenue and Seacoast, which discharges onto the south groin have reduced the frequency of flooding at that location. Significant stormwater back up still occurs at the Estuary and North of Naval Outlying Landing Field, due to clogging from sediment, trash and debris. Flooding at Carnation Avenue and Seacoast Boulevard affects one City residence, but requires collaboration with the Navy who manages the pump station. Nuisance flooding occurs on South Seacoast with a daily recurrence.

Impacts of coastal hazards and climate change on stormwater infrastructure, were quantified by:

- Number of storm drain inlets / Number of outfalls
- Length of storm drain pipes (feet)

Existing Conditions

Tidal Inundation
- 0 inlets / 5 outlets
- 66 feet of pipe

Coastal Erosion
- 6 inlets / 6 outlets
- 555 feet of pipe

Coastal Flooding
- 101 inlets / 30 outlets
- 8,785 feet of pipe

Open Coast: The most impacted areas along the open coast include outlets and pipes located along the northern stretch of Seacoast between Carnation and Evergreen, including the street ends at Palm, Date, and Dahlia Avenues. Inlets are vulnerable along the entire length of Seacoast.

Bay: Assets located on 8th Avenue between Cypress and Calla as well as at the RV Park near Interstate 75 and Rainbow Drive are immediately vulnerable.

Estuary: Vulnerable assets are located along Grove Avenue between 5th and Louden Lane.

Vulnerabilities

0.5 m (by ~2047)

Tidal Inundation
- 9 inlets / 8 outlets
- 1,112 feet of pipe

Coastal Erosion
- 24 inlets / 13 outlets
- 1,579 feet of pipe

Coastal Flooding
- 129 inlets / 30 outlets
- 10,928 feet of pipe

Open Coast: Existing stormwater asset vulnerability spreads further south along Seacoast reaching Imperial Beach Boulevard.

Bay: There is a slight extension of vulnerability to the assets located along 8th Avenue.

Estuary: The same assets that are vulnerable under current conditions remain vulnerable with the additional 0.5 meter of sea level rise.

1 m (by ~2069)

Tidal Inundation
- 12 inlets / 9 outlets
- 1,843 feet of pipe

Coastal Erosion
- 79 inlets / 16 outlets
- 5,184 feet of pipe

Coastal Flooding
- 141 inlets / 30 outlets
- 11,830 feet of pipe

Open Coast: Vulnerabilities begin to move landward and impact pipes and inlets east of Seacoast between Ebony and Imperial Boulevard.

Bay and Estuary: There is no significant expansion of vulnerability with 1 meter of sea level rise. The assets vulnerable under existing conditions remain vulnerable.

2 m (by ~2100)

Tidal Inundation
- 26 inlets / 11 outlets
- 3,258 feet of pipe

Coastal Erosion
- 94 inlets / 16 outlets
- 5,640 feet of pipe

Coastal Flooding
- 219 inlets / 42 outlets
- 24,203 feet of pipe

Open Coast: A small section of pipe northeast of Imperial Beach is impacted.

Bay: A considerable increase in vulnerabilities occur as floodwaters join the Bay and the Estuary. Stormwater assets along 8th Street between Palm Avenue and Elm Avenue become impacted.

Estuary: There is a considerable expansion of vulnerability near the Imperial Beach Sports Park east of Caspian Way. There is increased vulnerability on Connecticut Street between Grove Avenue and Imperial Beach Boulevard, which also becomes impacted east as Ivy Lane. Similarly assets north of Imperial Beach Boulevard to midway between Ebony and Elder Avenues and between 8th Street and 10th Street demonstrate projected vulnerability.

Adaptation Strategies

Range of Strategies: A range of strategies include retreat, elevating key vulnerable infrastructure, increasing conveyance and pumping capacity or flood proofing retrofits to protect existing system components.

Retreat: Phased relocation of the stormwater infrastructure must be tied to a community wide managed retreat strategy.

Accommodate: Increasing the pump capacity, creating detention basins and expanding the size of the conveyance are mid-term solutions, which may accommodate several feet of sea level rise.

Protect: Flood proof retrofits to the vulnerable pump stations to protect electrical and system operations may provide a short term relatively low cost option to accommodate 0.5 meter of sea level rise. Seal the manholes to avoid blowouts of covers during high flow events, which may cause additional risk to safety and response operations.

Secondary Impacts: Vary based on approach and integration of adaptation measures to community adaptation planning.

Findings

Summary

- Tidal Inundation already impacts many of the key stormwater outlets that drain into the Bay and Estuary.
- With 2 meters of sea level rise, the majority of the stormwater drainages will be impacted for the entire tide cycle, which in turn significantly increasing flood depths and frequency.
- 0.5 meter of sea level rise doubles the potential erosion impact to oceanfront stormwater outfalls.
- 2 meters of sea level rise affects 4.5 miles of the stormwater system and impacts more than half of the inlets.

Thresholds:

- With 1 meter of sea level rise, more than half of the stormwater drainages are impacted by tides at least 50 percent of the time.
- There are significant increases in all vulnerabilities at 2 meters of sea level rise due to the elevation of tides and the expansion of flooding inland as water from the Bay and Estuary potentially join.

Potential Next Steps

Policy

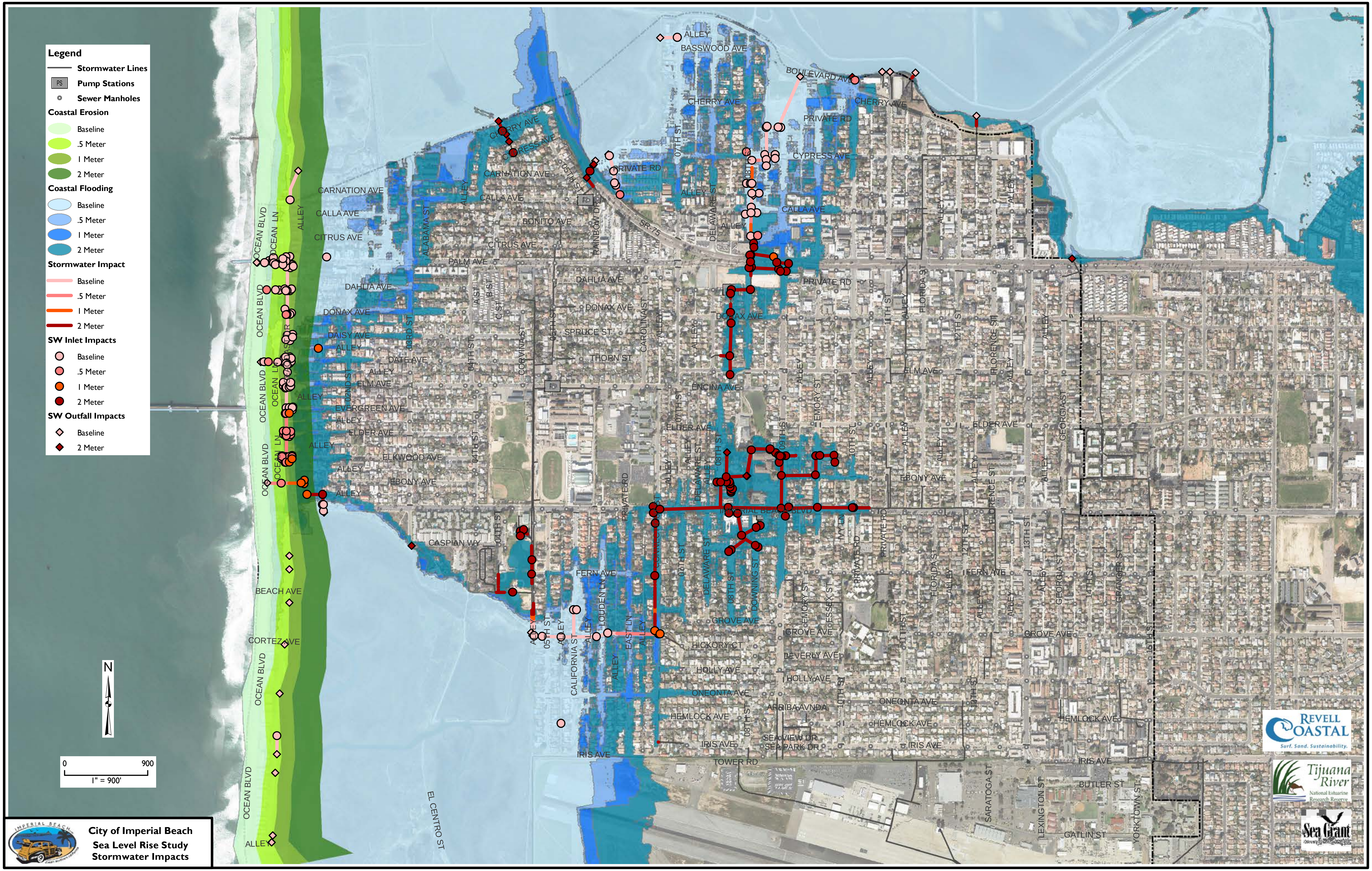
- Increase base floor elevation of new development to reduce potential storm water flood impacts.
- Revise stormwater policies in the Local Coastal Program, Capital Improvements Plan, and General Plan addressing sea level rise and future decline in conveyance.

Projects

- Conduct a stormwater system analysis that examines alternative pump locations, capacity, and expanded conveyance.
- Consider adding flap gates after expanding capacity.
- Develop stormwater retention basins that allow for reuse or release once tides drop to efficient levels.

Monitoring

- Monitor frequency, duration and depth of stormwater at low lying areas around the City.


Legend
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Sewer Manholes
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BASSWOOD AVE
BOULEVARD AVE
CHERRY AVE
PRIVATE RD
CYPRESS AVE
CARNATION AVE
CALLA AVE
BONITO AVE
CITRUS AVE
PALM AVE
DAHLIA AVE
DONAX AVE
DAISY AVE
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ELDER AVE
ELKWOOD AVE
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BEVERLY AVE
HOLLY AVE
ONEONTA AVE
ARRIBA AVNDA
HEMLOCK AVE
IRIS AVE
SEAVIEW DR
SEA PARK DR
TOWER RD
BUTLER ST
GATLIN ST
OCEAN BLVD
OCEAN LN
ALLEY
SR 75
RAINBOW DR
ALABAMA ST
CAROLINA ST
CORVINA ST
DELAWARE ST
FLORIDA ST
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GEORGIA ST
GRANGER ST
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EAST LN
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Schools

Overview

The City of Imperial Beach has its own school district, which includes 1 preschool, 5 elementary schools, 1 middle school and 2 high schools. In addition, the District manages 3 adult schools/alternative learning centers. Bayside Elementary historically has experienced flooding when high tide comes up through the storm drain and floods fields where there are contaminated soils.

The following measures of impacts have been identified:

- Number of school buildings

Existing Conditions

Coastal Flooding • 6 buildings	At current conditions, Bayside Elementary is the only school vulnerable to flooding. During high tides, water in the storm drains backs up and floods the lower field, where there are contaminated soils. During a current day 100-year storm, it is expected that up to 6 buildings within this location may experience more flooding.

Vulnerabilities

0.5 m (by ~2047)

Tidal Inundation • 3 buildings **Coastal Flooding** • 6 buildings	With 0.5 meter of sea level rise, West View Elementary also becomes vulnerable to Bay flooding from extreme tidal inundation. 3 buildings are expected to be impacted.

1 m (by ~2069)

Tidal Inundation • 3 buildings **Coastal Flooding** • 6 buildings	At 1 meter of sea level rise, vulnerability is not projected to increase at either Bayview Elementary or West View Elementary schools.

2 m (by ~2100)

Tidal Inundation Zone • 6 buildings **Coastal Flooding Zone** • 7 buildings	With 2 meters of sea level rise, it is anticipated that 1 more building at Bayview Elementary and 3 additional buildings at West View Elementary will become vulnerable to impacts from increased flooding.

Adaptation Strategies

Range of Strategies:

Retreat – relocate or remove school buildings from the hazardous flood-prone areas. Removal of contaminated soils at Bayside Elementary may reducing vulnerabilities to other contaminants that may be released with elevated flooding and groundwater. Alternatively, the City could relocate the schools to a more inland, centrally located location.

Accommodate – It is possible to elevate school buildings to accommodate higher flood water levels or examine additional setbacks for new buildings and school supporting infrastructure.

Protect – (Green) Contour additional elevations into a horizontal levee for areas in and around schools.

(Gray) Elevate levees along the Bayshore bike pathway, and levees and install pumps to protect the schools from tidal and coastal flooding from the Bay.

Secondary Impacts:

Retreat strategies may negatively impact schools and displace residents and children attending the schools. Accommodation strategies that involve elevating structures could be extremely costly depending on the types of structural foundation needed. Protection strategies (green) could provide some room for habitat transgression for roads adjacent to wetlands. Gray protection strategies could negatively impact Environmental Sensitive Habitat Areas (ESHA) and wetland habitat transgression as well as have escalating maintenance costs.

Findings

Summary

- No school buildings are susceptible to coastal erosion.
- Six buildings at Bayview Elementary School are currently exposed during storm events and will become routinely exposed by tidal flooding with only 0.5 meter of sea level rise. With 2 meters of sea level rise, an additional building is exposed to coastal flooding.
- Westview Elementary becomes exposed to tidal inundation and coastal flooding with only 0.5 meter of sea level rise. By 2.0 meters of sea level rise, the remaining school buildings become exposed.

Thresholds:

- There are significant increases in vulnerability with 0.5m of sea level rise as Westview and Bayview become exposed to tidal inundation and coastal flooding.
- With 2.0 meters of sea level rise, additional buildings become exposed due to the expansion of flooding inland as water from the Bay and Estuary potentially join.

Potential Next Steps

Policy

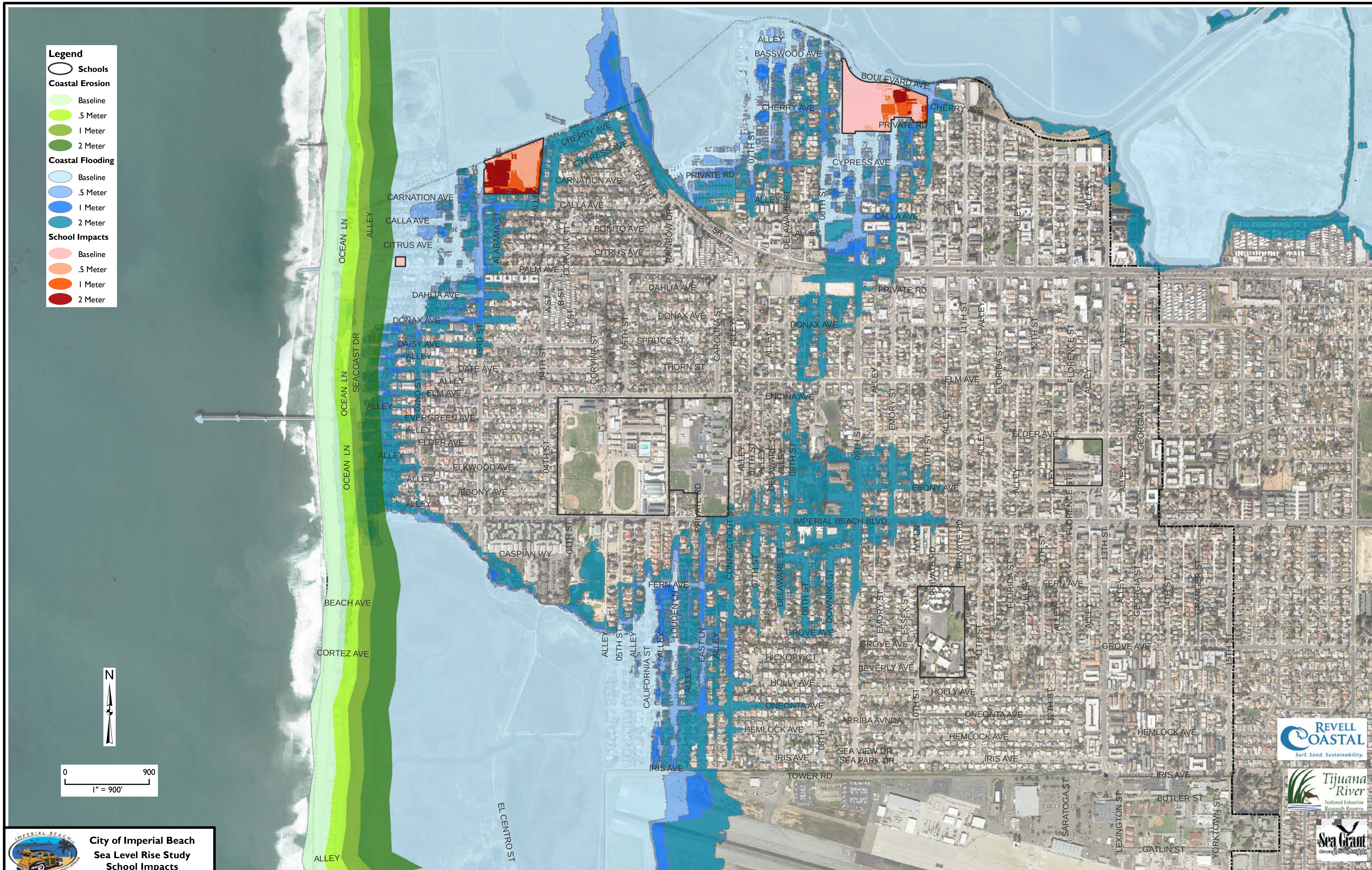
- Evaluate alternative school locations
- Include language in policy updates to consider sea level rise and flood hazards in the renewal of any future school leases.

Projects

- Remediate contaminated soils at Bayside Elementary
- Evaluate a horizontal levee option to increase flood protection capacity at both schools and provide some vertical habitat transgression opportunities.

