Title

Analyzing Flood and Sea Level Rise Impacts in Imperial Beach, California

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Abstract

Low-lying coastal areas are particularly vulnerable to the impacts of sea level rise and flooding. The City of Imperial Beach (IB), California currently experiences inundation effects that will intensify as sea levels rise. Inundation in IB has previously been studied by Sangsefidi et al., who explored the importance of studying the compounding impacts of isolated phenomena (e.g. sea level rise, groundwater, precipitation). Understanding regional adaptation priorities, stakeholder concerns, and implementation strategies is essential for coastal resilience and adaptation planning under projected climate impacts. This study used geospatial visualization and interviews with key decision-makers and stakeholders to assess current adaptation efforts and identify implementation barriers in Imperial Beach. Findings indicate that stakeholders have differing priorities, with City officials targeting beach nourishment projects to protect property and public access and estuary managers focusing on dune restoration and nature-based solutions in their territory. Service providers are focused on being able to maintain service provision as necessary in the future, the main approach being to protect assets where they are. However, complicated regulatory processes make project implementation difficult despite broader support for these adaptive measures, leaving city officials unequipped to carry out innovative projects without significant time and resources allocated to them.

Keywords: Sea level rise, adaptation, climate change, City of Imperial Beach, San Diego, Tijuana River, infrastructure, utilities, inundation, coastal resilience, estuary

Background and Relevant Context

Imperial Beach

Coastal areas experience multiple climate impacts, including elevated flood risk, coastal erosion, inundation, and saltwater intrusion into freshwater systems. Low-lying coastal areas are particularly vulnerable to inundation and sea level rise impacts. Understanding regional climate concerns and adaptation strategies will be essential in building coastal resilience to prepare for projected climate impacts.

Imperial Beach (IB), the southernmost city in California, is home to approximately 26,000 people (United States Census Bureau QuickFacts 2024). The city is surrounded by water on three sides: the Tijuana Estuary to the south, the Pacific Ocean to the west, and the San Diego Bay to the east (Revell Coastal 2016). In the coming years, the city faces the threat of sea level rise, which will increase the present risks from storms and flooding. The city performed a sea level rise assessment in 2016, using scenarios between zero and two meters of sea level rise to frame the assessment on time horizons up until 2100 (Figure 1). Tidal inundation already has detrimental impacts on stormwater outlets that drain into the Bay and the Estuary, particularly during high tide events. Nearly eight hundred feet of wastewater pipes were exposed to existing erosion hazards at the time of IB's Sea Level Rise Assessment in 2016 (Revell Coastal 2016).

There are three main approaches to coastal adaptation: protection, retreat, and accommodation. Protection is the defense of vulnerable areas through hard infrastructure or soft measures designed to prevent inundation and mitigate the effects of coastal hazards. Retreat involves the relocation of structures, abandonment of land, and resettling of populations residing in high-risk areas. Accommodation is the continued use of vulnerable areas, while accepting some losses of coastal zone values (IPCC 1990). A hybrid of these strategies may be implemented, and a final option outlined in IB's Sea Level Rise Assessment is to take no action (Revell Coastal 2016).

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

Figure 1. Sea level rise scenarios used in IB Sea Level Rise Assessment (Revell Coastal 2016)

Adaptation Options

Section 6 of the IB Sea Level Rise Assessment explores the following adaptation options:

1. Armoring of the coastline

Coastal armoring involves hardening the shoreline by constructing structures such as seawalls or rock revetments to protect the coast from erosion and wave action. Armoring prioritizes the protection of property from coastal hazards over natural coastal processes. Approximately 16% of California's coastline uses armoring (Swirad and Young 2022).

The city of IB's armoring strategy would focus on maintaining and using existing armoring structures until 2030. IB's armoring is made up of masonry walls, revetment, and seawalls (Figure 2). After 2030, the entire stretch of armoring would be upgraded to a vertical recurved seawall (Figure 3). In terms of benefits, coastal armoring reduces erosion to upland property (Revell Coastal 2016). Some drawbacks of his strategy include reduced beach access, visual effects, and a loss of sand supply from eroding cliffs (Griggs 2005).

Figure 2. Coastal armoring in IB, classified by type (Revell Coastal 2016)

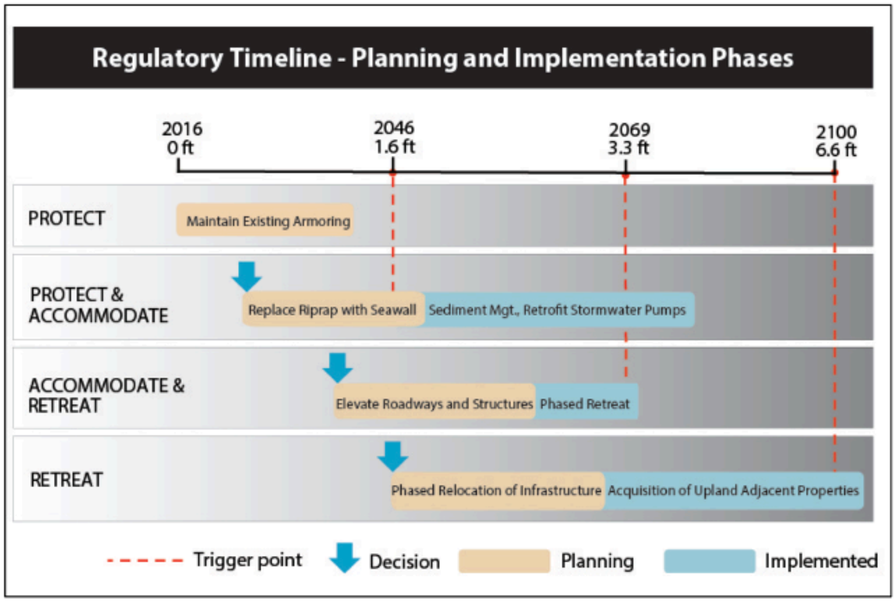


Figure 3. Imperial Beach SLR Adaptation Timeline (Revell Coastal 2016)

2. Phased relocation (managed retreat)

Managed retreat is defined as the planned relocation of structures and the strategic abandonment of vulnerable land to reduce exposure to natural hazards (Hino, Field, and Mach 2017). IB's Sea Level Rise Assessment evaluates a retreat approach that involves the public acquisition of properties with a lease-back option. This approach would allow the City to recover a portion of the investment in the properties before the structures would have to be removed. This arrangement requires lease agreements and financing mechanisms for the acquired properties (Revell Coastal 2016).

Managed retreat is rarely implemented due to its controversial nature: the process of relocating residents is complex and faces significant public resistance. However, on timescales greater than 25 years, managed retreat is favored and can permanently reduce natural hazard risks with minimal recurring costs (Hino, Field, and Mach 2017). In the long term, managed retreat strategies typically cost less than protection or accommodation approaches, which require maintenance costs (Abel et al. 2011). For low-lying coastal communities that cannot afford to invest in long-term protection or accommodation strategies, managed retreat may be an appropriate response to mitigate the risks of sea level rise and coastal hazards (Abel et al. 2011).

Hino, Field, and Mach (2017) developed a conceptual model of managed retreat, which addresses the alignment of interest between parties in discussions of retreat, and provides a framework to understand how specific observed examples of retreat would fit into their model (Figure 4). Post-disaster voluntary relocation programs are a case of retreat where parties have aligned interests, and this helps in overcoming regulatory obstacles (Hino, Field, and Mach

2017). In these scenarios, residents hold decision-making power in initiating the move, and broader society benefits from the relocation effort (Hino, Field, and Mach 2017).

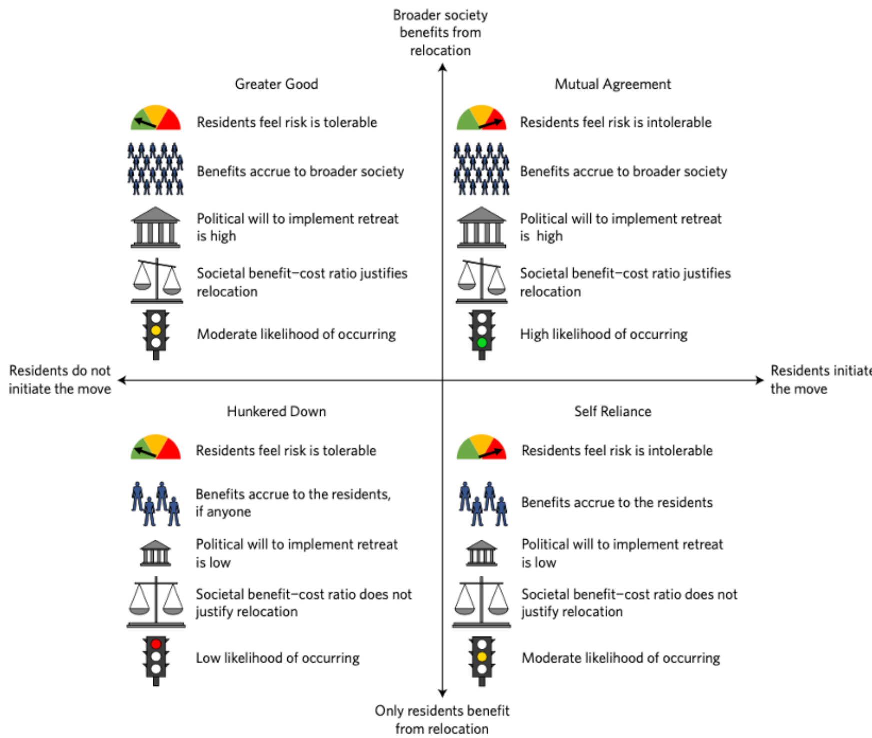


Figure 4. Conceptual Model of Managed Retreat (Hino, Field, and Mach 2017)

In IB, the managed retreat approach would involve removing shoreline armoring by 2030, allowing the coast to erode naturally. The removal of armoring would preserve beach systems and ecological benefits to the area, prioritizing environmental and associated recreational benefits over property protection. The implementation costs of retreat would include the removal of infrastructure and buildings, and the restoration of dunes (Revell Coastal 2016).