Monitoring

- Monitor extents, depths and frequency of inundation at both schools


Legend
Schools
Coastal Erosion
Baseline
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2 Meter
Coastal Flooding
Baseline
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School Impacts
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CYPRESS AVE
CARNATION AVE
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CITRUS AVE
PALM AVE
DAHLIA AVE
DONAX AVE
DAISY AVE
DATE AVE
ELM AVE
EVERGREEN AVE
ELDER AVE
ELKWOOD AVE
EBONY AVE
IMPERIAL BEACH BLVD
CASPIAN WY
FERN AVE
GROVE AVE
HICKORY CT
BEVERLY AVE
HOLLY AVE
ONEONTA AVE
ARRIBA AVNDA
HEMLOCK AVE
SEA VIEW DR
SEA PARK DR
IRIS AVE
TOWER RD
BUTLER ST
GATLIN ST
BEACH AVE
CORTEZ AVE
OCEAN LN
SEACOAST DR
EL CENTRO ST
SR-75
RAINBOW DR
ALABAMA ST
CORVINA ST
CAROLINA ST
DELAWARE ST
CONNECTICUT ST
CALIFORNIA ST
FLORIDA ST
FLORENCE ST
GEORGIA ST
EMORY ST
ESSEX ST
DOWNING ST
SARATOGA ST
LEXINGTON ST
YORKTOWN ST
GRANGER ST
BONITO AVE
SPRUCE ST
THORN ST
ENCINA AVE
BASSWOOD AVE
PRIVATE RD
ALLEY

Hazardous Materials

Overview

Businesses who use hazardous materials are required to file a business plan with the County of San Diego and the City Fire Department, which is included in the California Environmental Reporting System. The main sources of hazardous materials business plans in the City of Imperial Beach are primarily medical, fuel/auto or military related. The County codes dictate how the materials should be stored. The Fire Department is typically responsible for hazardous waste spills and clean up.

In addition, there are also a number of underground storage tanks on file with the Environmental Protection Agency (EPA). Underground tanks are not necessarily at risk if the tanks are intact, but over time with elevated groundwater and salinity levels, the deterioration of the tanks may increase. Several of these tanks are known to be leaking, and thus require remediation (I.e. clean up and monitoring). The clean up is typically the responsibility of the landowner, however once the tank leaks and spreads to adjacent parcels and neighborhoods, then the City may have to assume some of the clean up liabilities.

The impact of coastal hazards and climate change on hazardous materials were quantified using the following measures:

- Number of Businesses with hazardous material business plans (identified as "Hazardous Material Impacts")
- Number of Underground Storage Tanks
- Number of Tank Cleanup Sites

Disclaimer: *Hazardous materials outside, but near the City were not included in this analysis. For example, the Navy has a requirement that any hazardous materials transport to and from their facilities must utilize State Route 75 which goes through Imperial Beach. The type and quantity of hazardous materials, state of matter, dispersal mechanism and solubility in water was beyond the scale of this analysis.*

Existing Conditions

Coastal Flooding • 1 Business • 1 Tank Clean-up site	Under existing conditions, there is currently 1 military-related underground storage tank adjacent to Tijuana River National Estuarine Research Reserve (TRNERR) that is under current remediation, located at the edge of the Bay near Calla Avenue. One auto-related hazardous material site located near Palm Ave and 2nd Street is potentially exposed to coastal flooding hazards from a 100-year wave event.

Vulnerabilities

0.5 m (by ~2047)

Coastal Flooding • 1 Business • 1 Tank Clean-up site	With an increase of 0.5 meters of sea level rise, there are no additional businesses with hazardous materials or underground storage tank sites that are projected to become vulnerable to coastal hazards.

1 m (by ~2069)

Coastal Flooding • 2 Businesses • 1 Tank Clean-up site	With 1 meter of sea level rise, flooding potentially impacts a medical-related underground storage tank, located east of Calla Ave halfway between 16th Street and Thermal Avenue.

2 m (by ~2100)

Tidal Inundation • 1 Business • 0 Tank Clean-up Sites **Coastal Flooding** • 5 Businesses • 2 Tank Clean-up Sites	With 2.0 meters of sea level rise, there is currently one auto-related Hazardous Materials site that becomes vulnerable to flooding by tidal inundation. There are an additional 3 Hazardous Material sites: 2 that are military-related and 1 that is auto-related site. Both are vulnerable to coastal flooding. A military-related Underground Tank Cleanup Site is also vulnerable.

Adaptation Strategies

The majority of the hazardous material impacts identified in the vulnerability assessment are largely avoidable.

Range of Strategies: Hazardous storage plan strategies would range from a "do nothing" approach to protection of businesses with HMBPs, to policy options that would require different storage or clean up timelines to avoid exposing the community to the hazardous materials. The "do nothing" approach could have substantial clean up impacts with the City partially liable.

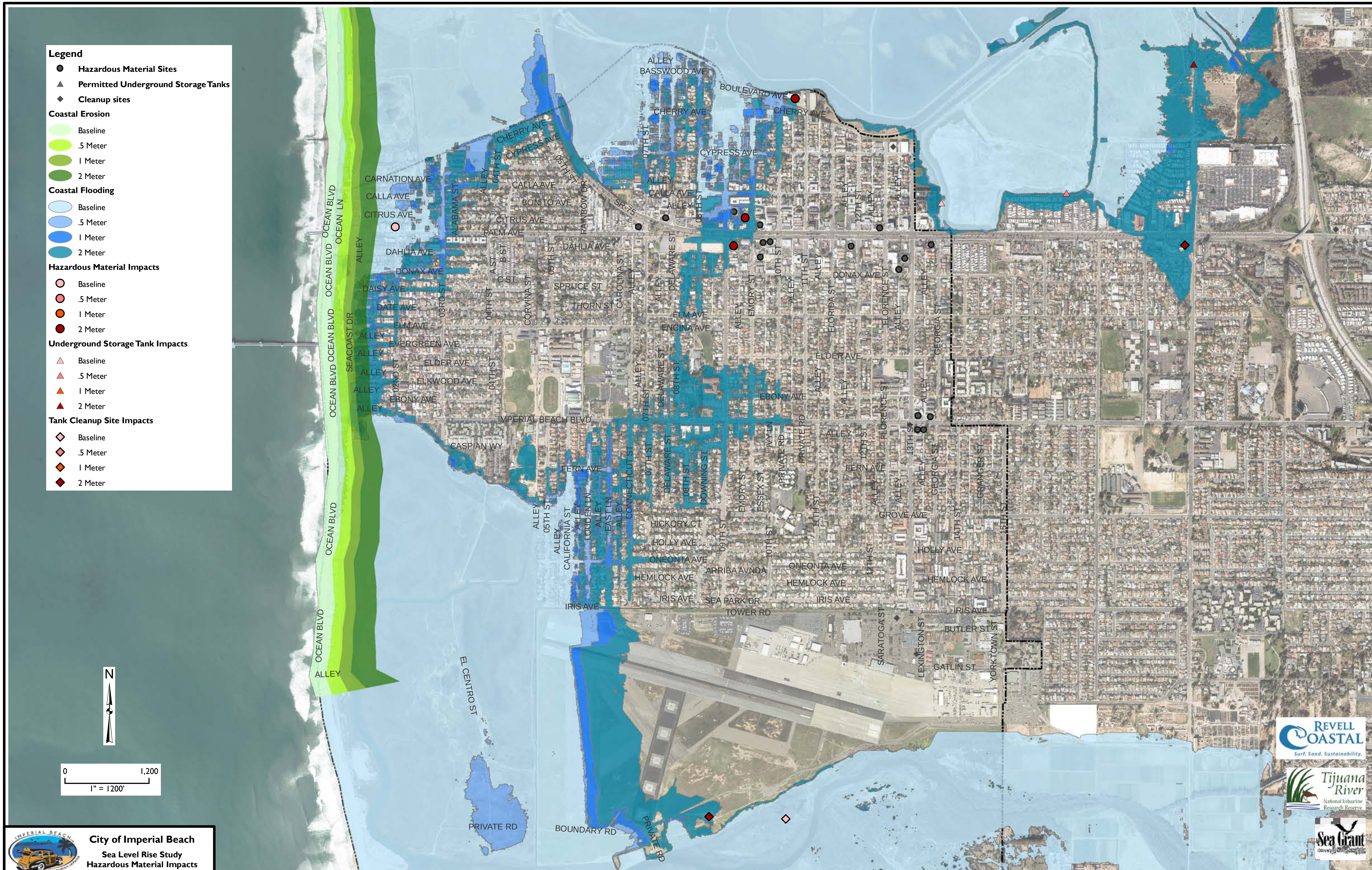
Retreat: relocate and/or enact policy changes which prohibit hazardous materials to be stored or underground tanks to be placed inside of any of the coastal hazard zones.

Accommodate: Increase the stability or storage elevation for hazardous materials. These should be relatively low cost options to store materials in a more flood-proof manner.

Protect: Leaking underground tanks have limited adaptation options other than to remediate or adjust the timing and exposure of the contaminants to coastal flooding or more prolonged tidal inundation through protection type options of levees, coastal armoring or providing a secondary containment unit made of salt tolerant materials around every underground storage tank.

Findings

Summary	Potential Next Steps
• Most of the hazardous tanks and potential exposure to hazardous materials come from military related issues. • Under existing conditions, only one of the hazardous material locations is adaptable by a City initiative. • No tanks or hazardous material storage sites are exposed to coastal erosion hazards with 2 meters of sea level rise. **Thresholds:** There is a modest increase in hazard material vulnerabilities at 2 meters of sea level rise, due to the expansion of flooding inland as water from the Bay and Estuary potentially join.	**Policy** • Establish more stringent policies for timing associated with cleanup. The timing should be based upon projected exposure to flooding. • Strengthen policies regarding storage for hazardous materials that would require additional elevation and containment. **Projects** • Cleanup or retrofit storage tanks prior to coastal flooding impacts are projected. **Monitoring** • Develop a routine monitoring of underground tanks testing for elevated groundwater and salinity that may increase the corrosion of the tanks and spread the hazardous materials beyond the parcel boundaries.



Legend
Hazardous Material Sites
Permitted Underground Storage Tanks
Cleanup sites
Coastal Erosion
Baseline
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Coastal Flooding
Baseline
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Hazardous Material Impacts
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.5 Meter
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Underground Storage Tank Impacts
Baseline
.5 Meter
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2 Meter
Tank Cleanup Site Impacts
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Technical Appendix B

Physical Processes

Figures

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Tables

Analysis of Adaptation Strategies

Purpose

The purpose of this technical appendix is to more fully discuss the results of the analyses and the details of the methodology as applied to the specific adaptation strategies examined in the larger report (particularly Section 7). The following 5 adaptation strategies were selected by the Steering committee to represent a wide range of potentially feasible alternatives to address open ocean coastal hazards.

- Hardening and armoring of the entire Imperial Beach coastline
- Managed retreat or Phased relocation
- "Business-as-usual" sand nourishment
- Dynamic revetment and dune development
- Five groins with associated sand nourishment

For purposes of the following analysis, it is assumed that each strategy would be applied uniformly to the entire urbanized portion of the City from the Coronado city limits in the north down to South end of Seacoast Drive, a total distance of about 1.5 miles.

1. Methodology and Assumptions

The economic analysis completed for this study, described in more detail in section 6.1.2 and the technical Appendix C Economic Analyses, estimates the benefits and costs of various adaptation strategies focusing on recreational and ecological benefits of the City's beach and coastal ecosystems, and the value of structures and infrastructure inland.

The economic analysis looks at the forecasted impacts of sea level rise and coastal storms on the City of Imperial Beach over a time horizon extending to 2100. In order for the economic analyses to proceed, certain input information on the physical response of the beach and upland was required. The key nexus between the physical and economic analyses required for the analyses is a time series of beach widths and upland property widths in response to the various adaptation strategies.

2. Physical

Beach Width versus Upland Property Response Model

A one-line quantified conceptual model was developed to estimate beach width changes and upland property changes over time under the five various adaptation strategies. The model was evaluated at 5-year time steps that were later interpolated to yearly beach width values through 2100.

The model calculates beach width (at each 5-year time step) resulting from the physical interaction between coastal erosion (accelerated with SLR), and each adaptation strategy. The numerical and visual representation allows the collaboration with the economists in evaluating the tradeoffs between the different adaptation alternatives based on their performance in maintaining a beach or protecting upland property, including the number of implementing treatments required, construction and maintenance costs, storm damages and fiscal impacts.

Model Inputs:

For all adaptation alternatives, the following common model inputs were used:

- Upland extent (which represents the extend of development potentially affected by coastal erosion was assumed to be 600ft.);
- Accelerated erosion rate for beach nourishment (which was assumed to be 10% per year, or 50% every 5 years);
- Beach nourishment width (fixed at 100ft for 500,000 cubic yards based on historic nourishments); and
- Beach width threshold, set to trigger or implement another adaptation treatment.

Additionally, the following additional inputs were required for the Hybrid Dune approach:

- Width of cobble nourishment (assumed 50 ft.);
- Beach width at which the cobbles start to erode (assumed at 175ft.);
- Cobble erosion rates (assumed at 90% of background accelerated erosion rate);
- Dune width (assumed at 30ft); ix) Dune erosion rates (same as background accelerated with sea level rise erosion rates); x) cobble width at which the dune starts to erode (assumed at 40ft.); and xi) Dune width at which a new complete treatment (beach nourishment, cobble replacement and dune) is triggered (assumed at dune width of 25ft.).

Model outputs include beach, cobble and dune width at each time step, as well as graphical representations of beach and upland development widths.

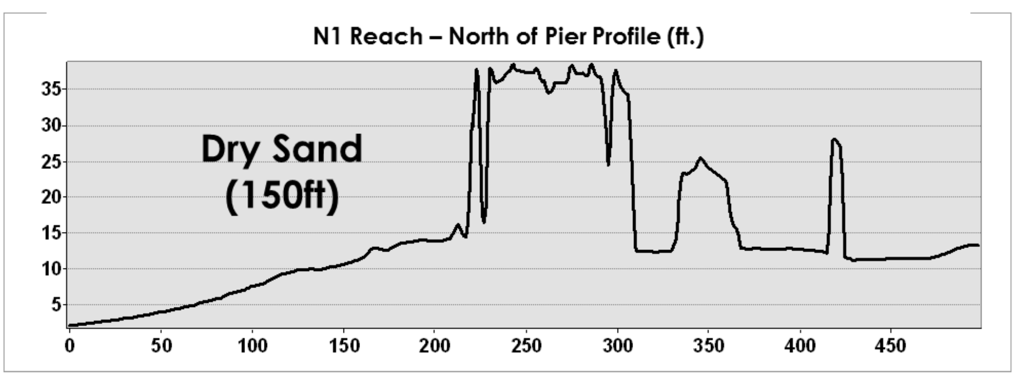
Shoreline Change Analysis

Shoreline change rates were calculated using the Digital Shoreline Analysis System (DSAS), developed by the United States Geological Survey. DSAS is a computer software that calculates shoreline changes by computing rate-of-change statistics.

Shoreline change rates were calculated for multiple beach transects, however given the similarities we selected two representative transects of a wide and narrow condition. One transect was located just north of the pier (N1, running parallel to Date Av. for 500ft), and one in the south Seacoast neighborhood (S1, running cross shore, about 500ft from the southern end of Seacoast Dr., for 45-ft), (Figure B-1).

Figure B-1. – Beach Transects used in the one-line beach width model

Horizontal profiles were extracted from first return LIDAR which shows the room top and buildings extracted along each profile for each reach (N1 and S1) as follows:



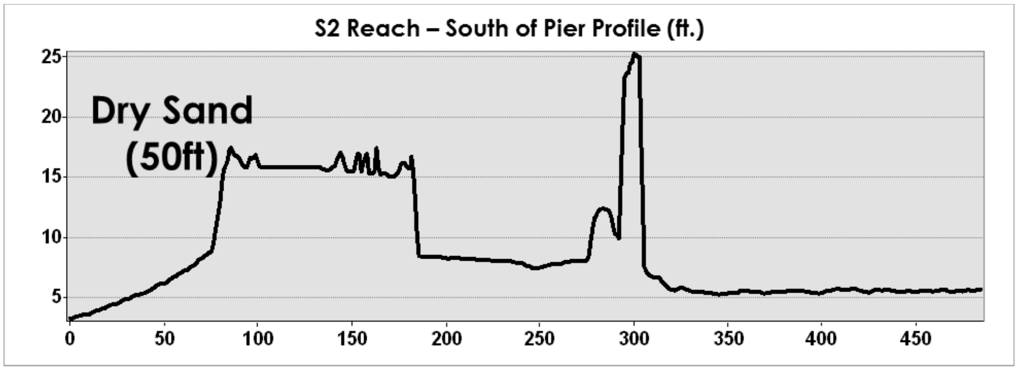


Figure B-2. Horizontal profiles (top: N1 reach; bottom: S2 reach)

Dry sand widths were derived from the beach profiles based on a mean high water mark 4.41ft (MHW of 4.60ft – 0.19ft NAVD88 from the La Jolla Tide gage). Further these widths were compared with available historic aerial photographs from google earth and ESRI's ArcGIS.

Multiple historical shorelines were used to calculate the long term shoreline change rates, including shorelines from 1852, 1887, 1933, 1972, 1998, 2005, 2008, and 2010. Shorelines were generated and downloaded from NOAA (ttps://coast.noaa.gov/dataviewer/index.html). Shoreline change analysis was conducted for 2 subsets of shoreline location. The first analyses was run for the shorelines up to 1972 which was before the nourishment practices began in the Silver Strand littoral cell. The second analyses was run for the entire shoreline time series. Comparison between the results showed minimal distinction for between the two analyses so the final analyses included the entire time series of available shoreline positions.

Once all historical shorelines were added to DSAS, long term rates were calculated (Figure B-3) with those that show a strong linear statistically significant shown in Figure B-4.

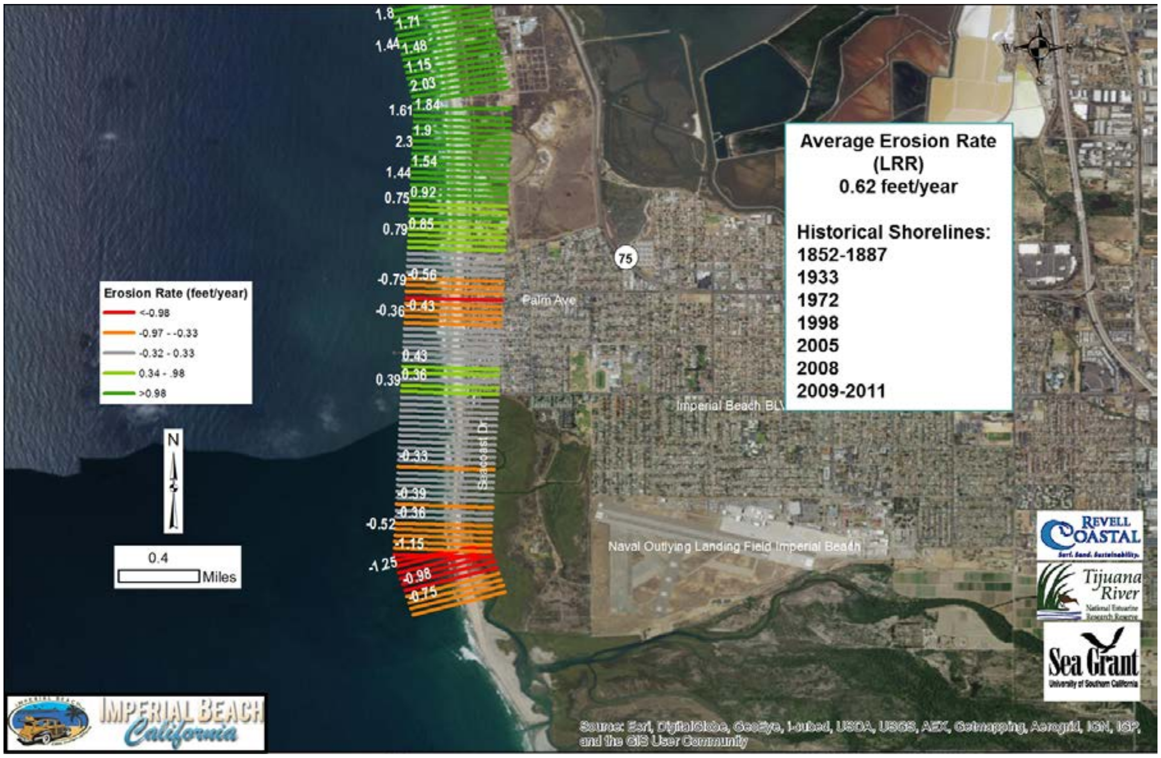


Figure B-3. - Average Long Term Erosion Rates (LRR). Green transects indicate accretion, red and orange transects indicate erosion. Erosion Rates for grey transects are within the acceptable range of uncertainties therefore were not labeled.

Figure B-4. Average Long Term Erosion with only transects with statistically significant erosion rates

Based on the results above, an erosion rate of 7.48 inches per year was used as the initial historic erosion rate for the study. Future erosion rates were accelerated based on existing erosion rates and escalated with SLR curve. (Table B-1). If other published erosion rates from the USACE (2002) of 4.7ft/year or 6.6ft/year were accelerated based on the 2.0m SLR curve, we could expect much higher erosion rates accelerated 46.6 feet (14.2m) and 65.1 feet (19.9 m) /year by 2100. These USACE rates were a result of some of analysis completed following a shorter time period between the 1940s to 1980s.

Table B-1 Erosion Rates Accelerated using the 2.0 m Sea Level Rise Curve (feet/year)

Year	This Study	Low USACE	High USACE
2000	0.6	4.7	6.6
2005	0.6	4.7	6.6
2010	0.9	6.9	9.6
2015	1.2	9.1	12.7
2020	1.5	11.3	15.8
2025	1.8	13.5	18.9
2030	2.1	15.7	22.0
2035	2.4	17.9	25.1
2040	2.7	20.1	28.1
2045	3.0	22.3	31.2
2050	3.3	24.5	34.3
2055	3.6	26.7	37.4
2060	3.8	28.9	40.5
2065	4.1	31.1	43.6
2070	4.4	33.3	46.6
2075	4.7	35.5	49.7
2080	5.0	37.8	52.8
2085	5.3	40.0	55.9
2090	5.6	42.2	59.0
2095	5.9	44.4	62.1
2100	6.2	46.6	65.1

Note that while all of these rates include the impact of storms in the shoreline change calculations, they remain conservative in that they do not account for specific storm impacts or El Niño related erosion events which could occur in any given year.

3. Adaptation Strategies

Armoring

The armoring strategy focuses on the protection of the upland property and continues to rely on the existing mix of coastal armoring structures through 2030. At that point in time, the coastal armoring structures are all upgraded to a uniform vertical recurved seawall. As erosion of the beach continues the beach is lost while the upland remains protected. The implementation and evolution of this strategy can be seen in (Figure B-5: Coastal Armoring).

Specific Assumptions

Physical –

- In 2030 when the revetment is removed then placement loss decreases from 25 feet under a revetment to a 5 feet wide with a seawall.

Economic –

- Our engineering/economic analysis assumes that existing seawalls will be built to the same specifications and will have a thirty-year lifespan.
- The economic methodology for armoring follows the methods outlined in section 6.1.2. In addition to the costs of constructing and maintaining a seawall, the study estimated the change in recreational and ecological value associated with armoring. Since armoring typically narrows the width of a beach, this loss of beach width was factored into our analysis. On the other hand, armoring strategies typically reduce upland erosion rates and this savings is also factored into the benefit/cost analysis.

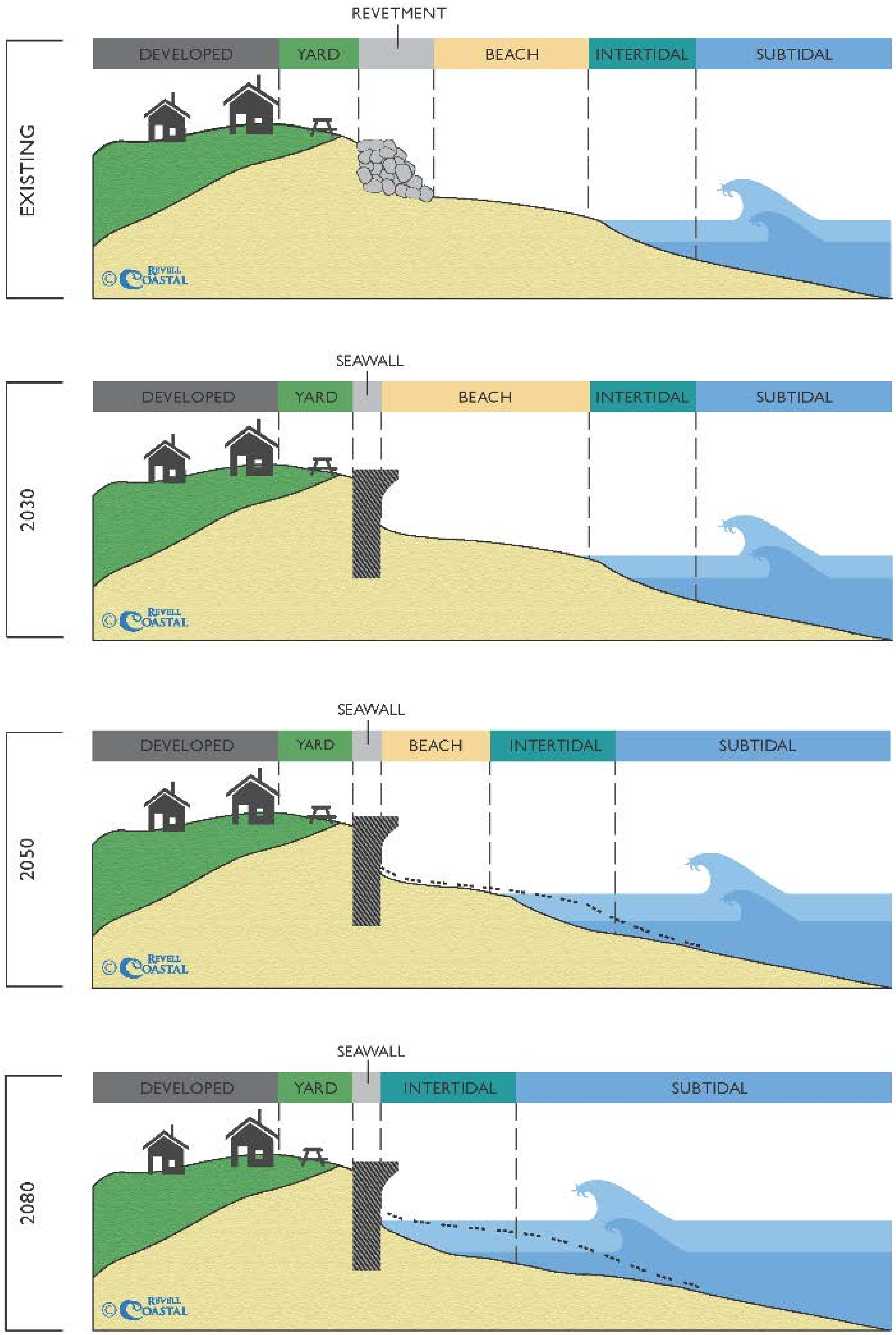


Figure 2-5. Evolution of the Armoring adaptation strategy

The economic analysis also accounts for the fact that maintenance costs for armoring solutions will increase when beach widths narrow, creating more wave energy. See the Economic Appendix C for more details about the economic analysis.

Physical Results

Results from the physical analysis of beach width versus upland property show that with armoring, dry sand beaches are likely to disappear by 2050 under narrow beach width conditions. Under wide conditions, typically seen following a nourishment, the dry sand beach is likely to disappears by 2065 and the damp sand beach disappears by 2075 (Figure B-6).

For both of these findings, it is important to note that this modeling did not include the impact of any major storm events which from historic observations can erode the beach 100+ feet in any given major storm event.

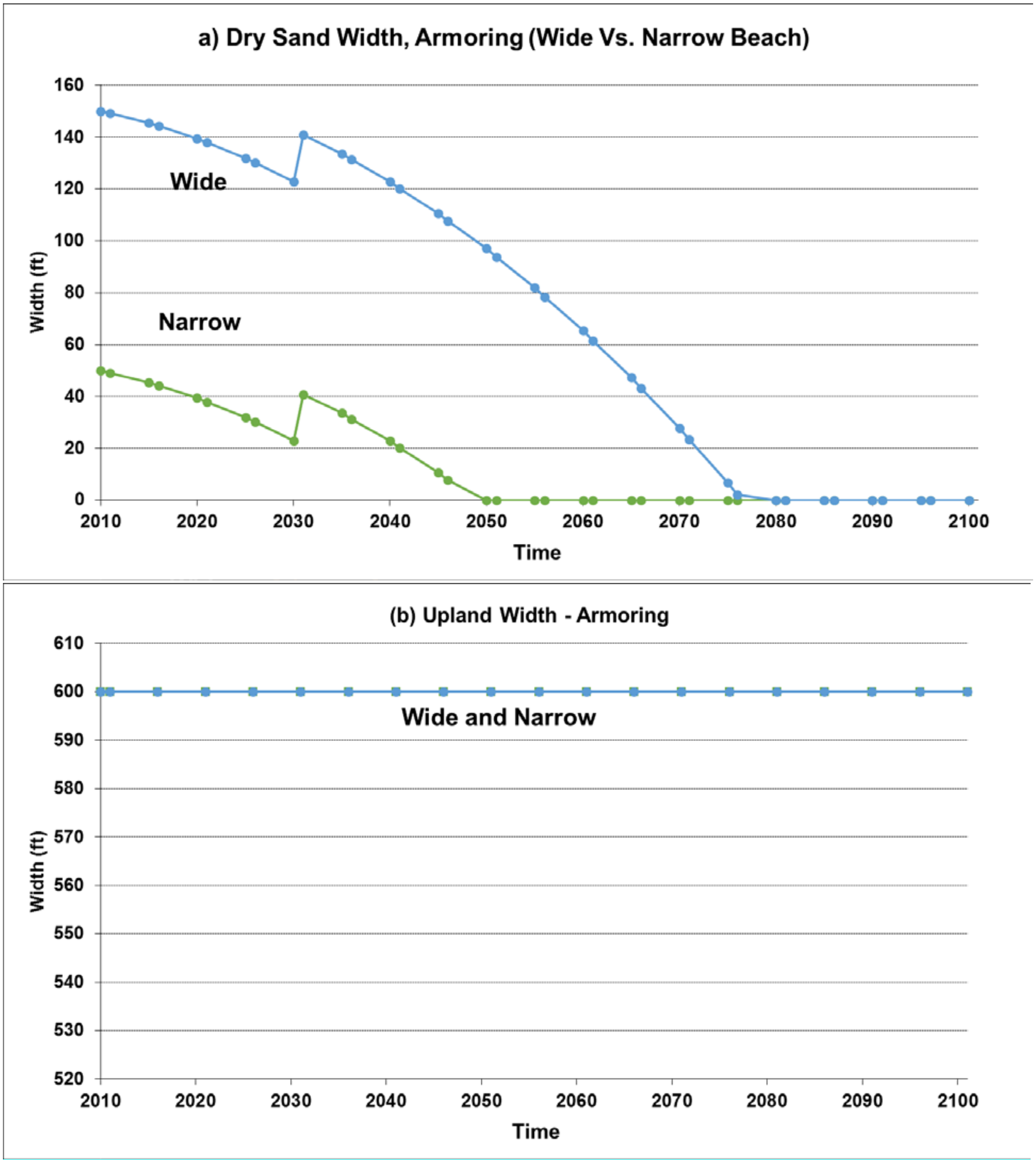


Figure B-6. a) Dry Sand Beach Width over Time with Armoring (Wide vs. Narrow Beach); b) Upland Width over Time with Armoring (Wide vs. Narrow Beach).

Managed Retreat

The managed retreat alternative prioritizes preservation of the beach and its associated recreation and ecological benefits above property protection. The intent of this alternative is to remove the shoreline armoring in 2030 and to allow the coast to erode inland thereafter. Over time, as buildings and infrastructure are damaged, removal costs and dune restoration costs occur. The implementation and evolution of this strategy can be seen in (Figure B-7: Managed retreat).

While there are many ways to implement managed retreat from both a policy and acquisition stand point, (See economic appendix for more details), this study considers a public acquisition of the at-risk properties, with a lease back option. This approach allows the City to recover a portion of the investment before the structures would have to be removed. This strategy would likely require a financing of the acquisition and a development of a lease agreement. The lease-back option is discussed in more detail in the Economic Appendix.

Specific Assumptions

Physical

- Structures removed in 2030 regain placement loss (25') then initiate managed retreat into upland
- After removal of structure and development, the beach reaches an equilibrium width of 75 (narrow) to 175ft (wide)

Economic

- The methods used here are as described in section 6.1.2. In addition, our analysis factored in the costs of removing structures, roads, pipes and water pumps, which is required for managed retreat.

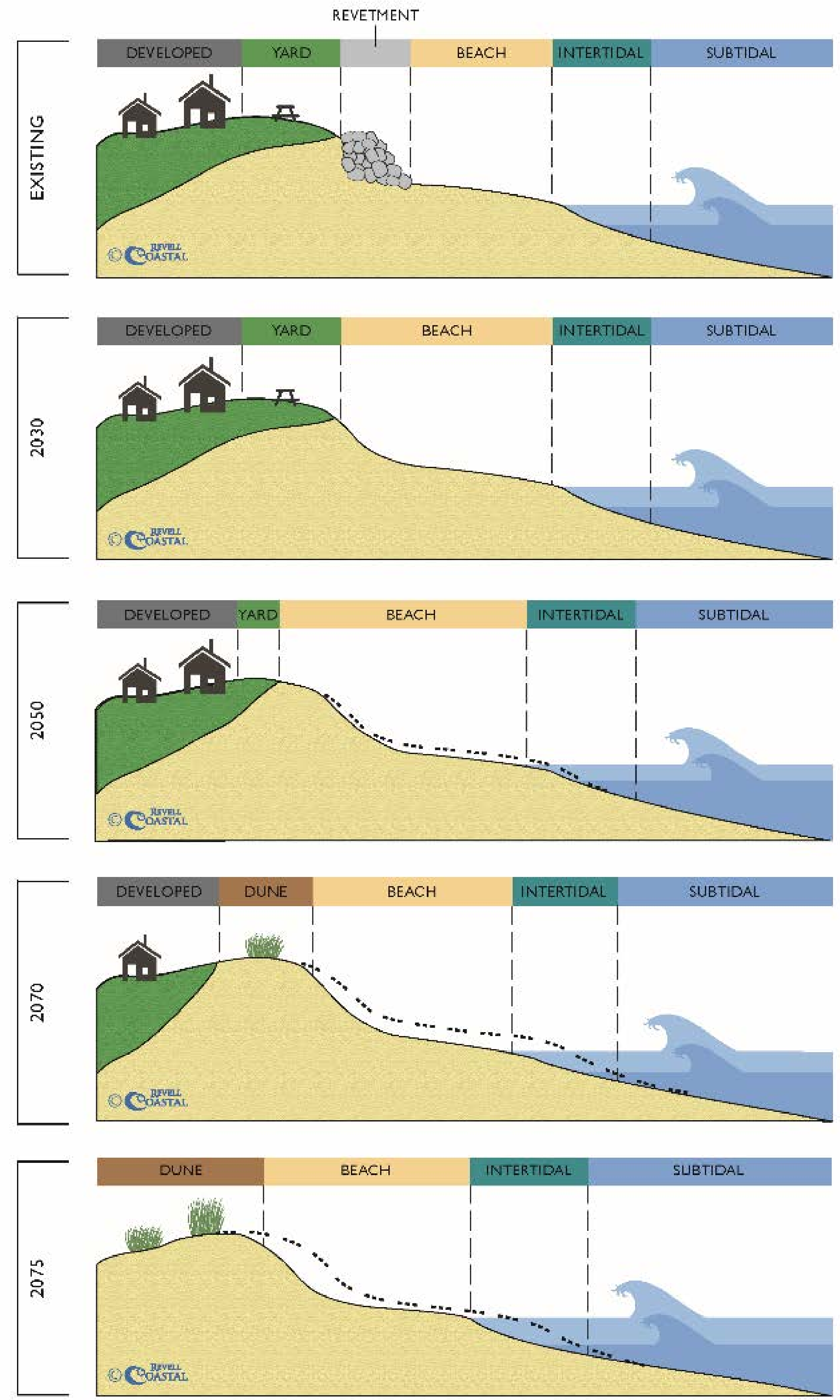


Figure B-7. **Evolution of the Managed retreat adaptation strategy**

Physical Results

Results from the physical analysis of beach width versus upland property show that under both of the beach width condition, that dry sand beaches would be maintained into the future in either a narrow condition (~75 feet wide), or a wide condition (~175 feet wide), (Figure B-8). Erosion of the upland development could reach up to 3 parcels inland which is on the inland side of Seacoast Drive.

For both findings, it is important to note that this modeling did not include the impact of any major storm events which from historic observations can erode the beach 100+ feet in any given major storm event.