3. “Business-as-usual” sand nourishment

Beach sand nourishment is the practice of deliberately adding sand to eroding shorelines to restore beach area (*Beach Nourishment and Protection* 1995). IB has been implementing this strategy since at least 1977, with both federally and regionally funded nourishment projects over the last fifty years (Figure 5). Nourishment projects between 1984-2001 were funded federally, while other projects have received partial or complete funding from regional stakeholders such as SANDAG (PSDS and WCU, n.d, SANDAG, n.d.). Beach sand nourishment has been the most common practice in IB, providing substantial recreational benefits due to its direct impact on beach width (Revell Coastal 2016). This option prioritizes protecting the existing upland structures where they are while also maintaining a beachfront.

Beach nourishment is a shore protection strategy that directly addresses the issue of sand budget deficits on beaches. In contrast to fixed barriers, nourishment projects are also described as “sacrificial barriers” that provide temporary protection until they are eventually eroded by wave action (*Beach Nourishment and Protection* 1995). Over a nourishment project’s functional lifespan, it will provide natural protection and additional recreational area for the community. When compared to beaches that have not been nourished, nourished beaches reduce storm damage risks to upland structures supporting a reduction in National Flood Insurance Program premiums (*Beach Nourishment and Protection* 1995).

Over time, nourished beaches will require renourishment in to maintain function. Additionally, beach nourishment does not remove the physical forces that cause erosion, wave damage, and flooding (*Beach Nourishment and Protection* 1995). Instead, beach nourishment mitigates these effects, and focuses on balancing the sand budget deficit experienced along beaches in the face of coastal erosion (*Beach Nourishment and Protection* 1995).

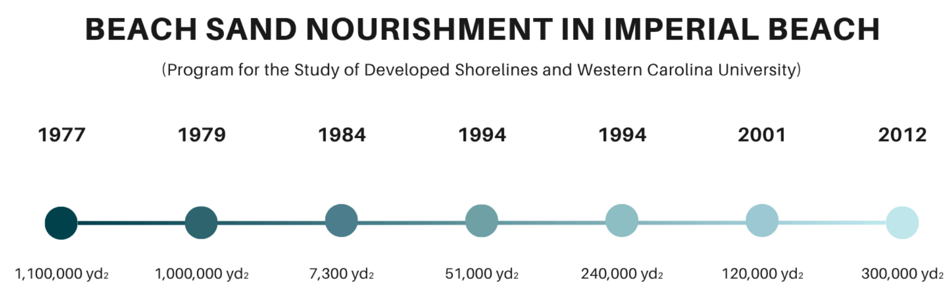


Figure 5. Timeline of beach nourishment in Imperial Beach, with volume of nourishment in yards squared (PSDS and WCU, n.d.)

4. Hybrid dune and cobble approach

The hybrid dune and cobble approach is a combination of beach sand nourishment, cobble placement, and dune creation (Revell Coastal 2016). This approach aims to replicate the natural coastal landscape as it existed before anthropogenic influence and extensive development. Hybrid coastal structures are a mix of ‘hard’ elements such as cobbles and ‘soft’ solutions such as dune restoration and sand nourishment to provide the protective benefits of both approaches (Figure 6). Dune restorations also have the potential to adapt with naturally occurring coastal erosion and accretion patterns, providing even greater benefit when properly maintained (Winters et al. 2020). Hybrid dune-based options are especially preferable along coasts that are urbanized and experience high-energy wave action, due to the need to address recreational, ecological, and protective aspects simultaneously (Winters et al. 2020).

Of the approaches listed in IB's Sea Level Rise Assessment, this is the closest to a green protection approach or nature-based solution (Revell Coastal 2016). The International Union for Conservation of Nature (IUCN) defines nature-based solutions as actions taken to protect, sustainably manage, and restore ecosystems that address societal challenges while providing benefits to both biodiversity and human well-being (IUCN CEM and WCPA 2016). Coastal nature-based solutions include barrier islands, mangrove forests, oyster reefs, and hybrid approaches such as the dune-cobble approach. These strategies are used to protect shorelines and communities from coastal flooding and sea level rise impacts (IUCN CEM and WCPA 2016).

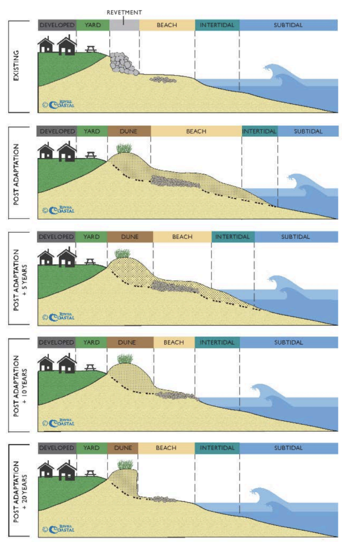


Figure 6. Hybrid Dune Approach (Revell Coastal 2016)

5. Groins with associated sand nourishment

Groins are sediment retention structures built perpendicular to the shore and they are often implemented with sand nourishment to fill the groin compartments ("Groins and Jetties" 2019). Coupling nourishment with the construction of additional groins in IB would reduce the likelihood of downcoast erosion impacts (Ludka et al. 2023) that are a typical disadvantage of the structures. While the impacts and effectiveness of groins are not well understood, additional groins may retain coarse-grained nourishment, reducing the volume of sand that drifts down the coast. The proposed plan would involve extending the two existing groins west of Seacoast Drive, and constructing three new groins along the coastline (Revell Coastal 2016).

Compound impacts in coastal regions

When assessing inundation risk, it is essential to account for the compound effects of multiple coastal hazards, including sea-level rise, storm-driven flooding, extreme precipitation, elevated groundwater, and high tides (Rahimi et al., 2020). These hazards, while individually significant, interact to produce amplified impacts, and taking this into consideration when studying the impacts of inundation can be critical.

In a study on inundation on Imperial Beach, Sangsefidi et al. (2023) found that the vulnerability of the city's storm drain system increases substantially when compound impacts are considered. Under NOAA's 2022 two-meter high sea level rise scenario, it was found that about one-third of the storm drain length in IB could be susceptible to sea water intrusion (SWI) and groundwater intrusion (GWI) (Sangsefidi et al. 2022). Additionally, it is estimated that GWI would increase up to four times under that scenario, highlighting the strain that the storm and wastewater systems can expect in the future. When compound flooding impacts take SWI and GWI into account, areas that are kilometers away from the coastline may be impacted (Sangsefidi et al. 2022). This study demonstrates how individual coastal hazards interact and result in more severe impacts, and highlights the importance of integrated approaches to coastal risk assessment.

Project Aims and Methodology

The primary aims of this project were to examine stakeholder perspectives on sea level rise impacts and adaptation strategies in IB, and to identify climate risk thresholds that trigger local adaptation responses.

The research methodology was made up of four components (Figure 7):
(1) a review of sea level rise assessments, adaptation strategies, and risk analysis literature specific to IB, (2) geospatial visualization including the creation of maps showing infrastructure data and inundation/flood projections, compiled into an ArcGIS StoryMap (3) interviews with key decision-makers and regional stakeholders, including representatives from the City of IB, San Diego Gas & Electric (SDG&E), and Tijuana River National Estuarine Research Reserve (TRNERR) to understand local perspectives on the city's adaptation efforts, (4) an analysis of current adaptation strategies based on the literature review and stakeholder interviews.

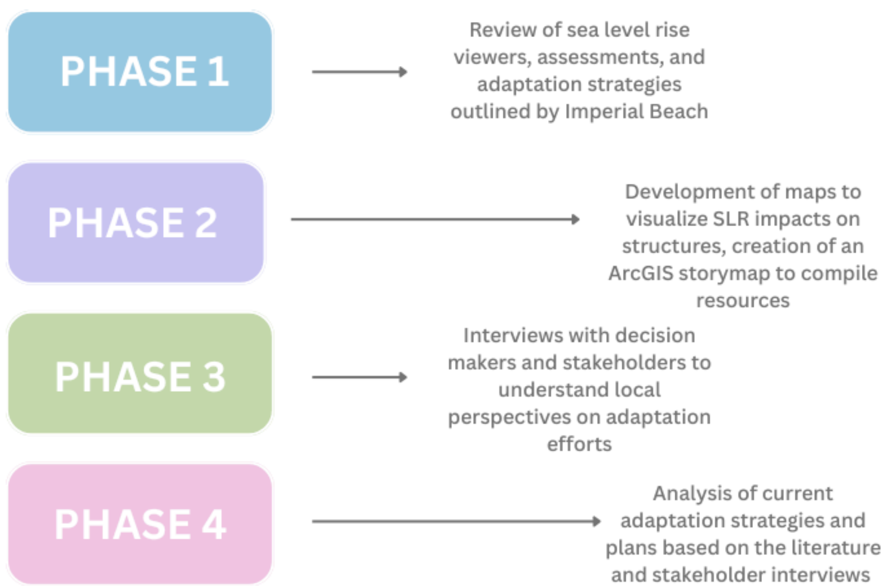


Figure 7. Project Methodology

Phase Three of this project involved interviewing the following individuals:

1. City of IB: Chris Helmer, Director of Environmental & Natural Resources
2. SDG&E: Dr. Yumin Moon, Numerical Weather Prediction Scientist
3. Tijuana River National Estuarine Research Reserve: Dr. Jeff Crooks, Research Coordinator

Interview questions:

The survey was designed to informally get a broad overview of stakeholders' understandings and adaptation plans regarding inundation and sea level rise in the Imperial Beach region.

a. How do the mapped current sea level rise projections align with the current situation and future expectations for the area?
b. Of the coastal adaptation strategies outlined in the city's sea level rise assessment (protection, accommodation, and retreat), which strategy does the [insert stakeholder here] see itself aligning with most?
c. What are [insert stakeholder here]'s biggest concerns regarding flooding and sea level rise?
d. Which neighborhoods/areas within IB are you most concerned about?
e. Is there a threshold of climate/SLR impacts that the [stakeholder] views as a tipping point?
f. On what time scale does the [insert stakeholder here] plan on changing/adapting their strategy?
g. Section 6 of the IB Sea Level Rise Assessment explores these adaptation options (listed below): What are your thoughts on these various strategies?