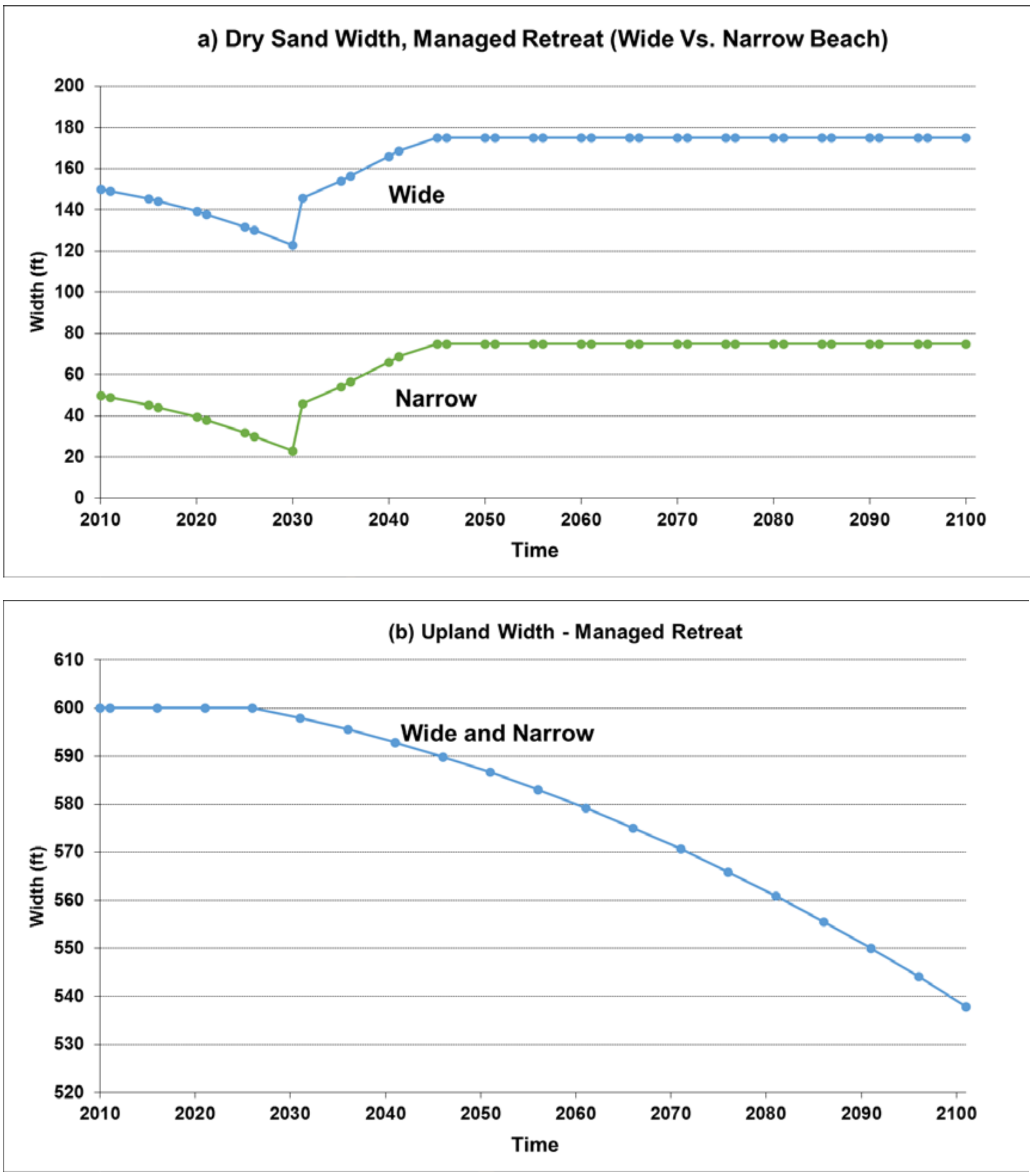


Figure B-8. a) Dry Sand Beach Width over Time with Managed Retreat (Wide vs. Narrow Beach); b) Upland Width over Time with Managed Retreat (Wide vs. Narrow Beach).

Nourishment

This "business as usual" nourishment alternative was selected to emulate what has been the most common practice in Imperial Beach, namely to periodically nourish the beaches while maintaining the existing structures. The intent of this alternative is to protect the existing upland and maintain a beach. The implementation and evolution of this strategy can be seen in (Figure B-9: Nourishment).

Specific Assumptions

Physical –

- Size tied to historic nourishment volume and size (~100' by 1.5 mile)
- Nourished sand decreases by 50% every 5 years following placement
- Renourishment triggered before upland property damages occur
- Upland eroded protected by existing armoring (with maintenance costs)

Economic

- Our cost estimating/economic analysis used recent data from the SANDAG nourishment project to estimate the costs (in cubic yards) of nourishment. Since there may be significant economies of scale in larger nourishment projects (e.g., mobilization costs for a hopper dredge may be large).
- The recreational benefits of nourishment are substantial. The CSBAT model was developed specifically for the State of California to estimate the economic benefits of increased beach width due to nourishment. More detail on this method are provided in section 6.1.2 and in our technical appendix on economics.
- The impacts of nourishment on beach ecology are mixed. Typically, nourishment projects involve burying existing ecosystems under tons of sand including bulldozing. Numerous studies (cited earlier) have found detrimental environmental impacts from nourishment. To account for this detrimental impact, this study assumed that the value of ecosystem services would be diminished by 50% in the first year after nourishment and gradually recover at a rate of 15% a year until full ecological capacity is reached (typically in 5-7 years).

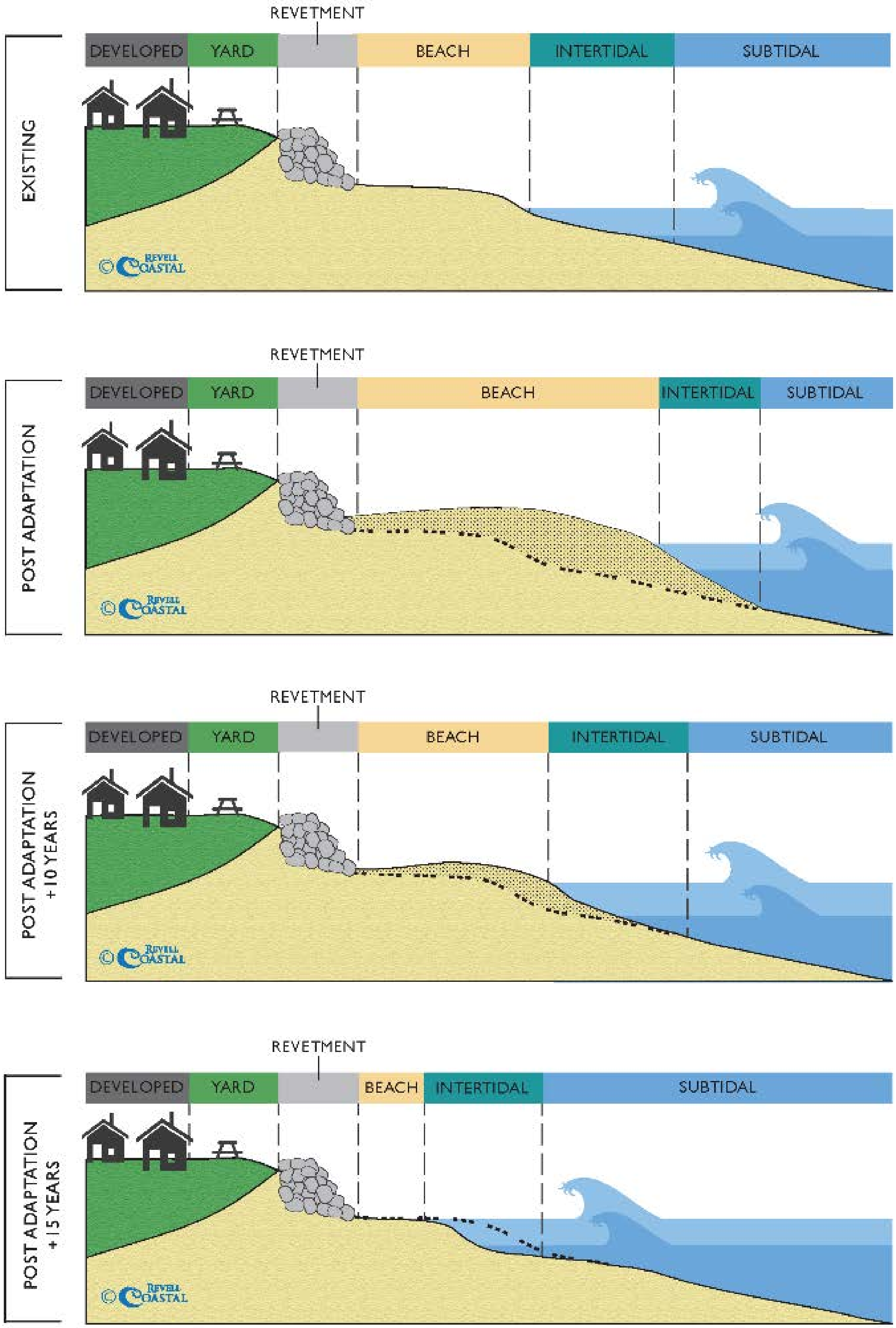
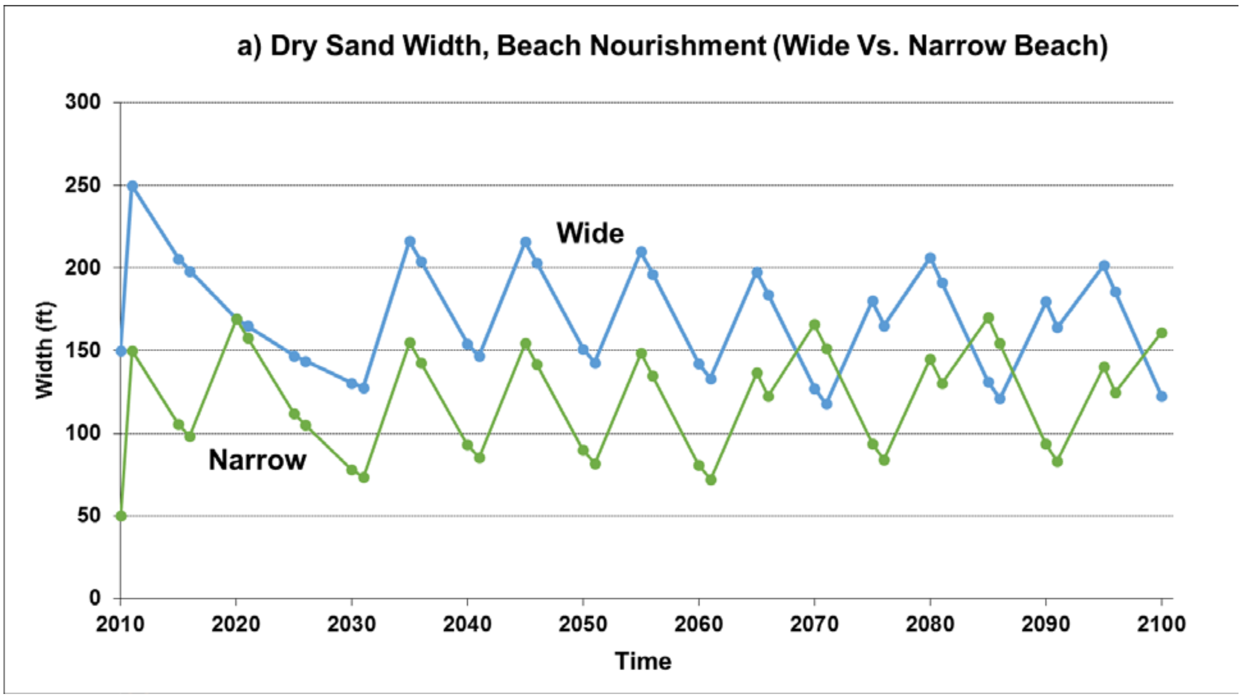


Figure B-9. Evolution of the Business As Usual Nourishment strategy.

Physical Results

Results from the physical analysis of nourishment, the beach width versus upland property show that with enough nourishment placements, the upland area can be protected while a sandy beach is maintained. To maintain a recreational beach to accommodate 6.5 feet of sea level rise, model results project that between 9 (wide) and 11 (narrow) times by 2100 to maintain beach width and protect upland property (Figure 2-10a). As sea level rises and erosion rates increase the frequency of nourishment increases. In the near future nourishments tend to occur every 15 years or so, but by the end of century, it is projected that the nourishment cycle would have to occur about every 5 years.

For both of these findings, it is important to note that this modeling did not include the impact of any major storm events which from historic observations can erode the beach 100+ feet in any given major storm event.



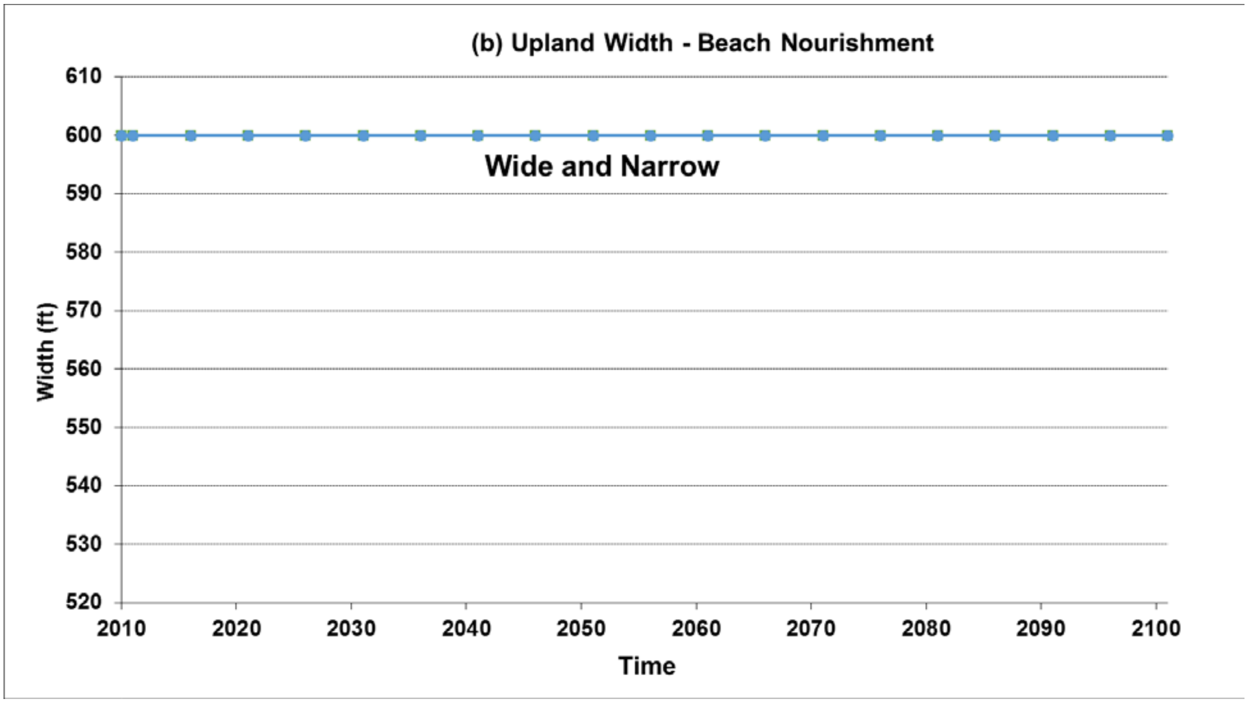


Figure B-10 a) Dry Sand Beach Width over Time with Nourishment (Wide vs. Narrow Beach); b) Upland Width over Time with Nourishment (Wide vs. Narrow Beach).

Hybrid Dune Approach

The hybrid dune approach alternative was selected to emulate what was likely the natural form and function of the coastal landscape prior to substantial human influence and development. Based on the historic ecology documented understanding of the historic condition with natural dunes and wide sandy beaches underlain by cobbles, this alternative is the closest to a green protection approach.

The intent of this alternative is to protect the existing upland with a combination of beach sand nourishment, cobble placement and dune creation. The resulting strategy then allows erosion of the beach which triggers a reduced rate of erosion in the cobbles until the cobbles narrow catalysting dune erosion. Once the dune is eroded by 1/3 with the crest elevation still intact, a new hybrid dune is implemented. The implementation and evolution of this strategy can be seen in (Figure B-11: Hybrid Dune Approach).

Specific Assumptions

Physical

- Size tied to historic nourishment volume and size (~100' by 1.5 mile).
- Cobble volume estimated based on historic observations, assumed 50 feet.
- Dune crest placed at 100 year TWL (Everest 2001 - ~20 feet NAVD).
- The nourishment experiences an accelerated erosion rate of 50% of the nourishment length every 5 years. We assume this accelerated rate to be constant throughout the 5 years (I.e. 10% loss per year).

- Once beach width is reduced to 175ft. Cobbles erode at a reduced rate of 90% of the background erosion rate.
- Once the cobbles width reaches 25ft, Dune erodes occurs at the background erosion rate accelerated with sea level rise.
- Reconstruction is triggered once the dune is eroded by 1/3.
- **Economic**
- We assumed that dunes have recreational value similar to beach width
- The economic assumptions for a hybrid dune are similar to nourishment.