    - Hardening and armoring of the IB coastline
    - Managed retreat or phased relocation
    - "Business-as-usual" sand nourishment
    - Dynamic revetment and dune development
    - Groins with associated sand nourishment (sediment retention structures)

h. What does [insert stakeholder here] see in terms of future steps?
i. Are there parts of current plans or assessments that you view as blind spots? Are there missed topics that need to be addressed?

Further questions tailored to specific stakeholders

j. Can you speak about what Climate Adaptation Vulnerability Assessment (CAVA) is, and how these results will be used? (for SDG&E)
k. How does inundation impact electrical lines and infrastructure, and the provision of service? Would subsurface lines be at risk if inundated? Is there a way to protect them from damage due to inundation? (for SDG&E)
l. How do SLR projections align with future expectations for service provision? (for SDG&E)
m. What is SDG&E's current plan regarding flooding and inundation? (for SDG&E)
n. What does adaptation look like for stormwater and wastewater management?

o. The city is preparing for 1m of SLR by 2070: does stormwater/wastewater management have specific targets to hit in that same timeline?
p. When speaking to other stakeholders, they expressed that the range of uncertainty in SLR predictions and climate hazards in general makes it difficult to understand how much to adapt. Does the city share this perspective?

Results and Discussion

The city of IB is particularly vulnerable to the impacts of sea level rise because it is surrounded by water on three sides: the San Diego Bay, which lies to the North, the Tijuana Estuary to the South, and the Pacific Ocean to the West (Revell Coastal 2016). The city has taken significant steps to assess the impacts of sea level rise on the city and adapt to these impacts in the coming years. Flood events already affect IB, with impacts expected to intensify as sea levels continue rising. Flash and tidal flood events are already impacting residential structures in IB; areas of intersection with parcels reflect where flooding impacts structures (Figure 8).

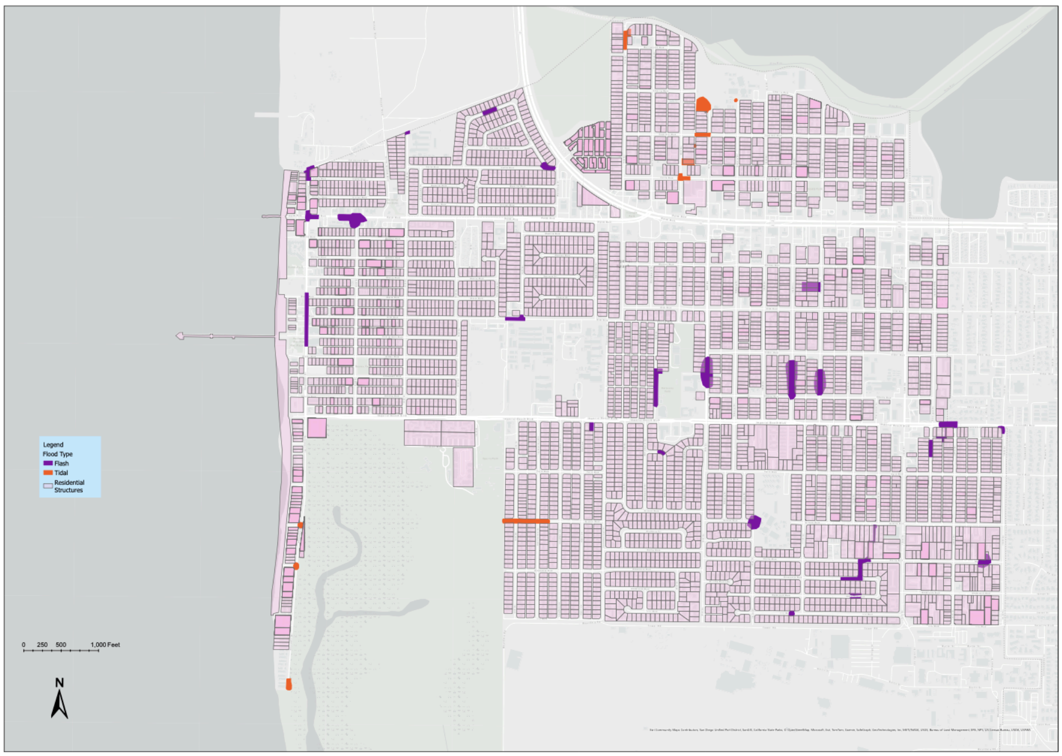


Figure 8. Current flood zones and residential structures in IB (City of Imperial Beach, n.d.)

The U.S. Geological Survey's Coastal Storm Modeling System (CoSMoS) provides projections for storm-induced coastal flooding depth and extent under present conditions, and under future sea level rise scenarios (USGS 2016). The CoSMoS v3.0 Phase 2 projections can be used to understand how sea level rise will increase the extent of the land impacted by flooding in Imperial Beach (Figures 9 and 10).

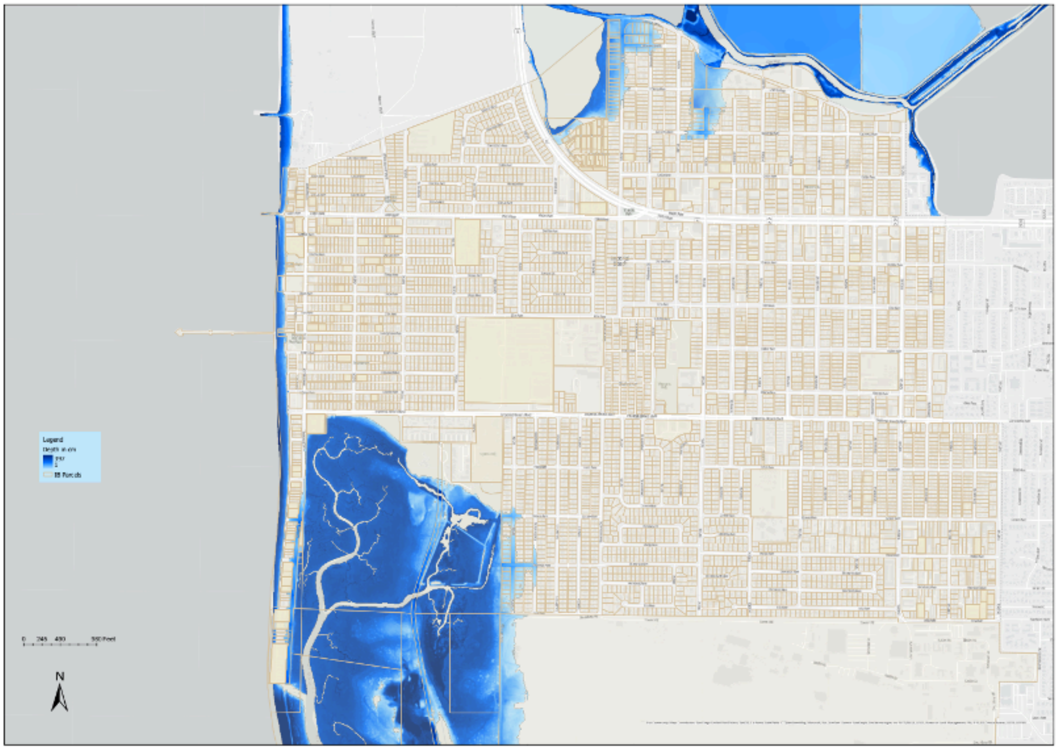


Figure 9. CoSMoS Flood extent in 1m SLR scenario (USGS 2016)

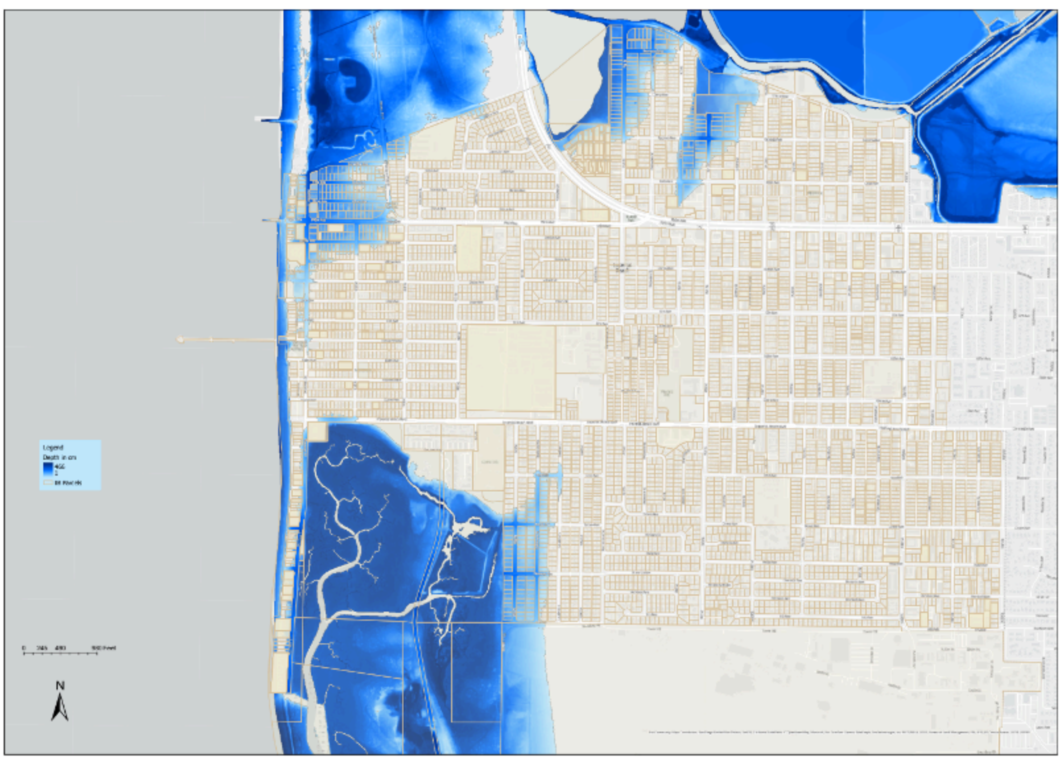


Figure 10. CoSMoS Flood extent in 2m SLR scenario (USGS 2016)