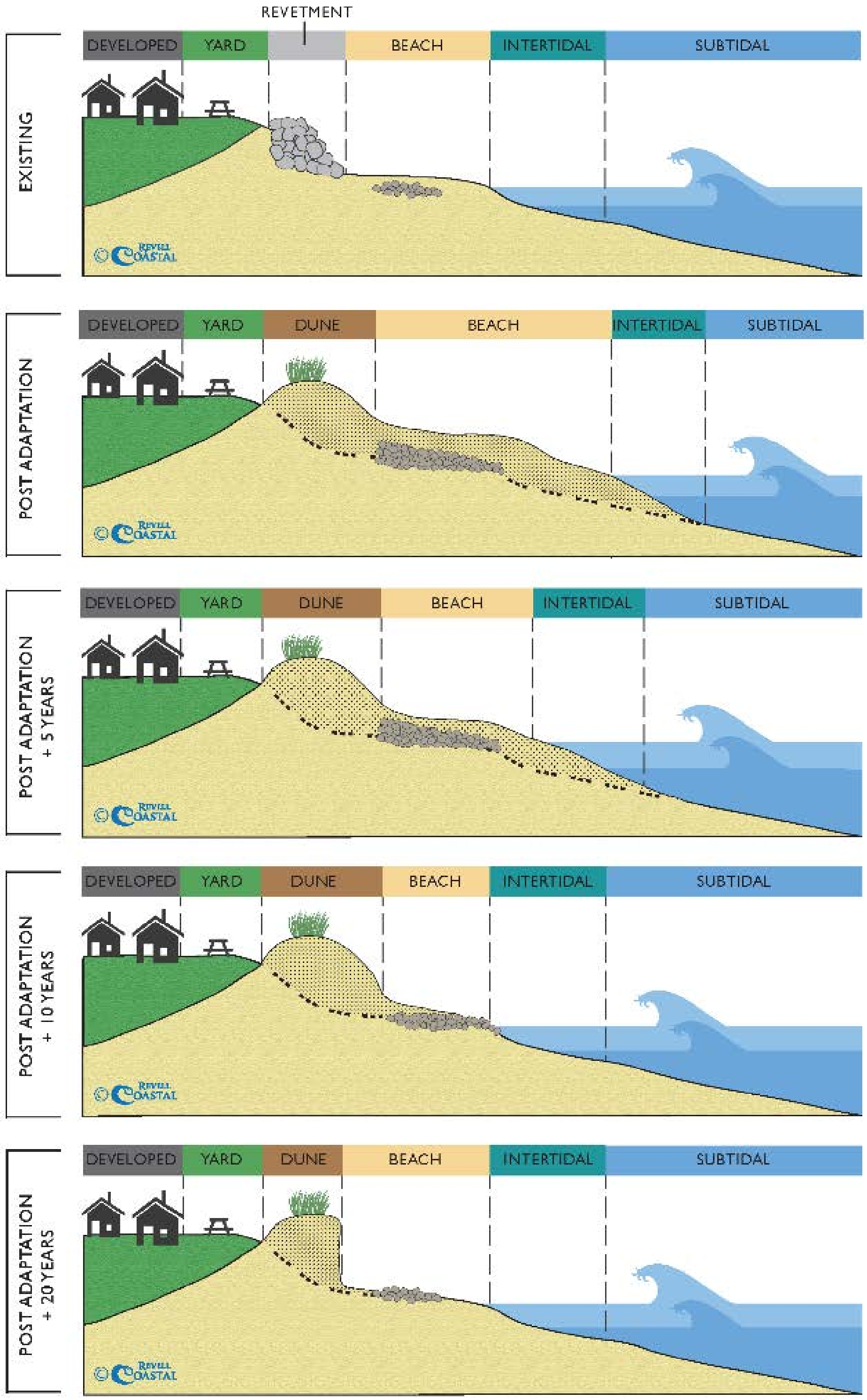


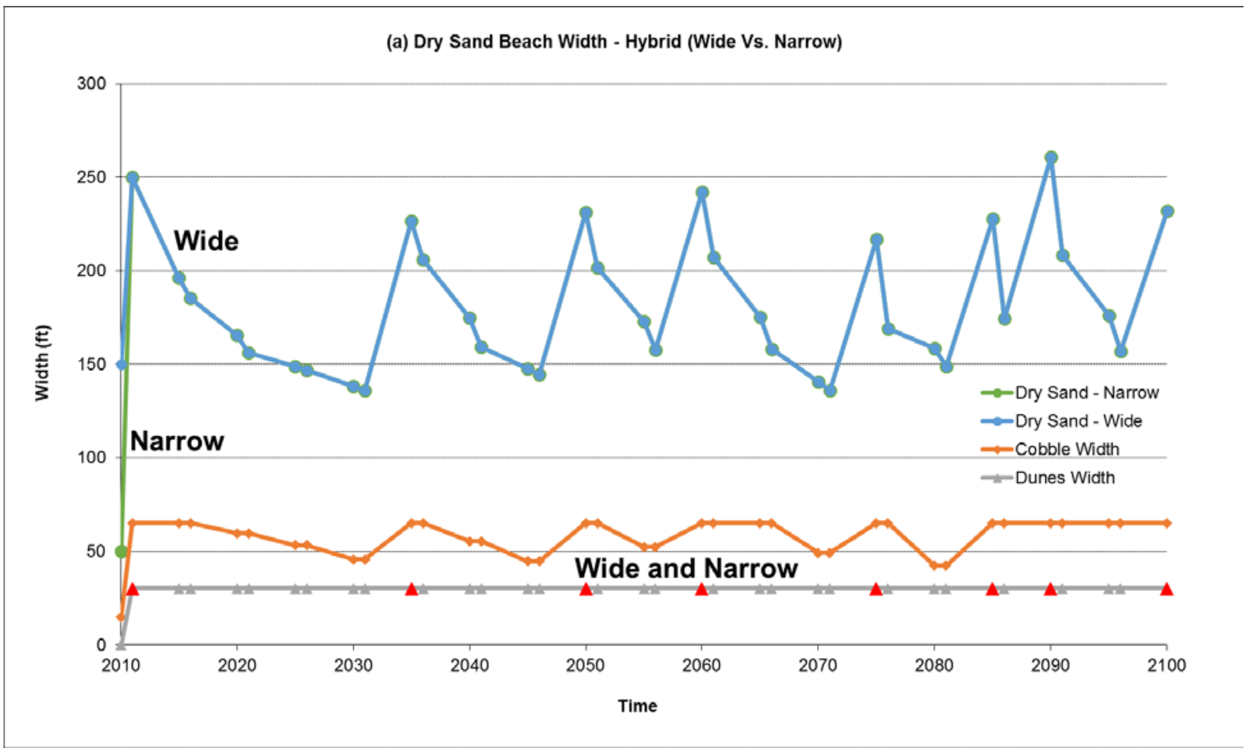
Figure B-11 Evolution of the Hybrid Dune Approach nourishment strategy.

Physical Results

Results from the physical analysis of beach width versus upland property show that both the upland can be protected while maintaining a sandy beach with enough hybrid dune nourishment placements. To maintain a recreational beach to accommodate 6.5 feet of sea level rise, model results project 8 (wide) and 9 (narrow) times by 2100 to maintain beach width and protect upland property. The key difference between the wide and narrow beach is that under the narrow condition, there must be a double nourishment in the beginning to provide enough space to construct the entire strategy and then it is maintained the same as the wide beach.

As sea level rises and erosion rates increase the frequency of the hybrid nourishment placements increases. In the near future nourishments tend to occur every 15 years or so, but by the end of century, it is projected that the nourishment cycle would have to occur about every 5 to 10 years (Figure B-12).

For both of these findings, it is important to note that this modeling did not include the impact of any major storm events which from historic observations can erode the beach 100+ feet in any given major storm event.



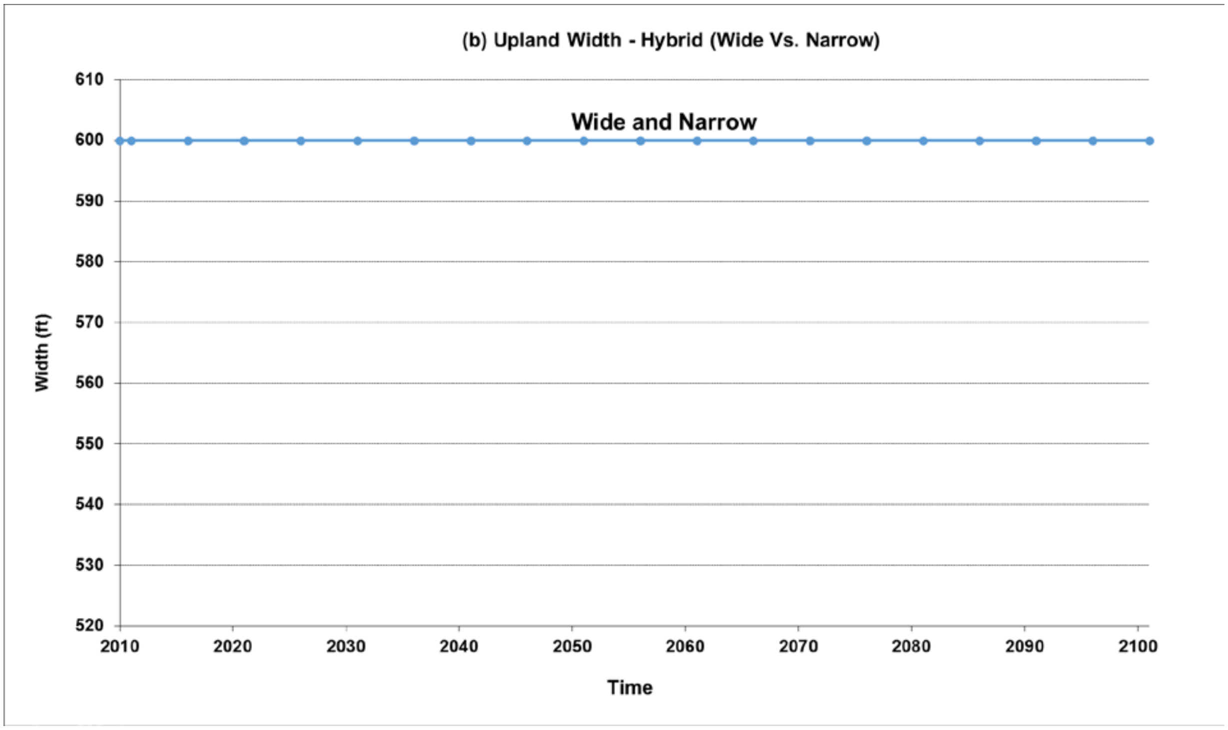


Figure B-12 a) Dry Sand Beach Width over Time with Hybrid Approach (Wide vs. Narrow Beach); b) Upland Width over Time with Hybrid Approach (Wide vs. Narrow Beach).

Groins

The intent of this alternative is to protect the existing upland with a completion with revisions of the original Army Corp of Engineers 5-groin concept, with some extension of the existing two groins and the construction of 3 new groins to a length of 930 feet. The construction of the groins as a sediment retention structure is coupled with a nourishment which fills the groin compartments and reduces the likelihood of downcoast erosion impacts to the City of Coronado and Silver Strand State Beach. This charging of the groin field is akin to filling up a leaky barrel (aka filling with sand) and should mitigate the downcoast erosion commonly associated as the primary downside of groins. It is also assumed that the existing coastal armoring structures remain and the widen beach from the nourishment reduces the armoring maintenance costs.

The resulting strategy constructs the groins and nourishment with additional nourishment triggered once the beach reaches a certain threshold beach width. As the beach narrows, additional implementations and the evolution of this strategy can be seen in (Figure B-13: Groins).

Specific Assumptions

Physical

- Groin based on 350-foot extension as per Joe Ellis recommendations and consistent with the San Diego Beach retention strategy with specific measures from Oceanside where each groin totals 930 feet
- Groin retains sand for some equilibrium distance downcoast (based on San Diego Beach Retention Strategy

- Nourishment of 100 feet to avoid downcoast impacts
- Nourished sand retained with 25% loss every 5 years
- Background erosion accelerated with Sea Level Rise
- Wide Beach is re-nourished when it narrows below 150ft
- Narrow Beach is re-nourished when it narrows below 75ft

Economic

- In this study we assumed that groins did not have a positive or negative impact on recreational experiences.
- Groins can increase the recreational experience for fishermen or possible surfers, but can also detract from the aesthetics of a beach. Groins do inhibit the movement of some biota on the beach, but this was also not factored into our analysis.

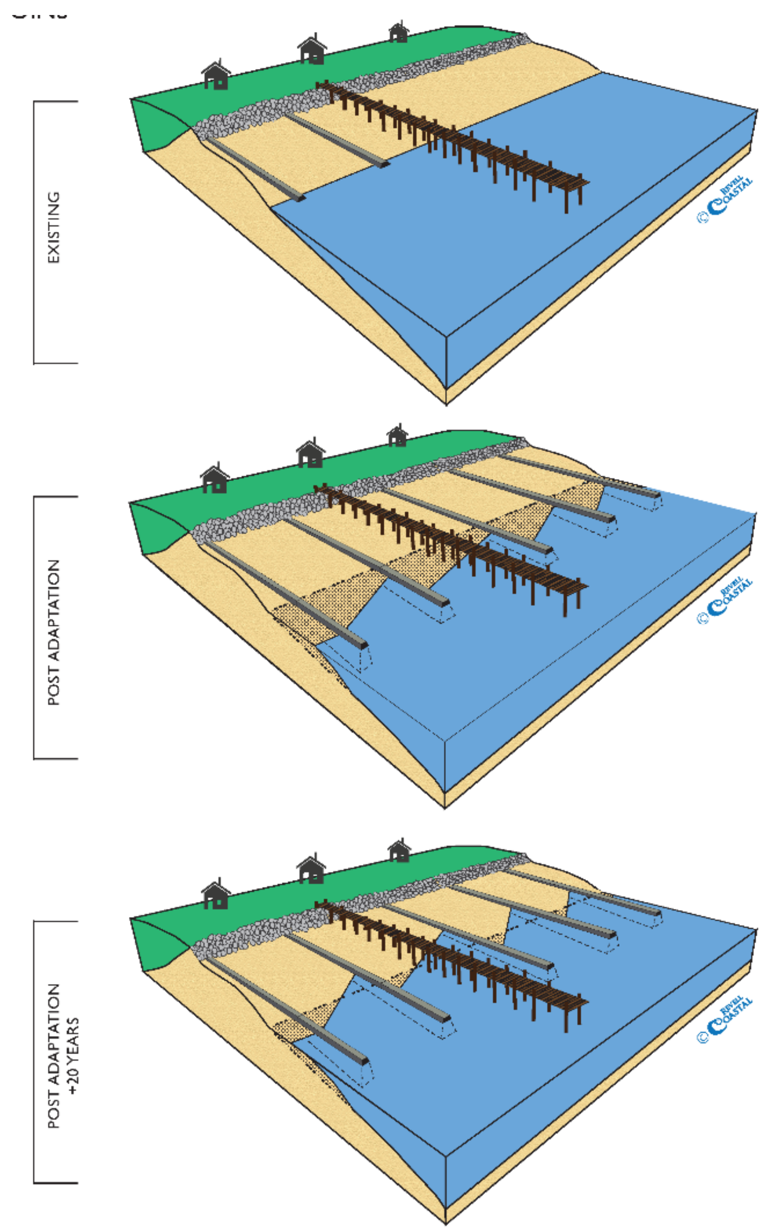


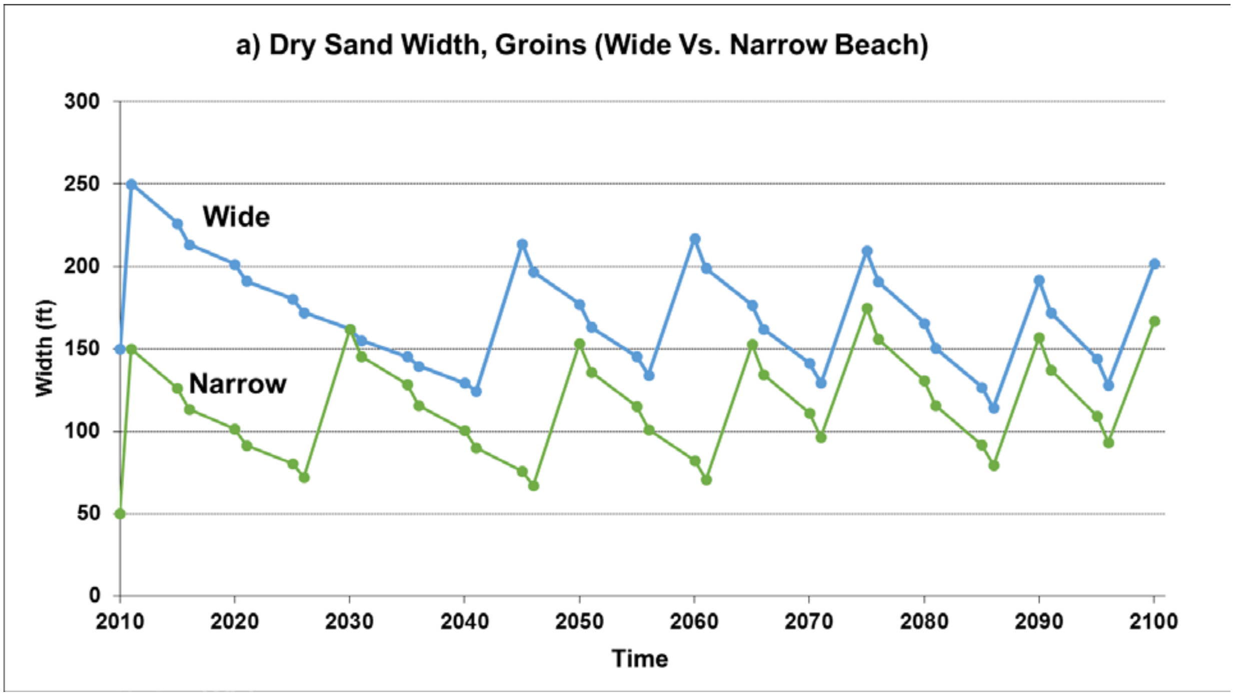
Figure B-13 Sand retention with groins adaptation strategy implementation over time.

Physical Results

Results from the physical analysis of beach width versus upland property show that both the upland can be protected while maintaining a sandy beach retained with groins. To maintain a recreational beach to accommodate 6.5 feet of sea level rise, model results project 6 (wide) or 7 (narrow) nourishment placements along with groin maintenance by 2100 to maintain beach width and protect upland property (Figure B-14).

As sea level rises and erosion rates increase the frequency of the nourishment placements increases. In the near future nourishments tend to occur every 25 years or so, but by the end of century, it is projected that the nourishment cycle would have to occur about every 10 years.

For both of these findings, it is important to note that this modeling did not include the impact of any major storm events which from historic observations can erode the beach 100+ feet in any given major storm event. Since the 1970s, beach nourishments have typically lasted between 10 and 15 years depending on the size of placement.



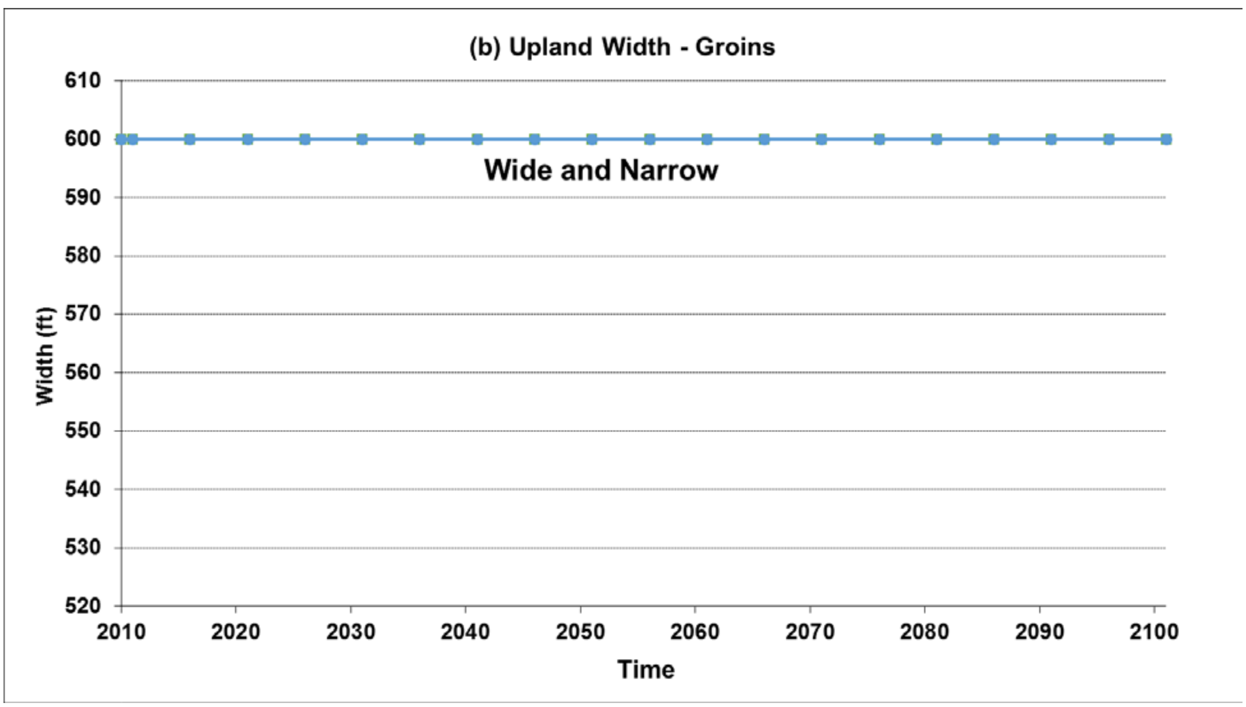


Figure B-14 a) Dry Sand Beach Width over Time with groins (Wide vs. Narrow Beach); b) Upland Width over Time with groins (Wide vs. Narrow Beach).