Current Areas of Concern and Upcoming Projects

The southern region of IB experiences significant tidal action, causing issues such as inundation on private property, in storm drain systems, and upstream flooding events (Figure 11). The beachfront near Palm Drive experiences wave overtopping during storm events, which compromises safety and public access to beaches (Figure 12). The Bayfront neighborhood is located in North IB, and it is exposed to water due to its proximity to the San Diego Bay (Figure 13). The south end of Seacoast Drive is an area of high priority, and the city is looking to develop solutions that maintain public beach access, preserve the environment, and benefit the community at large. Seacoast Drive is also experiencing sand transport from the shore into the estuary, causing negative impacts by burying wetland habitat and filling in tidal channels. The sand transport reduces tidal flushing capacity for the estuary, which reduces biological richness that is associated with tidal exchange. Wave overtopping of seawalls and protective structures occurs during high tide events along IB's shoreline (Merrifield et al. 2021). Seacoast Drive requires a measure to protect the region from wave overtopping, and the city is currently evaluating potential approaches to mitigate these effects.

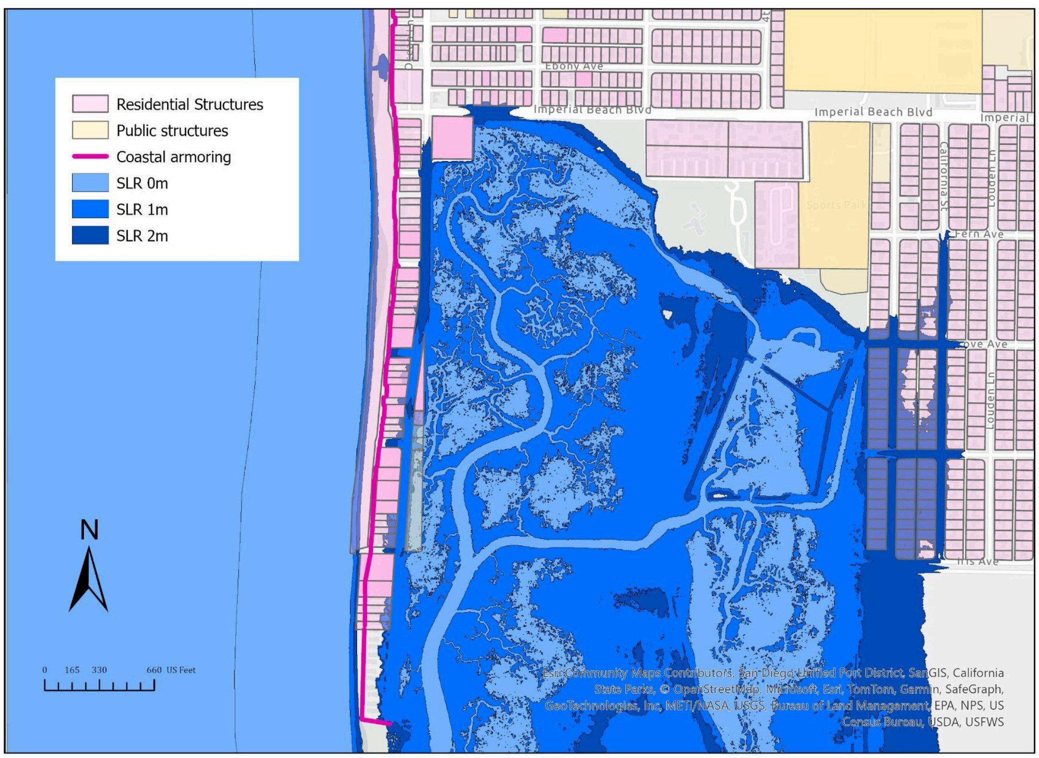


Figure 11. South end of Seacoast Drive

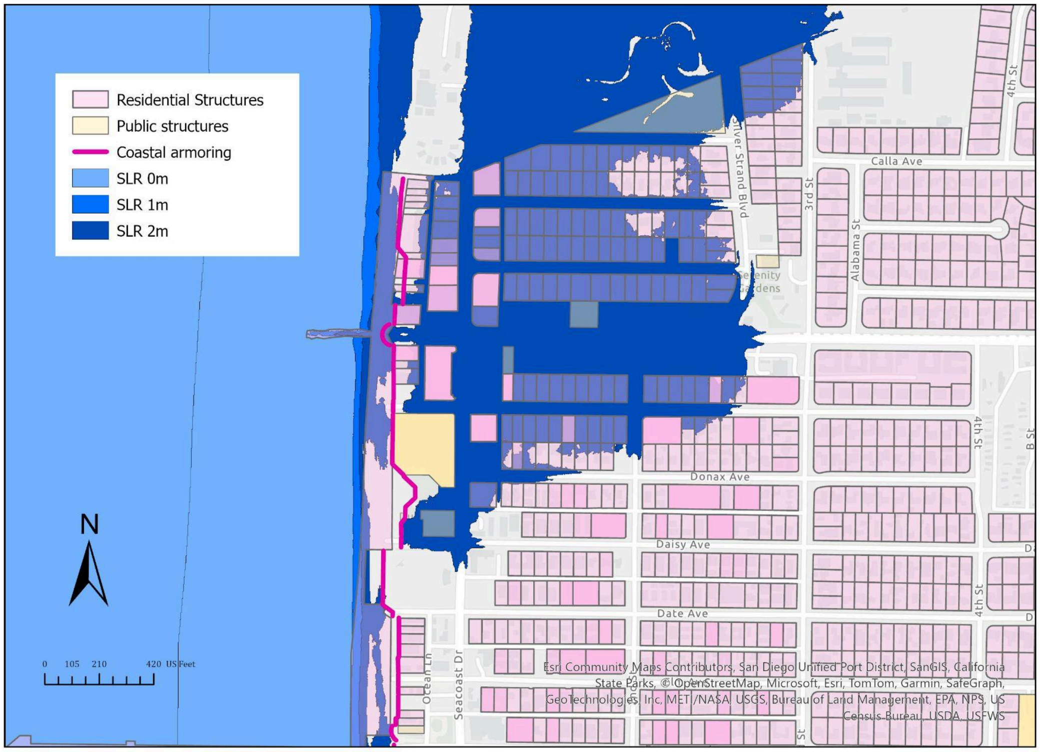


Figure 12. Beachfront near Palm Drive

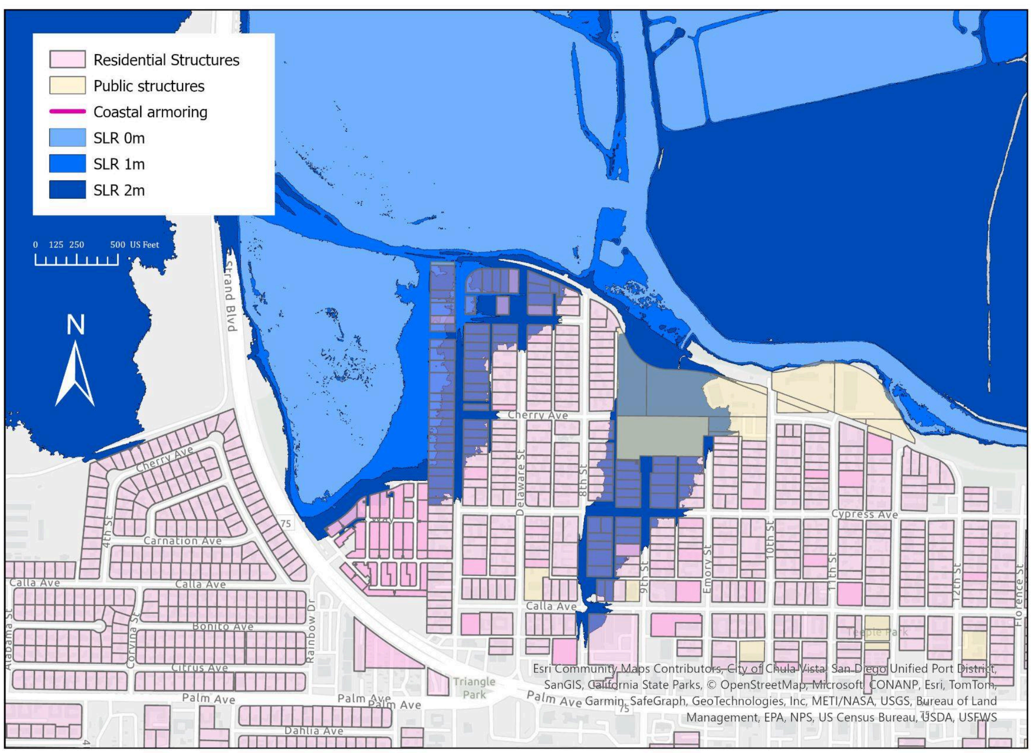


Figure 13. Bayfront Neighborhood

The City of IB is designing a coastal resilience corridor to enhance flood protection for the Bayfront neighborhood while preserving the bay ecosystem (City of Imperial Beach, n.d.). The Bayshore Bikeway Resiliency project will address tidal flooding through upsizing of storm drain infrastructure, stormwater pump installation, and elevation of the bike path to protect it from up to 3.5 feet of sea level rise. The project is in planning stages and will be in the permitting phase through the end of 2026 (City of Imperial Beach, n.d.). The Imperial Beach Resilience Plan, another upcoming project in IB, will propose specific infrastructure recommendations for implementation in the city (Helmer 2025). This planning document will assume that private property and the built assets are there to stay, and evaluate options for protective infrastructure to defend structures rather than evaluating relocation strategies.