Technical Appendix C

Economic Analyses

Figures

Tables

Economic Methodology

This section provides a more in-depth analysis of the methods used in this study. We've divided this discussion into three parts:

- A discussion of recreation and the data/methods used to estimate the benefits/impacts of beach recreation.
- A discussion of the analysis of inland property, in particular parcel/buildings and infrastructure at risk.
- A discussion of the adjustments made for future values.

Although beach spending is a useful metric, economists measure the (non-market) value of beach recreation not by how much people spend, often referred to as economic impact, but by their willingness to pay to recreate at a beach. Since beaches in California are free, economists have developed various techniques to elicit how much a beach trip is worth, based on a visitor's willingness to pay for the beach experience.

Our estimates for the economic value of beach recreation are based on attendance estimates and an economic valuation model developed by Dr. King for the State of California and the U.S. Army Corps of engineers, the California Sediment Benefits Analysis Tool, (CSBAT) a benefits transfer model. The CSBAT model allows one to estimate the gain or loss in recreational value as beach width decreases (e.g., due to erosion) or increases (e.g., due to nourishment). These techniques are discussed in more detail below.

1.1 Attendance

We estimated attendance from three sources: (1) King and Giliam (2015) estimate attendance for a number of SANDAG fill sites including Imperial Beach); (2) Transient occupancy tax data from the City of Imperial Beach, combined with surveys performed by King and Giliam (2015) allow us to project annual attendance; (3) interviews with lifeguards from the City of Imperial Beach who have an informal daily lifeguard count.

1.1.1 Attendance Counts

The data for the SANDAG study was taken from periodic counts and estimates from a study conducted by Dr. King and Mr. Giliam. From May of 2012 to June of 2013, research assistants traveled to beaches across San Diego County in order to conduct periodic counts at each of the SANDAG fill sites. For each beach, the assistants performed head counts at various times throughout the year. The daily attendance for each beach was then estimated by multiplying the number of people observed at the beach during the counting by an attendance multiplier. Attendance multipliers (also sometimes referred to as "turnover factor") are used to estimate how many people visit a beach on an entire given day based on how many people are counted at the beach at one particular time during that day[1]. These attendance estimates will then be used in subsequent sections in order to determine both the local economic impact and the increase in recreational value produced by the RBSP II nourishments

Table 1. Attendance Multipliers for Southern California Beaches

Attendance Multipliers		
Time of Count	**Not Surfing**	**Surfing**
10:00 - 11:00	3.05	3.45
11:00 - 12:00	2.65	3.00
12:00 - 13:00	1.82	2.13
13:00 - 14:00	1.66	1.72
14:00 - 15:00	1.51	1.71
15:00 - 16:00	1.58	2.25
16:00 - 17:00	2.03	5.48

Table 1 (above) shows the various multipliers that can be applied to head counts taken at various times of day at Southern California beaches in order to estimate the total attendance at that beach for the entire day. For example, if at 12:30 p.m. we conducted a head count, we would multiply the number of non-surfers we counted by 1.82 and surfers by 2.13 in order to estimate the total number of non-surfers and surfers that recreate at the beach for the day.

In order to ensure both accuracy and consistency, assistants were trained beforehand as to the proper manner in which these head counts should be performed. For example, assistants were careful to distinguish between and gather accurate samples from both surfers and non-surfers. They were instructed to perform head counts during both the busy season (May – September) as well as the slow season (October – April). Finally, they also were sure to gather attendance data both during slower weekdays (Monday – Friday during the slow season, Monday –Thursday during the busy season), as well as Fridays during the busy season, in addition to the much busier weekends (Saturdays and Sundays). Thus, assistants gathered representative samples for the 10 different categories of beach trips, as shown in **Table 2** (below) for each fill site:

Table 2. Types of Attendance Counts

Types of Attendance Counts			
		Surfing	**Non-Surfing**
Slow Season (Oct.- Apr.):			
	Sat-Sun	x	x
	Mon-Fri	x	x
High Season (May - Sep.):			
	Mon-Thur	x	x
	Friday	x	x
	Sat-Sun	x	x

[1] See *Philip King, Aaron McGregor (2012).* Who's counting: An analysis of beach attendance estimates and methodologies in southern California. Ocean & Coastal Management 58 (2012) 17 25

From this data we were able to approximate the annual attendance at each beach. 3 (below) lists the estimated number of total annual visits to each beach in 2013.

Table 3. Annual Attendance for RSBP II Beaches

Annual Attendance for RSBP II Sites	
Fill Site:	**Annual Attendance:**
Oceanside	363,367
N. Carlsbad	255,144
S. Carlsbad	110,428
Batiquitos	198,918
Moonlight	330,536
Cardiff	93,783
Solana	50,194
Imperial	312,171

1.1.2 Transient Occupancy Tax (TOT) Revenue

The SANDAG project above was not limited to providing attendance counts, but also included an intercept survey for beach visitors in order to gather data on beach visitor characteristics (e.g., residence, income, etc.) beach preferences (e.g., activity at the beach) and beach related spending (see below). Using the data thus gathered regarding lodging expenditures during overnight trips, and the annual transient occupancy tax (TOT) revenue for the City of Imperial Beach, we can thus provide an independent estimate of annual beach attendance.

Table 4. Attendance Estimates Based on TOT Revenue

Year	TOT Revenue	Lodging Expenditures	Lodging Exp./ Overnight Visit	Overnight Visits	Estimated Attendance
2004	$233,919	$2,339,190	$25.25	92,631	364,688
2005	$279,826	$2,798,260	$25.25	110,810	436,259
2006	$265,355	$2,653,550	$25.25	105,079	413,698
2007	$259,508	$2,595,080	$25.25	102,764	404,582
2008	$209,022	$2,090,220	$25.25	82,772	325,873
2009	$175,791	$1,757,910	$25.25	69,612	274,064
2010	$163,723	$1,637,230	$25.25	64,833	255,250
2011	$224,220	$2,242,200	$25.25	88,790	349,567
2012	$230,942	$2,309,420	$25.25	91,452	360,047
2013	**$223,612**	**$2,236,120**	**$25.25**	**88,549**	**348,619**
2014	$386,421	$3,864,210	$25.25	153,021	602,444
2015	$639,983	$6,399,830	$25.25	253,430	997,756
2016	$395,486	$3,954,860	$25.25	156,610	616,577
Average:	**$283,678**	**$2,836,775**	**$25.25**	**112,335**	**442,263**

Table 4 (above) illustrates how we used the annual TOT revenue for the City of Imperial Beach (the second column) to estimate the annual beach attendance in Imperial Beach (the final column). Using the year 2013 as an example (the same year in which the SANDAG attendance counts were performed), a TOT revenue of $223,612 and a 10% TOT rate together imply that the total spending on lodging within the city would be $2.24 million dollars annually. The average lodging expenditures, per person per night, during an overnight trip is $25.25, meaning that the $2.24 million dollars was distributed among 88,500 overnight visits to Imperial Beach. Since only 25.4% of all visits to the beach are overnight visits, the estimated attendance for the entire year of 2013 is 349,000. This is slightly higher than the attendance estimate arrived at above (312,000), but not unreasonably so and may be due to the construction of a new hotel in Imperial Beach. The average attendance for Imperial Beach, based in TOT revenue, is 442,000 visits per year.

1.1.3 Lifeguard Counts

The third method used to estimate the annual beach attendance involved consulting the daily head counts gathered by the lifeguards of Imperial Beach. On April 12th, 2016, we interviewed the lifeguard captain, Robert Stabenow, in order to collect their attendance count data and the methods employed in these estimates. As noted above (King and McGregor, 2012), lifeguards prioritize the safety and well-being of beach visitors over the accurate quantification of daily attendance. Practical constraints such as these and the lack of a standardized methodology often lead to a significant overestimation of beach attendance by lifeguards.

Table 5. Annual Beach Attendance based on Lifeguard Daily Counts

Year	Estimated Attendance	Multiple of TOT Estimates
2009	3,537,400	12.9
2010	2,591,800	10.2
2011	1,918,700	5.5
2012	2,447,700	6.8
2013	2,166,000	6.2
2014	2,601,000	4.3
2015	3,278,000	3.3
Average:	**2,648,657**	**4.3**

Table 5 (above) clearly illustrates the tendency for the summation of daily estimates by lifeguards to be significantly greater than those arrived at by ways of actual head counts or TOT revenue. For 2013, the lifeguard estimate is over six times that arrived at through the other two methodologies, although the results do seem to converge over time. The average annual attendance, as estimated by daily lifeguard estimates is 4.3 times that arrived at by TOT revenues. This discrepancy is due to two factors: 1) the tendency mentioned above for all lifeguards to overestimate attendance and 2) the jurisdiction of the Imperial Beach lifeguards, and thus their attendance estimates, includes the visitors to the pier and other locations that are not part of the sandy beach proper.

Given the uncertainty surrounding attendance, we decide to use a value of 500,000 per year, which is somewhat higher than our estimates, but much lower than lifeguard counts. We also believe that the construction of two hotels and other improvements at Imperial Beach is likely to lead to an increase in attendance above and beyond the increase in population/income we did model in this project.

1.1.4 Sensitivity to Attendance and Recreation Value

Due to the imprecise methods and the uncertainty regarding actual attendance, we performed a sensitivity analysis with respect to attendance and day use value (the two variable are interchangeable such that doubling one while reducing the other by 50% results in zero net change). Our model assumes 1) a Max Day Use value of $38, 2) an annual attendance of 500,000 and 3) that the 500,000 attendance number corresponds to a 125 ft. beach width. (below) depicts how the results vary as we increase beach attendance (up to 2 million) or decrease it (down to 125,000).

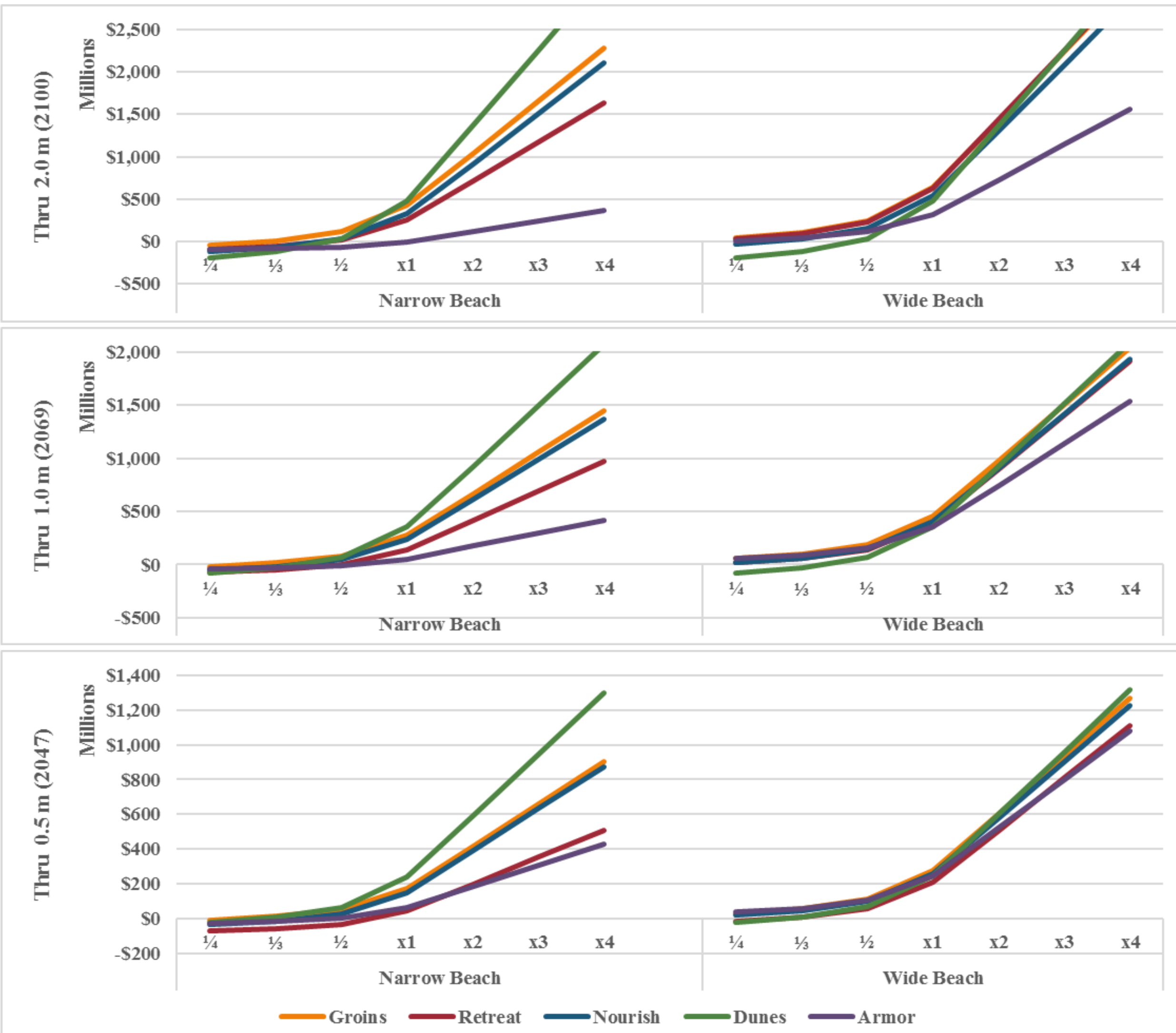


Figure 1. Sensitivity to Recreational Value (Annual Attendance and Day Use Value)

Within the narrow beach scenario, larger annual beach attendance makes Retreat and Armoring significantly worse compared to the nourishment strategies that attract beach visitors with a wider beach. For this same reason, Dunes stands out above the rest due to its wide, sandy beach. If, however, recreation value is only 50% of what we estimate due, for instance, to annual attendance being half of our estimates, then Groins are preferred above Dunes in the narrow beach, especially in the short run.

Within the wide beach scenario, Dunes do not beat Groins or Retreat unless recreational value is at least 2.5 times that assumed by our model (1.25 million annual visits, if we assume the same day use value). A larger recreation value, again, makes Armoring much worse than the other strategies. Retreat also does worse than the three nourishment options within the short run, if the annual attendance is larger than our 500,000 estimates.

To summarize, the sensitivity results of our model do not vary greatly with respect to our attendance estimates. On the one hand, an annual attendance closer to that provided by the lifeguards of Imperial Beach make nourishment strategies somewhat better and, on the other hand, make armoring and (in some cases) retreat significantly worse.

1.2 Beach Survey and Beach Width

In addition to periodic counts, King and Giliam conducted a survey of beach visitors at SANDAG fill sites. Our estimates of visitor type (day trippers vs. overnight visitors) at Imperial Beach is based on these survey results—in this report we only used responses from Imperial Beach visitors since visitor type varies significantly by beach/reach.

The SANDAG survey was also used to calibrate beach width preferences. (In this case we used the entire sample of all beaches.) The survey asked beach-visitors how many more or fewer times they would visit that particular beach if its width were, respectively, double or half what it was on the day of the survey. These changes in annual attendance will allow us to estimate the impact that beach nourishment has on annual attendance counts.

1.2.1 Decreasing Beach Width

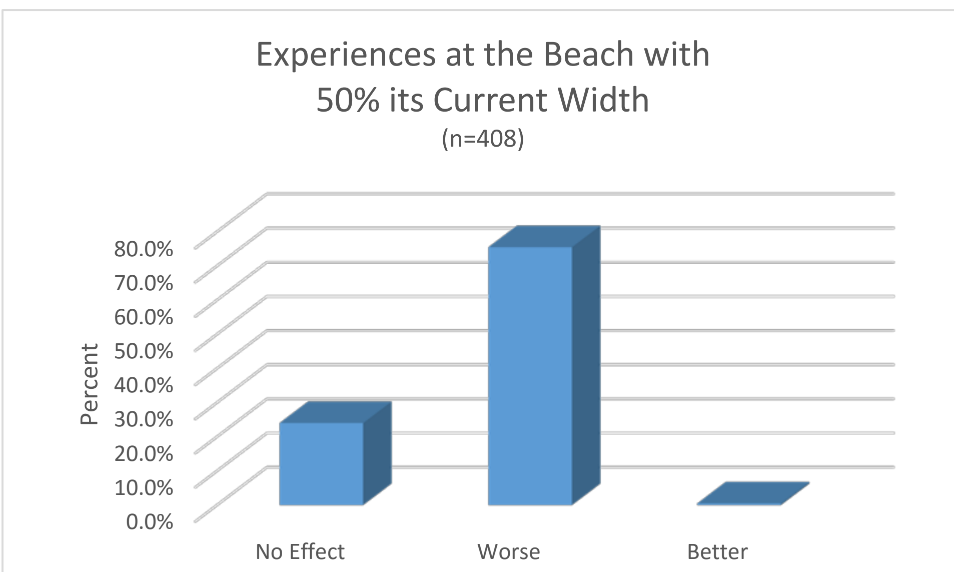


Figure 2. Respondent's Experiences at a Beach with 50% its Current Width

Respondents were asked, "Suppose this beach was half its current width. Would this change your experience at the beach?" **Figure 2** (above) shows that **a strong majority (76%) indicated that this**

decrease in beach-width would negatively affect their experience at the beach. A significant minority (24%) indicated that their experience would remain unchanged by such a decrease. Less than 1% thought that a decrease in beach-width would make their experience better.