<u>Challenges in Adaptation Planning and Implementation</u>

Imperial Beach faces significant challenges in implementing coastal adaptation projects, despite the benefits they would provide to the city (Helmer 2025). Significant obstacles to advancing these projects are the complicated permitting processes and regulatory hurdles involved in project planning. Current regulatory frameworks create an imbalance in the time and financial investments needed for project approval when compared to the construction costs. Additionally, projects located near sensitive habitats are frequently shut down, even when providing environmental benefits. Helmer expressed how regulations are getting in the way of innovative adaptation strategies, and expressed a need for changes in regulations to allow for faster and more cost-effective project implementation.

IB is targeting beach nourishment as the city's primary adaptation strategy, due to regulatory hurdles that make it one of the only viable options at this time (Helmer 2025). Alternative approaches, such as living shorelines or other smaller projects, require the same amount of effort to permit as larger projects. This permitting framework pushes the city away from smaller-scale adaptation approaches and incentivizes larger projects, or projects that are integrated with larger regional efforts. One example of this is the San Diego Association of Governments' (SANDAG) regional nourishment project which addresses multiple beaches across the San Diego region: this project makes sense to do across the region, but would take much more effort to carry out at individual beaches (Helmer 2025, (SANDAG, n.d.).

The current infrastructure in IB can accommodate three feet of sea level rise and manage it well (Helmer 2025). Sea level rise exceeding three feet will interfere with the ability to provide services to the lowest-lying areas, because at that point, water will constantly overtop current protective features and impact vulnerable neighborhoods (Helmer 2025). This threshold gives the city approximately one hundred years to adapt to the oncoming climate impacts. However, financial, political, and environmental uncertainties have resulted in much shorter strategic planning horizons being used in the city. Regulatory barriers also restrict the ability to plan into the long term, leading the city to focus on short-term adaptation strategies rather than long-term strategic plans (Helmer 2025).

Impacts of Inundation on Stormwater and Wastewater Infrastructure

In the face of rising sea levels and groundwater emergence, stormwater and wastewater systems face significant challenges, including infiltration, exfiltration, and the need to upgrade aging infrastructure to handle rising tides. Across the country, stormwater and wastewater lines are made of clay. Connection points in these pipes are not tight fits, and there are cracks all around these areas, meaning our stormwater and wastewater systems across the country have cracks in them.

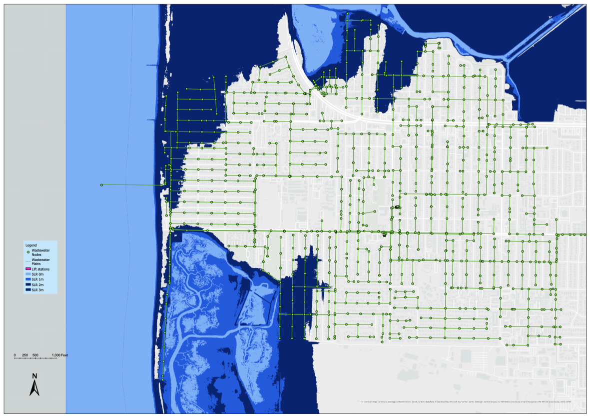
Infiltration occurs when external water enters the pipe system through cracks and connection points, while exfiltration occurs when water leaks from pipes into the surrounding area. Exfiltration from wastewater systems poses risks by causing high bacteria counts and concerns about water quality. Sea level rise worsens the issue of infiltration due to the inundation of pipes in both sea water and groundwater in areas experiencing emergence.

IB has separate stormwater and wastewater systems, and these systems face significant challenges with infiltration. The city currently infiltrates about twice as much water as it has imported in (Helmer), and it is their current goal to minimize infiltration in the system. While infrastructure can function in inundated conditions, it is essential to manage infiltration issues to prevent excessive intrusion of groundwater and seawater into the collection systems. Additionally, it is critical that pump stations remain above base flood elevations to keep wastewater flowing and maintain functionality of the system.

Wastewater nodes are assets or structural elements that represent significant points in wastewater infrastructure, such as manholes, outfalls, and junctions (City of Imperial Beach, n.d.). Wastewater nodes in IB are already experiencing inundation, with the number of impacted nodes predicted to increase as sea levels rise, if no protective action is taken (Figures 14 through 18).

Scenario/Conditions	Number of Wastewater Nodes Inundated
Current areas of flooding	63 nodes
One meter of sea level rise	75 nodes
Two meters of sea level rise	161 nodes

Figure 14. Inundation of Wastewater Nodes



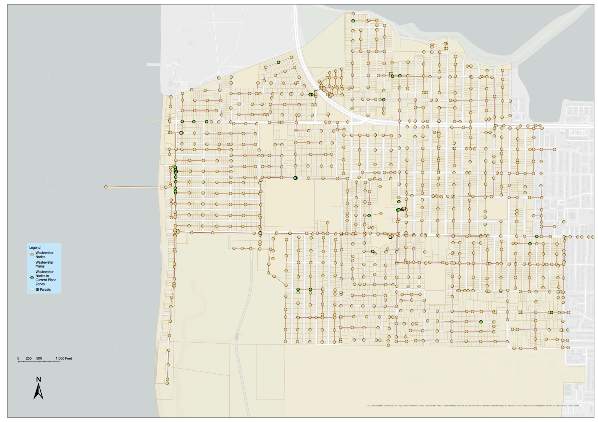
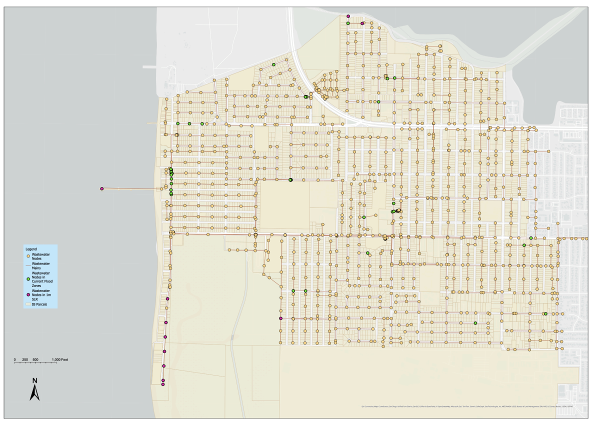


Figure 15 and 16. Wastewater infrastructure and inundation in IB (left), Wastewater infrastructure in current flood zones (right)



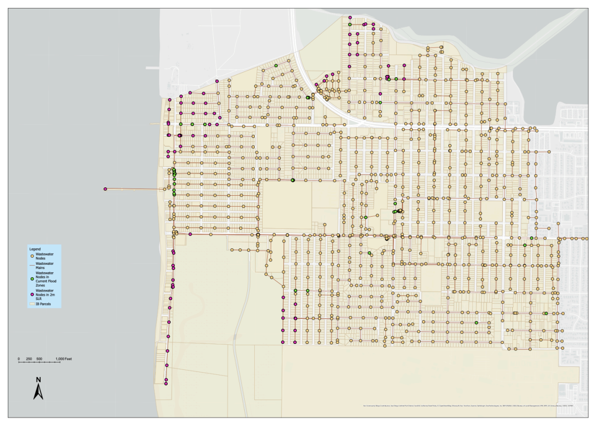


Figure 17 and 18. Wastewater infrastructure inundated in 1m SLR scenario (left), Wastewater infrastructure inundated in 2m SLR scenario (right)

<u>Infrastructure Adaptation Options</u>

The primary strategy for reducing infiltration in pipes is relining pipes and lateral connections to seal the existing cracks. Implementation of this strategy is complex due to challenges accessing infrastructure on private property. Private lateral connections often experience more leakage than pipes, but they remain difficult for agencies to access due to property restrictions. IB is working with San Diego State University to develop an autonomous monitoring system that will use closed-circuit television to map locations of cracks and infiltration spots in the sewer network. This system assessment takes place once every ten years, as it is costly and time-intensive.

Wastewater systems present different challenges than stormwater systems, because outflow from wastewater systems must be treated before discharge. On the other hand, stormwater conveyance systems can discharge directly into receiving waters without being treated. Traditionally, stormwater pipes are driven by gravity, but due to high tide conditions that reduce conveyance capacity, locations may require pumps to convey water and to avoid backflow and subsequent upstream flooding. IB's storm drain pipes accommodate a five-year return period storm, and the city's management strategy focuses on the containment of flood waters to the streets to protect residential property.