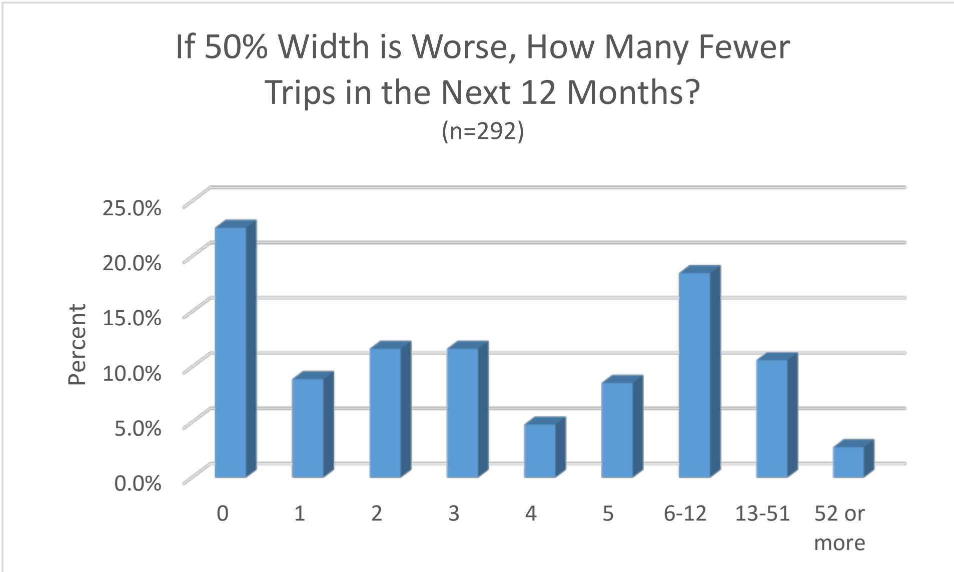


Figure 3. Decreases in Attendance Due to a 50% Decrease in Width

The strong majority who indicated in the previous figure that reducing the beaches width by half would make their experience worse were asked, "If worse, about how many fewer trips to this beach would you take over the next 12 months?" Somewhat unexpectedly, **Figure 3** (above) shows that the most popular response (23%) was that the respondent would not decrease their number of visits to the beach at all. Of the remaining 77% who said that they would decrease their number of visits to the beach, the responses were more or less evenly distributed, ranging from "1" to "52 or more". The second most common response among this group came from those who said they would reduce their number of visits to that beach by 6-12 times over the next 12 months.

The two respondents who indicated that reducing the beaches width by half would make their experience better were asked, "If better, about how many more trips to this beach would you take over the next 12 months?" **Figure 4** (below) indicates that one respondent answered that they would not increase their number of visits to the beach at all, while the other indicated that they would visit the beach 3 more times over the next 12 months.

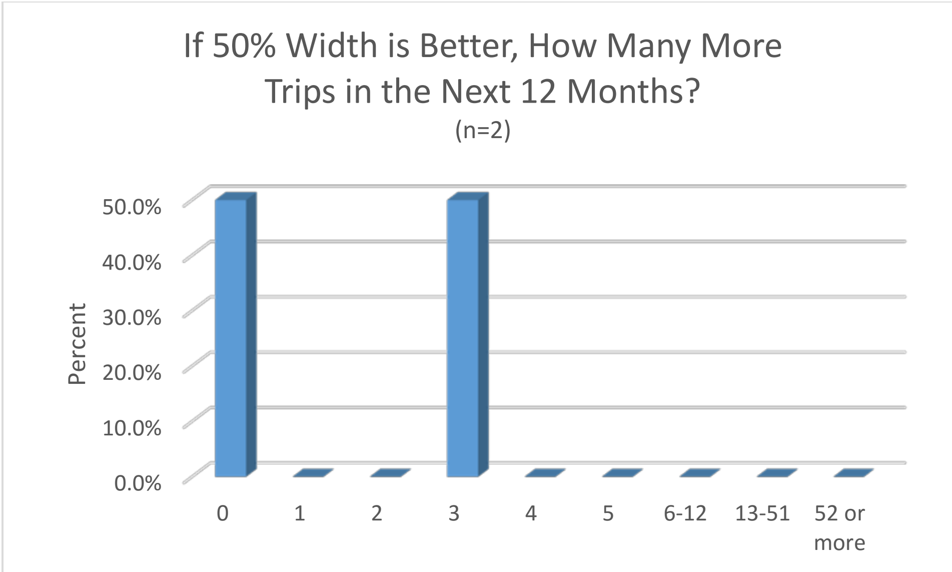


Figure 4. Increases in Attendance Due to a 50% Decrease in Width

1.2.2 Increasing Beach Width

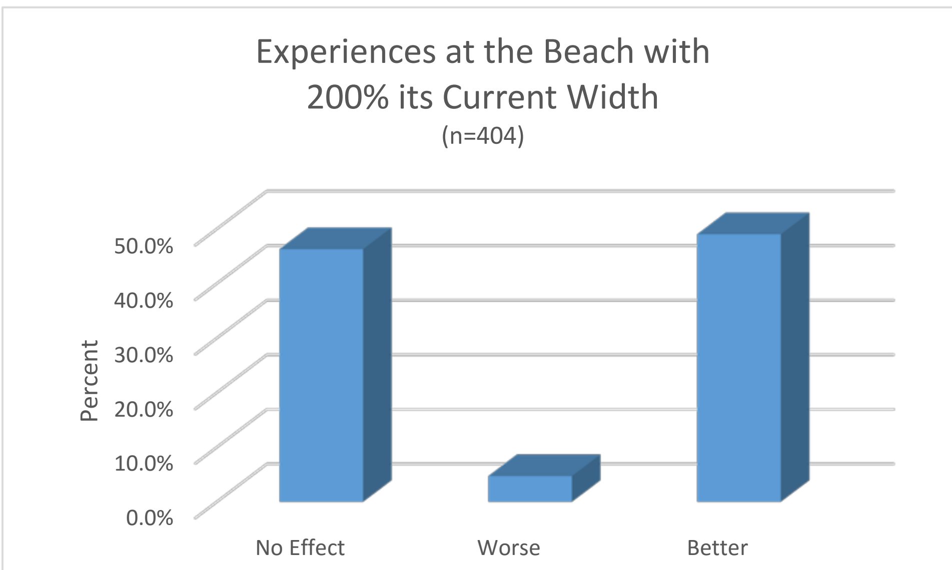


Figure 5. Distribution of Respondent's Experiences at a Beach with 200% its Current Width

While the preceding three figures were concerned with respondents' preferences regarding a smaller beach-width, we were also concerned with their preferences regarding a larger beach-width. Respondents were thus asked, "Suppose this beach was twice its current width. Would this change your experience at the beach?" **Figure 5** (above) indicates that of the 404 responses, **approximately half (49%) answered that this increase in beach-width would positively affect their experience at the beach** while, again, almost half (46%) indicated that their experience would remain unchanged by such an increase in beach-width. A small minority (5%) thought that an increase in beach-width would make their experience worse.

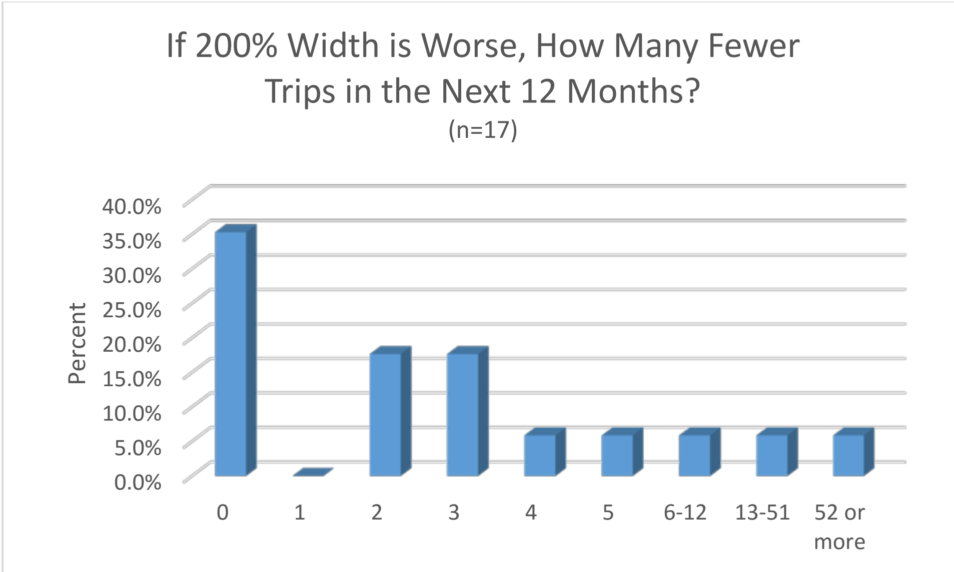


Figure 6. Decreases in Attendance Due to a 100% Increase in Beach-width

The 5% who indicated in Figure 10 that doubling the beach-width would make their experience worse were also asked, “If worse, about how many fewer trips to this beach would you take over the next 12 months?” **Figure 6** (above) shows that of these 17 responses, the most popular (35%) was that the respondent would not decrease their number of visits to the beach at all. Of the remaining 65% who said that they would decrease their number of visits to the beach, the more popular responses were a decrease in 2 and 3 visits (18% for each) over the next 12 months with the remaining 30% of respondents indicating that they would decrease their number of visits to the beach by more than 3.

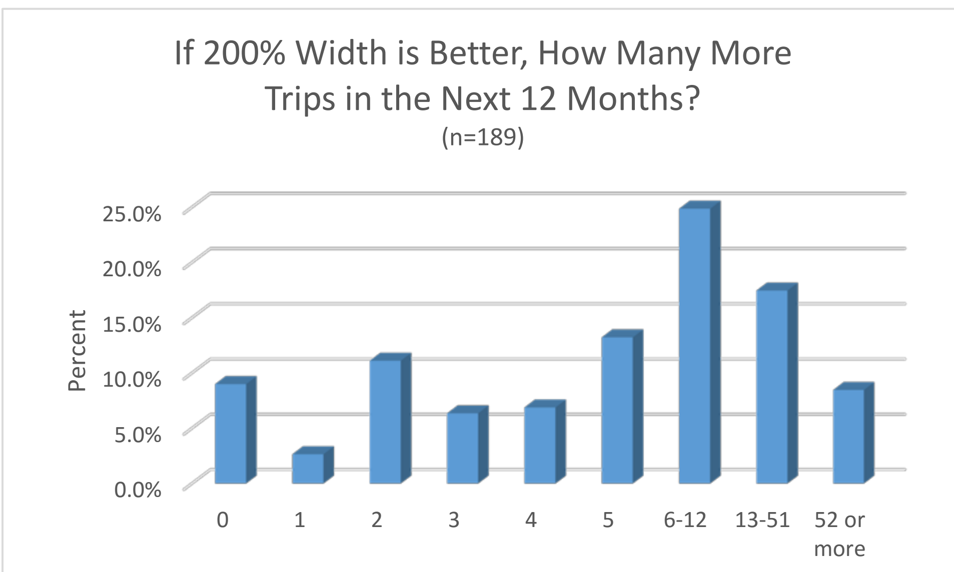


Figure 7. Increases in Attendance Due to a 100% Increase in Beach-width

Those 49% who indicated in **Figure 5** that doubling the beach-width would make their experience better were asked, “If better, about how many more trips to this beach would you take over the next 12 months?” **Figure 7** (above) shows that of the 189 responses, the most popular (25%) was that the respondent would visits the beach 6-12 times more over the next 12 months. The next strongest responses were very similar with 18% visiting the beach 13-51 times more often and 13% visiting 5 more times. Only 9% of respondents indicated that they would not increase their number of visits to a wider beach over the next 12 months.

1.2.3 Increases to Annual Attendance and Day Use Value

According to survey data, beach-visitors state that an increase in beach-width would lead to a corresponding increase in their annual attendance at that beach. This should come as no surprise since the increase in day use value caused by an increase in beach-width can easily be construed as the very cause of such an increase in beach attendance. Larger recreational values for a visit to the beach express a greater desire for, and therefore a higher frequency of visits to that beach. Thus, an increase in beach-width not only contributes to an increase in the recreational value for a visit to the beach, but also contributes to an increase in the number of visits to that beach.

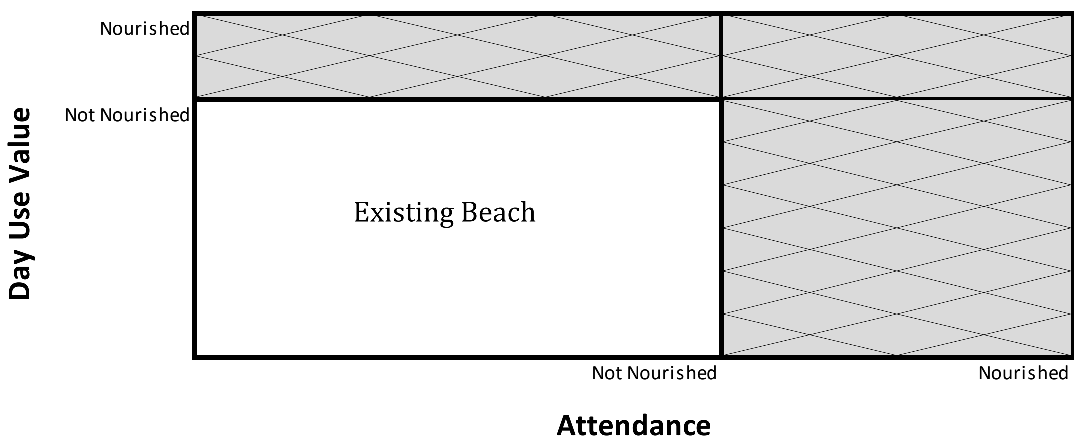


Figure 8. Measuring Increases in Recreational Value

We can, therefore, use the projected increases in both day use value and beach attendance in order to estimate the total recreational benefits produced by increases or decreases in beach width. The smaller, white rectangle in **Figure 8** (above) represents the total recreational value of a beach prior to nourishment. This recreational value is, as always, a product the beaches day use value per visit (the vertical axis) and its annual visits (the horizontal axis). Beach nourishment both increases its day use value and the annual attendance, thus expanding the smaller, pre-nourishment (white) rectangle in the figure above to the larger, post-nourishment (the white rectangle plus the shaded area) rectangle. The shaded region in the figure above is, then, a visual representation of the degree to which nourishment increases the total recreational value of a beach.

1.2.4 Sensitivity to Beach Width Preferences

As noted earlier, our model assumes an annual attendance of 500,000 for a beach width of 125 feet. Thus, a stronger sensitivity to beach widths proves beneficial for those strategies that keep the sandy beach wider than 125 feet and costly to those beaches that keep the sandy beach narrow than this same 125 feet.

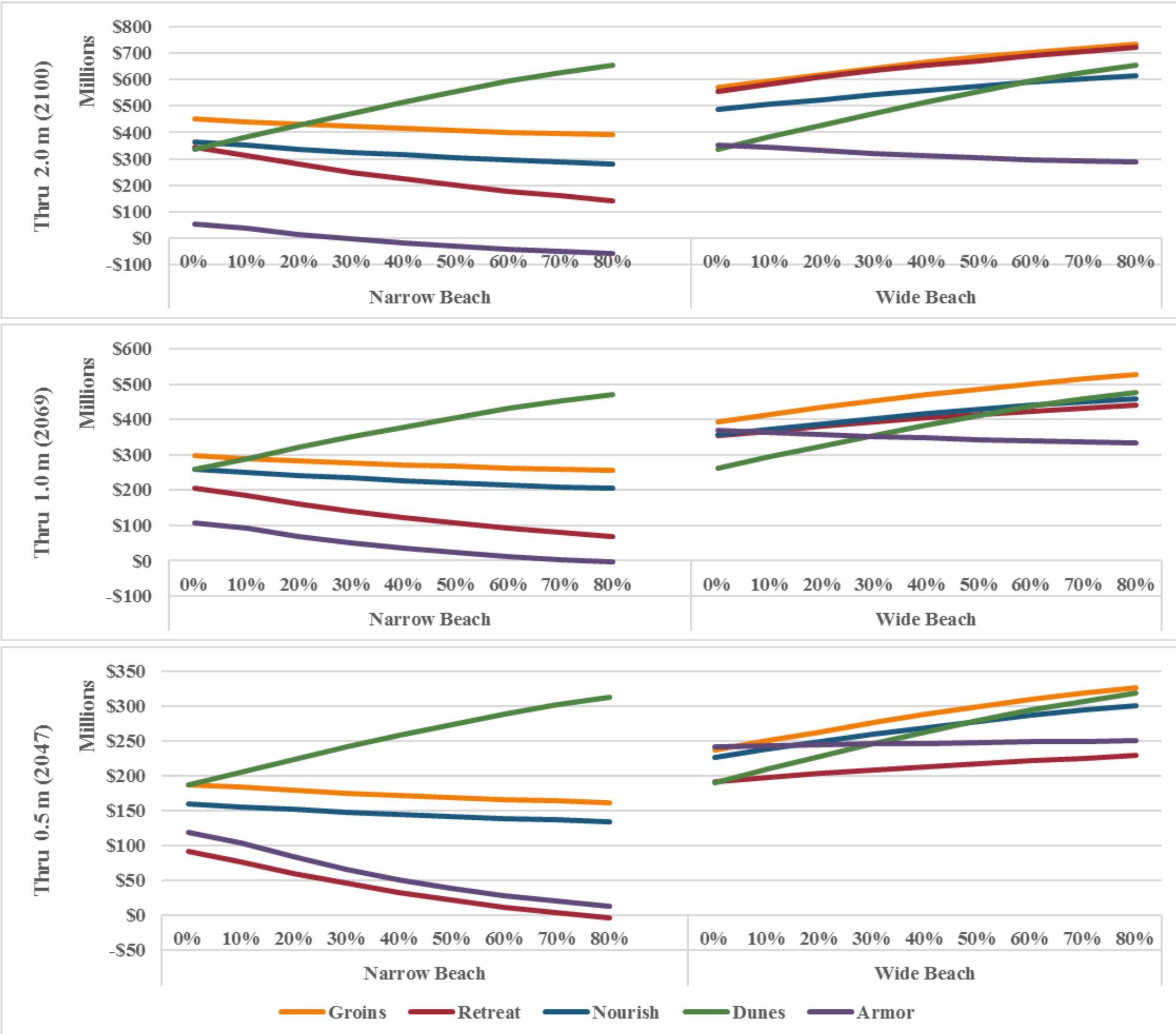


Figure 9. Sensitivity to Beach Width Preferences

Our survey data indicates that by doubling the beach width, annual attendance will increase by 30%, and that by halving the sandy beach width, annual attendance will decrease by that same 30%. Figure 9 (above) thus illustrates how our results vary as this 30% sensitivity ranges from 0% (total insensitivity to beach width) to 80% (a very strong sensitivity to beach width).