Infrastructure options include the installation of pump stations to address gravity flow issues in systems in tidal areas. Due to infrequent rain in San Diego, temporary jockey pumps are another effective solution to quickly convey water in coastal areas. The use of retention areas to provide temporary water storage capacity can also offer additional flood mitigation. Similarly, low-impact development approaches promote infiltration/storage of water upstream to reduce impacts on the system downstream. Overall, the stormwater management strategy emphasizes retention and infiltration of water upstream, supplemented by pumping infrastructure where necessary downstream.

Stormwater appurtenances are structures of the stormwater system that help to control rainfall runoff, such as basins, outfalls, and manholes (Engineering Training Institute 2022). Stormwater appurtenances in IB are already experiencing inundation, with the number of impacted assets predicted to worsen as sea levels rise if no protective action is taken (Figures 19 through 23).

Scenario/Conditions	Number of Stormwater Appurtenances Inundated
Current areas of flooding	63 appurtenances
One meter of sea level rise	82 appurtenances
Two meters of sea level rise	169 appurtenances

Figure 19. Inundation of Stormwater Appurtenances

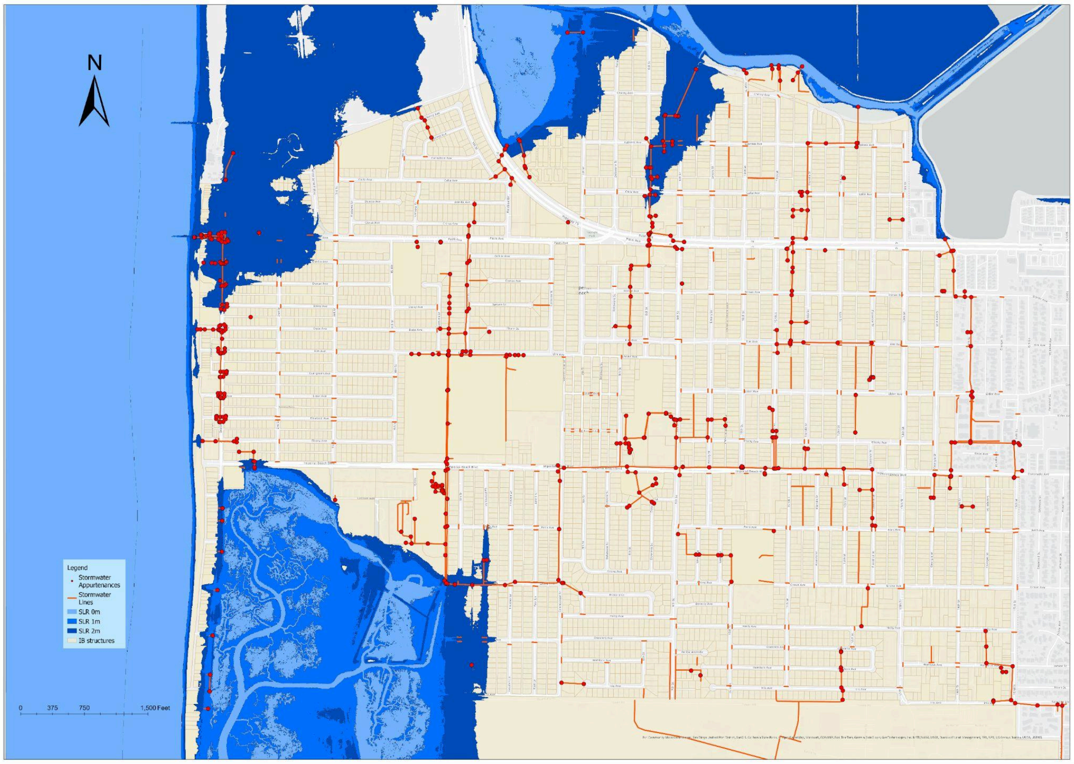


Figure 20. Stormwater infrastructure and inundation in IB

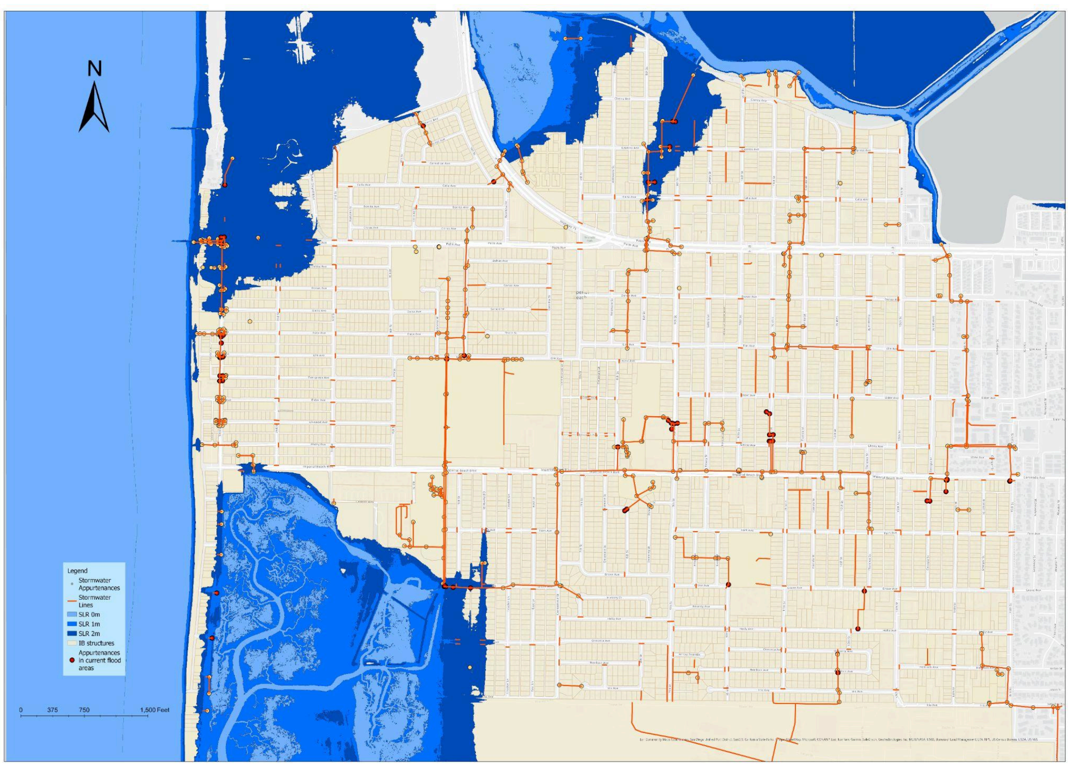


Figure 21. Stormwater appurtenances inundated in current flood zones

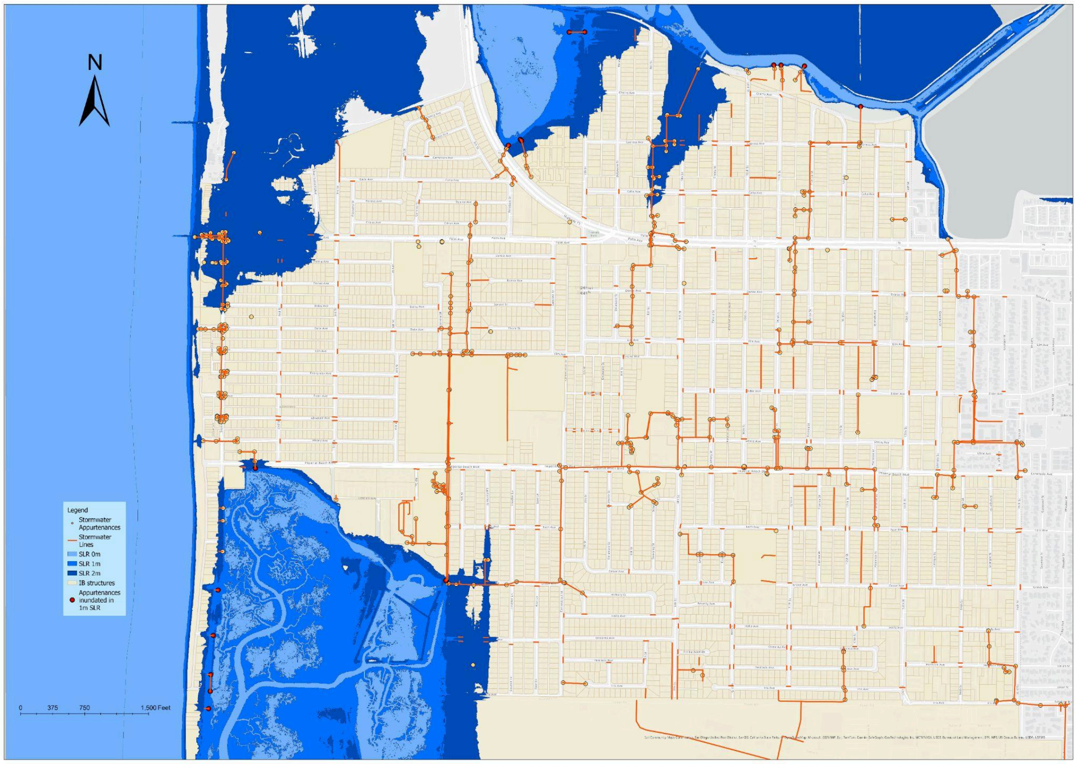


Figure 22. Stormwater appurtenances inundated in 1m SLR scenario

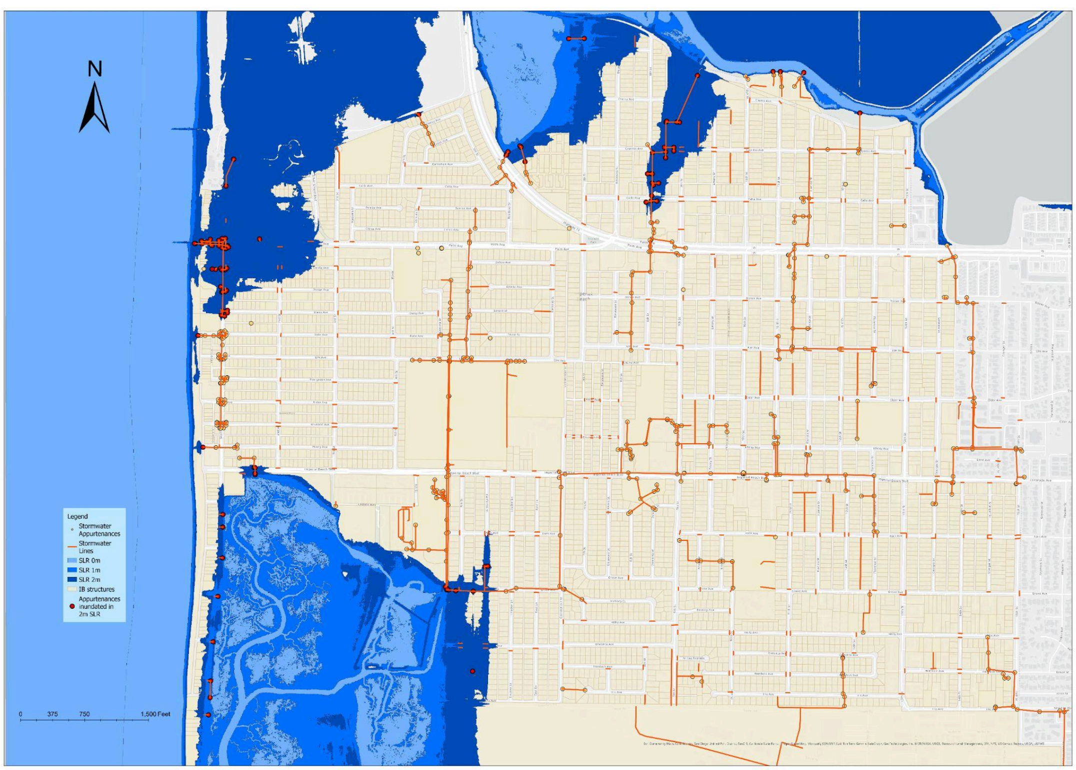


Figure 23. Stormwater appurtenances inundated in 2m SLR scenario

San Diego Gas and Electric (SDG&E)

SDG&E is a regulated utility company in the state of California that supplies electricity and natural gas to San Diego County and southern Orange County (UCAN, n.d.). The California Public Utility Commission (CPUC) mandates that regulated utility companies conduct a Climate Adaptation and Vulnerability Assessment (CAVA) every four years. The CAVA protocol requires utilities to evaluate projected climate hazards using the latest climate model simulations to assess potential impacts on their infrastructure and operations. The examined hazards include extreme temperature, wildfires, changes in precipitation, and sea level rise (SDG&E 2025). Sea level rise analysis in this report also accounts for isolated coastal flooding impacts.

Acting in accordance with the CPUC's regulatory policies, SDG&E filed its most recent CAVA report on May 15, 2025. Yumin Moon, a numerical weather prediction scientist at SDG&E who worked on the climate exposure section of the report, provided insights regarding vulnerability assessments within SDG&E's service territory. The CAVA report outlines the proportion of assets exposed to coastal flooding in 20-year and 100-year coastal floodplains, using CoSMoS datasets to gauge asset vulnerability.

The 2025 CAVA Assessment indicates that sea level rise impacts to utility infrastructure are limited in the SDG&E's service territory, while also noting low vulnerability for inland flooding near the coast. Within the service area, Imperial Beach was not found to experience the most severe sea level rise or inundation impacts (Moon 2025). The report also found that the percentage of assets exposed to coastal flooding is projected to more than double between the baseline years and 2070, especially in low-lying areas which include parts of Imperial Beach (SDG&E 2025). Moon identified sea level rise projection uncertainty as a challenge for utility planning after working on the latest CAVA report. Enhanced certainty in sea level rise projections would allow companies to implement more effective preparation strategies to protect infrastructure (Moon 2025).

SDG&E's sea level rise adaptation strategies vary depending on specific asset characteristics and exposure levels. The company's primary adaptation approaches are relocating assets to areas with minimal sea level rise exposure and installing protective infrastructure to prevent inundation of existing assets (Moon 2025). Asset relocation is the most direct approach; however, it tends to be expensive and would likely be considered in more extreme situations. Installation of protective infrastructure offers a strategy to maintain assets in current locations while reducing vulnerability to inundation. In terms of vulnerability thresholds that necessitate adaptation measures, tipping points are dependent on multiple factors, such as climate hazard type, asset location, current setup/condition of equipment within those areas, and cost. SDG&E's vulnerability assessment focuses on case-specific decisions rather than applying uniform vulnerability thresholds across the service territory (Moon 2025).

Sea Level Rise Impacts on the Tijuana Estuary

The Tijuana River National Estuarine Reserve is one of the few estuarine systems in Southern California where marshes have transitional areas to naturally move as sea levels rise (Crooks 2025). The Tijuana Estuary's availability of accommodation space allows its adaptation approach to focus on maintaining the natural functions of the system. While other wetland systems require sediment supplementation in the face of rising sea levels, the Tijuana estuary's plan involved continuing to dig to lower elevations because of the amount of sediment input the system receives from Mexico. Overall, TRNERR's management strategy in the face of climate change prioritizes enhancing and ensuring the resilience of the existing wetland system (Crooks 2025).

Crooks stated that from his perspective, CoSMoS projections may overestimate flood extent due to high rates of sediment deposition in the wetland areas. Areas that are mapped as permanently inundated in CoSMoS flood projections are frequently above water due to the accumulation of sediment. While CoSMoS projections are valuable in understanding impacts on the built environment, analysis based purely on changes in depth will leave important variables such as sediment dynamics and habitat connectivity out of the equation when trying to understand ecosystem migration (Crooks 2025).

Tijuana River Mouth and Flood Management

The state of the Tijuana River mouth is critical in determining flood impacts and the health of the estuary system. The closure of the river mouth makes flooding on the South end of Seacoast Drive significantly more likely (Crooks 2025). TRNERR aims for the natural system to be a buffer and protect the surrounding communities. In the same vein of thought, TRNERR is trying to implement dune restoration and living shorelines, especially near roads where access is blocked due to flooding in the southern areas of IB (Crooks 2025).

Former intertidal salt marsh habitats have been buried under sediment deposits from the hillsides of Mexico, reducing the amount of water that the estuary system is able to hold. This results in a decreased flood storage capacity in the estuary, and sediment dumping also threatens the ability of the tidal inlet to have open water flow. For the system to function optimally, it is critical to maintain free water flow through the tidal inlet, as the open inlet allows water to drain out of the area. Sedimentation rates have increased substantially in previous years, with some areas that used to experience deep water flow becoming completely buried in sediment (Crooks 2025).

CURRV Scenario Planning Framework

TRNERR has developed a scenario planning framework to prepare for climate impacts in the Climate Understanding and Resilience in the River Valley, or CURRV project. The planning exercise envisions four possible futures of the estuary system based on two variables: extreme river flow events and tidal prism. Tidal prism is the volume of water that tides bring in and out of the estuary. Precipitation patterns, management practices, and land use patterns impact extreme river flow events. Tidal prism and extreme river flow both have a significant influence on the management of the region, and both will likely be influenced by climate change. Using these variables to frame planning, TRNERR envisioned four different futures to organize thinking about potential futures for the estuary and river valley. The project evaluates vulnerabilities in each of these scenarios and classifies vulnerabilities based on their impacts on the physical environment, natural habitats, and the built environment (Boudreau et al. 2017).

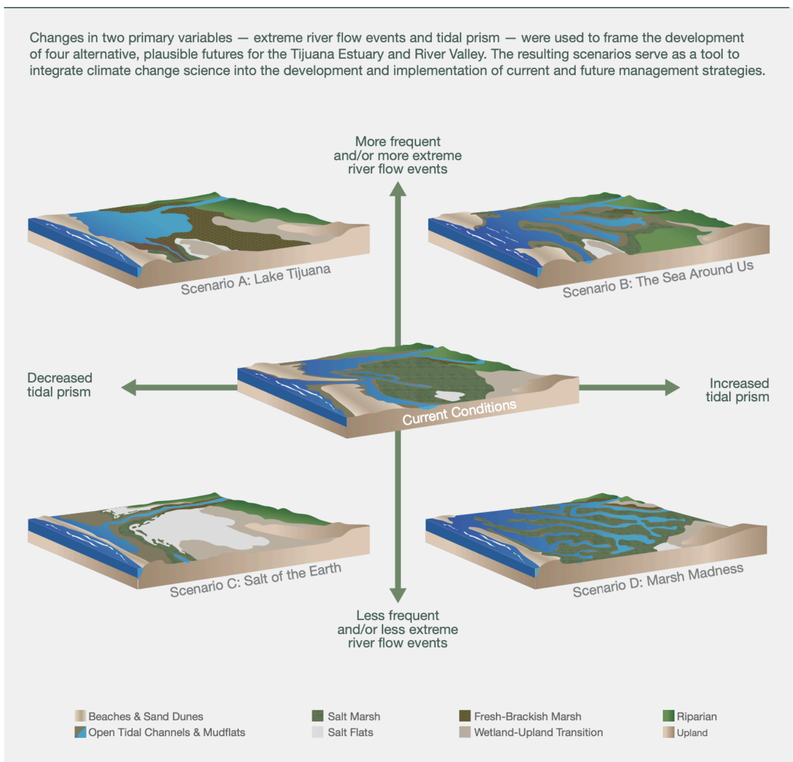


Figure 24. CURRV Developing Scenarios (Boudreau et al.)