Unsurprisingly, within a narrow beach the only strategy that benefits from a strong sensitivity to beach width is that which keeps the width above 125 feet: Dunes. While Groins are preferable to Dunes in the short run, given a sensitivity to beach width lower than that assumed by our model, the latter eventually surpass the former in the long run. Groins are preferred above the other three strategies for all sensitivities and time horizons.

Groins also perform well within the wide beach scenario. While Retreat is comparable to Groins in the short run, this is very temporary due to the avoided constructed costs.

1.2.5 CSBAT Model and Day Use Value

To estimate losses in recreational value due to beach erosion, we use a standard model that is reasonably tractable—a benefit transfer (BT) approach, which allows one to apply estimates from previously estimated sites to similar beaches. In practice, BT is much cheaper than other methods and also has the advantage of consistency. This study used the Coastal Sediment Benefits Analysis Tool (CSBAT), developed for the US Army Corps of Engineers and the State of California, to value beach recreation (per user per day). CSBAT uses the following six criteria to assess the recreational value of California beaches:

Weather;
Water quality and surf;
Beach width and quality;
Overcrowding;
Beach facilities and services; and
Availability of substitutes.

The functional form used in the CSBAT analysis is a Cobb-Douglas utility function, of the general form:

Value of a Beach Day = M* $A^a * A_2^b * A_3^c * A_4^d * A_5^e * A_6^f$

Where:

M is the maximum value for a beach day

A_1 … A_n represent each beach amenity (rated on a scale of 0 to 1)

a … f are the weighting of each amenity value

$a + b + c + d + e + f = 1$.

The CSBAT model has been calibrated with data from existing studies. The Cobb-Douglas function exhibits diminishing marginal utility with respect to beach width. In addition, the model employed in this study caps beach width benefits at 300 ft (~90 m). This is consistent with a number of studies indicating that beaches can, in fact, be too wide (e.g., Landry et al. 2003, Pendelton et al. 2011). However, wider beaches also diminish crowding, the benefits of which are taken into account in the model.

Coastal erosion, and in particular beach erosion, threatens communities in California which rely on beach tourism. To address these potential losses, we use estimates of economic value based on the CSBAT model (King 2001) and spending estimates from King and Symes (2004) updated for inflation using the Consumer Price Index (CPI). The key variable in estimating spending and revenue is the percentage of day-trip visitors versus out-of-town visitors (who spend more). We assume that spending per visitor does not change as beach width changes—thus, all of the economic and tax revenue impacts estimated in this study are a result of estimated changes in beach attendance. It is possible that changes in beach width could affect the composition of overnight/day-trip visitors, which would affect spending/tax estimates, but this impact was considered secondary and is not estimated in this study. Tax revenue impacts are based on spending estimates combined with data from the California Statistical Abstract, a collection of social, economic, and physical data for the State (2009).

1.3 The Growing Costs of Sand

The final variable to which our results are moderately sensitive is the increasing costs of sand with which the beach is nourished. Our model assumes a 1% annual increase in the cost of sand such that the $20 million nourishment today will cost approximately $50 million in 2100. Our sensitivity analysis (Figure 10 below) indicates that our results are very robust within the narrow beach. Retreat is preferable to the Nourishment options in the short run, but Dunes become much better over time. Within the wide beach, Retreat is again preferable in the short run assuming any growth in the cost of sand. In the medium and long runs of the wide beach scenario, however, the costs of sand will have to growth by more than 3% annually ($200 million for a nourishment in 2100) in order for Retreat to be better than Groins.

Figure 10. Sensitivity to Increasing Costs of Sand

1.4 Property Analysis

Economic damages from storm events were estimated by relating the depth of flooding at each exposed structure to the replacement cost of that structure. This technique is widely used in flood damages assessments, including those conducted by the USACE. The USACE has developed a suite of curves that establish a simple mathematical relationship of the percent of a structure's value that is at risk to damage for each subsequent foot of flooding observed. The damage curves used in this study (USACE 2003a, USACE 2003b, GEC 2005) account for various types of flooding events (e.g., short duration, long duration, freshwater, saltwater) and structure types (e.g., residential, commercial, governmental). The USACE curves were linked to structure values that were estimated using historical sales price data for San Diego[2] Assessor parcel database.

1.4.1 Chronic Flood and Erosion Damages

To identify the market value of land and structures at risk to erosion, efforts were taken to adjust valuations from the Assessor database so they reflect market values. In California, county assessors' identify a property owner's tax burden by totaling the land and improvement (generally structure) value. Because of Proposition 13 (CABOE 1978), a property's land and structures are only reassessed at the current market rate when they change ownership through sale; an exception exists when improvements are made to the property. Without incurring a change of ownership, the assessor recorded value can only be increased up to two percent annually. When considering the significant gains in California property values, this two percent annual rate of inflation can lead to the assessed value for properties that have not changed ownership in many years to be significantly lower than a comparable property on the open market. Further, the market value of properties in certain communities have increased at a much higher rate than other communities because of factors such as development and changes in employment sectors. Fortunately, there are detailed indices that track changes in home prices by zip code, and other consumer prices on a monthly basis dating back to the time Proposition 13 took effect in California. The Case-Shiller CA-San Diego Home Price Index was used to adjust the assessor valuations of residential property to reflect current market rates. A consumer price index was used in a similar fashion for all other types of properties (e.g., commercial, industrial).

The price indices used in this study allowed for re-estimating structure and improvement values found in the Assessor database. However, these indices could not be applied to a number of non-taxable public properties (e.g. Schools, TRNERR, etc) in the Assessor database that record both the land and improvement value at $0. The number of these parcels was small and we identified and valued each on a case-by-case basis using insurance valuations contained within the city property schedule and personal correspondence with the South Bay Union School District and the Unified Port of San Diego.

1.4.2 Infrastructure

The two most important types of infrastructure estimated in this project are roads and water treatment equipment. We assumed that all roads/ infrastructure would need to be replaced when threatened by erosion and relocated when threatened by tidal flooding. We determined the timeline and "trigger points" where replacement or relocation would occur. Our analysis does not include the additional costs of finding and or acquiring a new corridor or site.

1.5 Future Demand for Beach Recreation

In this report, we have generally assumed that the real costs and benefits of various adaptation strategies is constant. Put simply, once one corrects for inflation the prices/costs of most property and engineering

[2] S&P/Case-Shiller CA-San Diego Home Price Index: https://fred.stlouisfed.org/series/SDXRSA#

solutions will stay constant. However, for beach recreation, this assumption is quite limiting since existing demographic/population projections by the State of California indicate that both the State and County will experience population growth. In addition, State/County forecasts indicate that real per capita income will grow.

To simplify, we assumed that attendance increased with the population growth and that the demand for beach recreation in Imperial Beach has an income elasticity of one--that is, SANDAG's projection for annual increase in household incomes within Imperial Beach of 0.7% will increase beach visits by 0.7%, annually. Similarly, the projected annual increase in Imperial Beach population of 0.5% will also increase beach attendance by 0.5%, annually[3]. We believe these assumptions are reasonable. Fortunately, our sensitivity/robustness analysis indicates that growth projection do not alter the relative ranking of our results.

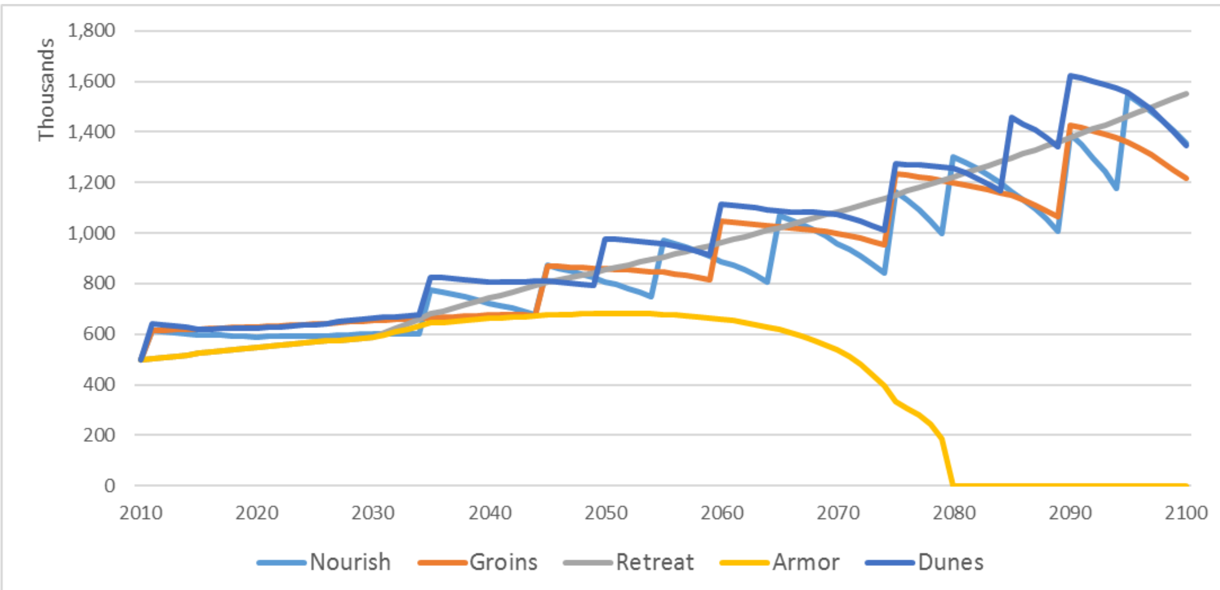


Figure 11. Change in Annual Attendance (Wide Beach)

The growth rates in population and household income, projected beach widths and the measured sensitivity of visitors to beach width allow us to project annual beach attendance into the future for the various adaptation strategies. Figure 11 (above) illustrates the projected annual beach attendance within the wide beach scenario. The figure clearly depicts the gradual increase in annual beach attendance over time for all adaptation strategies except for Armoring. The semi-frequent and relatively small spikes in beach attendance correspond to beach nourishments. It is the dramatic drop in beach attendance around 2070 that makes Armoring such an unfavorable adaptation strategy in the long run. In reality, this impact may occur a bit earlier given that as the beach narrows some of it will become damp sand that is wet for part of the tidal cycle.

Figure 12 (below) provides a similar illustration for annual attendance within the narrow beach scenario. Since the Dunes strategy provides a much wider beach than the other strategies within the narrow beach scenario, its attendance projections are consistently higher than the others. Beach attendance also drops off much faster for Armoring in the narrow beach, making it a very unfavorable strategy. Both Groins and Nourish will have slightly higher attendance, on average, than Retreat within the narrow beach.

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[3] http://datasurfer.sandag.org/download/sandag_forecast_13_zip_91932.pdf

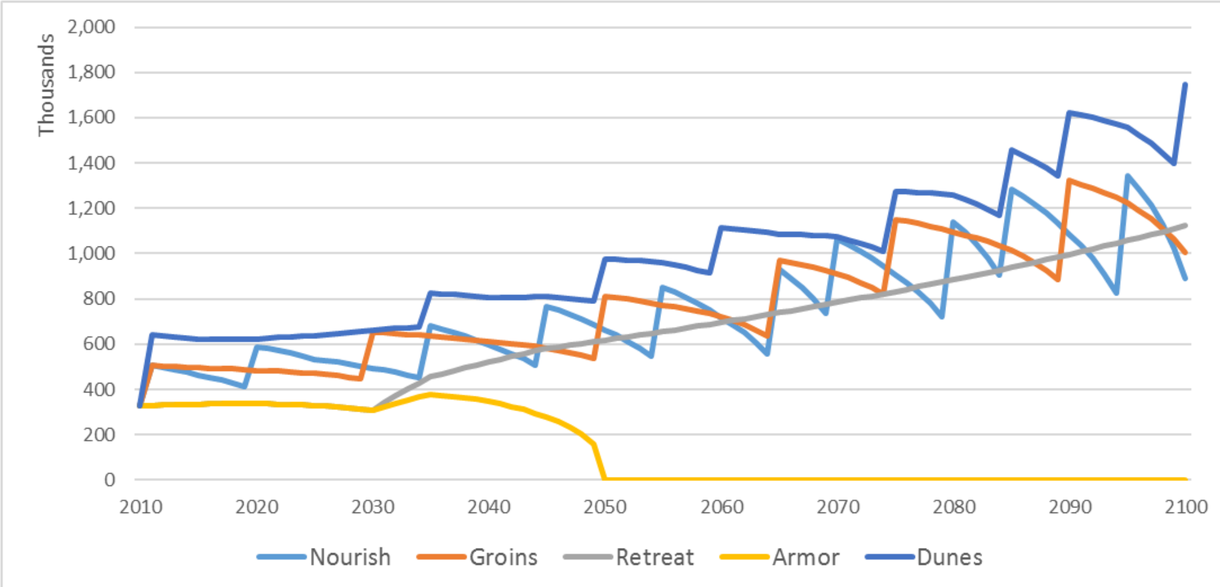

Figure 12. Change in Annual Attendance (Narrow Beach)

1.5.1 Discount Rate

When considering benefits and costs that are incurred over a number of years, the dollar values must be adjusted to reflect the fact that a dollar received today is considered more valuable than a dollar received in the future. One important reason for this is the fact that a dollar received today could be invested to produce additional wealth. To do this, it is important to identify the period of time that will account for most of the relevant benefits and costs and to select a discount rate that will account for the diminishing value of benefits received in the future.

The choice of an appropriate discount rate is generally even more critical in the analysis since a higher discount rate implies that future benefits and costs are weighted lower. For most private projects the choice of a discount rate is relatively simple—whatever the appropriate market rate is. For example, if a private company is considering a $100 million investment in a new factory that would yield a future stream of returns (profit), the firm would use their cost of capital. If they can borrow money at a 5% rate of interest, then 5% would be the discount rate.

For social projects, the discount rate is often tied to something similar—the cost of government bonds over the appropriate time horizon. For example, on a federal project lasting 30 years, one can apply the interest rate on a 30-year treasury bond (3.8% on January 10, 2014).

A number of economists have argued that using market interest rates when analyzing social costs and benefits is inappropriate for a variety of reasons. First, the social rate of time preference –that is the rate at which society values present consumption over future consumption—is not necessarily given by the market interest rate (Zhuang, Liang, Lin, & Guzman, 2007). A number of economists have conducted empirical studies of the social rate of discount and have found rates ranging from 0.1% to 3% (Liang, Lin, & Guzman, p.6).

Standard discounting practices face another critical problem in that the rates that are typically used discount goods and services to future generations. Applying a discount rate of 3%, for example, implies that we only value the benefits or costs born in the year 2100 1/20th what we value the same benefits and costs today; if one uses a 2% rate, this weighting changes to from 1/20th to 1/7th. Even applying a rate as low as 1% implies that benefits/costs 100 years from now are only weighted at 1/3rd of today's benefits.

Given the potentially enormous costs of climate change to future generations and the longer time scale, many environmental economists have proposed applying lower discount rates when analyzing the economic impacts of climate change. One of the most widely cited reports, the Stern report (2006), applied a 1.4 % discount rate. Arrow et al. (2014) point out that climate change modeling presents a unique set of issues given the uncertainty involved and the potential for catastrophic outcomes (even if the probability of such outcomes is low). Consequently, many climate change models use a declining discount rate over time—implying that a longer time horizon should receive a lower discount rate. A number of European countries have already adopted such an approach. For example, Great Britain has adopted a declining rate formula for climate change projects where the discount rate can reach 0.75% after 300 years (Arrow et. al., 2014, p. 11). Our analysis uses a 1% discount rate, which is consistent with Arrow and others, but we also conducted a sensitivity analysis using other discount rates.

Appendix D. Recommendations by Revell Coastal, LLC

The following are potential adaptation strategies being recommended for additional evaluation from Revell Coastal, LLC and are based on the findings of the report and our understanding of the community. ***These recommendations do not represent the entire Study team, Steering Committee, or the City's perspectives***.

It is possible that these will make certain members of the community uncomfortable. The intent is to provoke additional dialog among the City and regional stakeholders that will be needed to make hard decisions to prepare Imperial Beach for the future.

The following potential adaptation strategies are recommended for additional evaluation from Revell Coastal, LLC and are based on the findings of the report and understanding of the community. ***These recommendations may not represent the entire Study team or the City's perspectives***.

Short Term (next 30 years)

- Develop a holistic sediment and beach sand management plan specific to IB and TRNERR including sand and cobbles. Consider both placement and capture of existing sand resources. This could include the use of experimental cobble groins, sand fencing, and wrack and driftwood management.
- Change policies on South Seacoast Dr. to improve building standards (e.g. t raise base floor elevations, allow moveable foundations) and implement phased relocation or managed retreat (e.g. reduce street maintenance and City obligations .
- No new armoring on existing unarmored oceanfront parcels.
- Repair of existing structures should be limited and evaluated on a reach by reach basis in the context of the adjacent condition of structures and the longer term community vision. The community may prefer to phase this implementation - first in areas such as southern South Seacoast Drive first, then southern Seacoast Drive and Carnation neighborhoods.
- For parcels with revetments, only minor repairs (<25%) should be granted and preference should be given to a one time replacement on private property with a vertical seawall with an economic life of 20 to 30 years. After which a managed retreat policy should be implemented.
- Develop and implement a public acquisition and lease back option to implement managed retreat.
- Form a Coastal Hazard Abatement District among ocean front property owners (perhaps 3 for South Seacoast, Carnation, and Central Business district along the ocean front). The CHAD should not be exempt from CEQA requirements. These CHADs would provide support for maintenance and/or replacement of existing armoring structures, and contribute to any future nourishment efforts.
- Groins show some promise but much more specific engineering studies are required if that is something that the City is interested in pursuing.
- Consider the hybrid dune concept (which is based on the historic ecology and physical processes) along portions of the TRNERR oceanfront.
- Develop in-lieu fees and tax revenues to fund long-term adaptation strategies.

Medium Term (~50 years)

- Initiate policies to facilitate long term managed retreat (repetitive loss, real estate disclosures, building code revisions, etc.).
- Investigate ways to reduce City maintenance responsibilities along South Seacoast while maintaining public access as appropriate.
- Managed retreat of residential and commercial properties along South Seacoast.
- Identify, plan and permit community favored nourishment/retention structures to maintain a recreational beach.

Long (>80 years)

Develop managed retreat strategies through regulatory means to avoid expensive City investment.