Beach Nourishment Impacts on the Tijuana Estuary

Ludka et al. (2022) examined the alongshore variability of beach nourishment and its effects on the Tijuana River mouth. Beach nourishment took place in 2012 to protect vulnerable residential properties on Seacoast Drive from flooding (Ludka et.al). In 2016, a powerful El Niño event sent water levels up by approximately one foot. During this time, the Tijuana river mouth closed, potentially due to the nourishment and intensified drift during the El Niño event (Ludka et al. 2022, Crooks 2025). Dr. Crooks described how the estuarine reserve could tell the sand had come from previous nourishment efforts due to the size and weight of the grains of sand that had blocked the river mouth (Crooks 2025). The 2016 El Niño event gave TRNERR an understanding of a future with about one foot of sea level rise. Elevated sea levels allowed the ocean to push sediment into the system, resulting in a blocked river mouth (Crooks 2025). These conditions were closely aligned with the CURRV scenarios involving closed river mouths.

A closed river mouth negatively impacts species residing in the estuary, as well as the built environment. The closure of the river mouth in 2016 caused hypoxic conditions in the estuary and resulted in the death of many biota, including multiple leopard sharks (Ludka et al. 2022). Similarly, endangered bird species that construct floating nests require tidal exchange from an open inlet to reproduce successfully (Crooks 2025).

Based on the threshold observed during the 2016 El Niño event, TRNERR aims to maintain an open river mouth to keep water flowing freely in and out of the estuary. This management approach drives TRNERR's restoration strategy, which focuses on excavation and deepening tidal channels to maintain current estuarine functions (Crooks 2025).

Pollution and Sea Level Rise

Historically, the Tijuana Estuary has been able to thrive despite experiencing daily inputs of contaminated water. The current pollution situation differs from prior conditions because the volume of polluted flows is greater, and the extent of the estuary with filtering abilities is smaller due to the burial of marsh by sediment. Climate change and sea level rise exacerbate pollution risks due to potential river mouth closure scenarios, which could result in sewage-contaminated water flooding the streets and nearby areas (Crooks 2025).

Estuary Management and Sea Level Rise

The reserve's management approach recognizes wetland systems and living shorelines as natural buffers against sea level rise issues by increasing water storage capacity and reducing flood impacts. Many at the reserve would prefer nature-based solutions within TRNERR's management area, while acknowledging the need for a mix of grey and green infrastructure for the city (Crooks 2025).

Current restoration efforts focus on increasing flood storage capacity in the estuary and maintaining water circulation to preserve river mouth connectivity. Both of these techniques emphasize the wetlands as a natural buffer, and prioritizing the resilience of the system will allow it to mitigate sea level rise impacts in the future. Additionally, dune construction throughout the area provides protection for the system as well. These strategies provide protective benefits for adjacent communities through flood risk reduction (Crooks 2025).

Managed retreat

Coastal jurisdictions face a situation of either managed retreat or unmanaged retreat in the long term. While timelines may differ by location, as sea levels rise, coastal areas will have to adapt. Proposed phased relocation programs must address property value impacts and how policies will impact the current residents of designated retreat zones. Discussions of managed retreat are complicated and difficult to sustain into the future, especially due to the negative impact of discussing specific residential properties on property values (Crooks 2025).

Managed retreat decisions exceed the authority of local governments, particularly because discussions involve private property (Helmer 2025). City officials do not consider retreat to be politically feasible at the local level. In contrast, decisions made by the state or federal government to help local agencies assign compensation to impacted areas could be successful, although this approach is often reactionary. Federal Emergency Management Agency (FEMA) interventions are an example of this approach, where federal agencies determine appropriate locations to rebuild after natural disasters. The reactive approach after disasters opens a political window of opportunity where cities can build back in a more resilient manner (Helmer 2025). California has yet to implement comprehensive buyout programs, but many states are already experiencing coastal hazards such as hurricanes that necessitate these responses (Helmer 2025). IB is developing hazard mitigation plans, so the city can access alternative funding sources for reconstruction in the case of a disaster (Helmer 2025).

SDG&E’s current replacement of gas lines serving Seacoast Drive reflects how utility infrastructure decisions influence retreat planning. The utility is facing challenges due to inundation of these lines in brackish, contaminated groundwater. The company’s decision to continue replacing this infrastructure indicates its commitment to continue providing service to this area for the foreseeable future (Helmer 2025). This decision demonstrates how utility planning can shape regional vulnerability and adaptation plans.

Limitations

Considering the limited time of this research, the scope of this project was limited in its ability to comprehensively assess the adaptation strategies of all the stakeholders, especially service providers, in IB. Similarly, a lack of access to private data regarding utilities servicing IB was a limiting factor in obtaining a more complete assessment of the impacts of inundation on infrastructure relating to electricity, natural gas, water lines, and more. A future study could focus on further exploring the impacts of sea level rise and inundation on more stakeholders, and on understanding these stakeholders’ perceptions of oncoming inundation and coastal hazards. Stakeholders to include in further analyses could be California American Water, SDG&E, and AT&T. Being able to understand which assets are being impacted, potentially through mapping, as stormwater and wastewater have been analyzed, would provide an in-depth understanding of where inundation impacts infrastructure and assets in this region.

Conclusion

This study examines stakeholder perspectives on sea level rise impacts and adaptation strategies in Imperial Beach, California. Several adaptation measures are being considered in IB, including coastal armoring, infrastructure elevation, and beach nourishment. Additionally, two projects are in planning stages right now: the Bayshore Bikeway Resiliency Project and the Imperial Beach Resilience Plan. These initiatives signal broader support for adaptive measures in the city, and will provide benefits to vulnerable locations in the city.

Through interviews with key decision makers and stakeholders in IB, this project identified areas of concern in the city, issues faced in utility provision, and current obstacles in implementing coastal adaptation measures. Adapting to inundation and sea level rise is a process in which stakeholders have vastly different concerns and priorities. The city is focused on beach nourishment projects and elevating infrastructure where it is possible, while TRNERR is implementing dune restoration and maintaining open water flow. Stormwater and wastewater systems are working to retain and infiltrate water upstream, while utilizing pumps to mitigate downstream flood impacts. Lastly, SDG&E's efforts are concentrated on protecting at-risk assets from inundation by implementing protective structures to keep their infrastructure safe. However, despite political will and broad support in the region for adaptation measures, the planning and complicated regulatory processes make it difficult to implement beneficial projects for the community.

These initial findings open up opportunities for further exploration. Future research could incorporate more stakeholders, such as providers of telecommunications and water in the city. Another potential direction could be the exploration of policy solutions to regulatory hurdles faced by municipalities when attempting to implement coastal adaptation measures. While this is a study focusing on the City of IB, a similar framework can be utilized to understand the unique situations faced by other areas vulnerable to inundation in the future. Additionally, the position of the city and other stakeholders is representative of what coastal communities are grappling with globally, making the qualitative analysis of this project relevant for understanding coastal climate adaptation on a broader scale.

Appendix A: Capstone Deliverable (Storymap)

[Link to Storymap]

Appendix B: Additional Maps

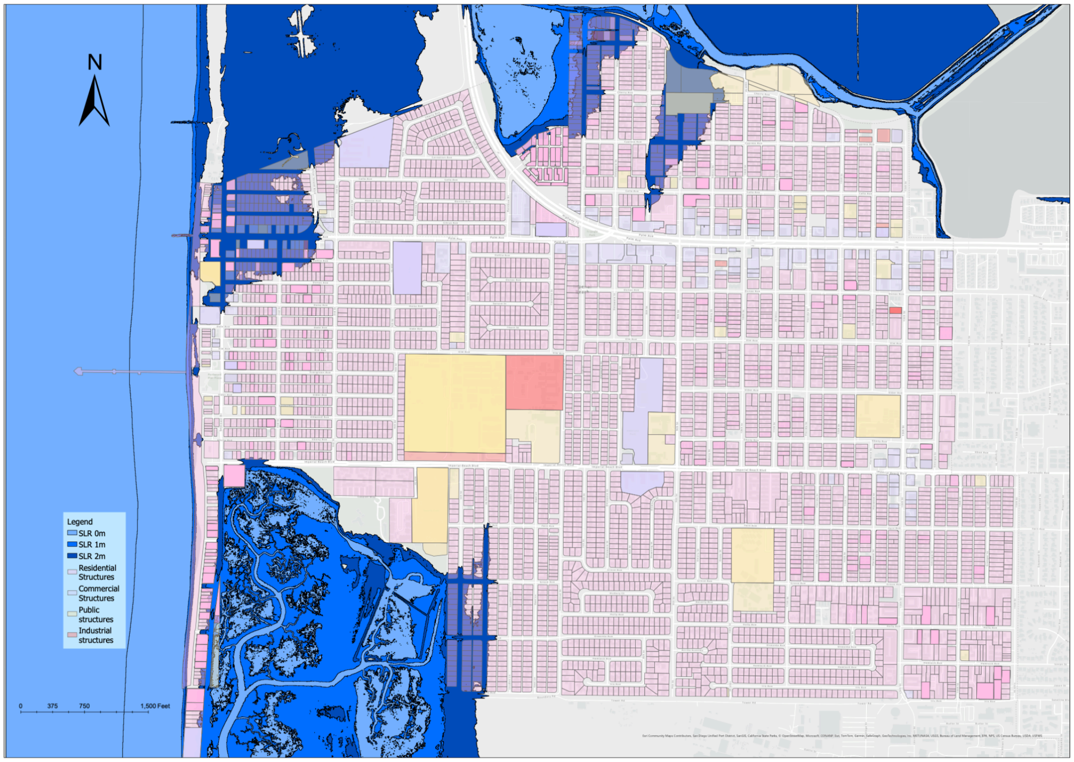


Figure 25. Marine and Tidal Inundation and Structures

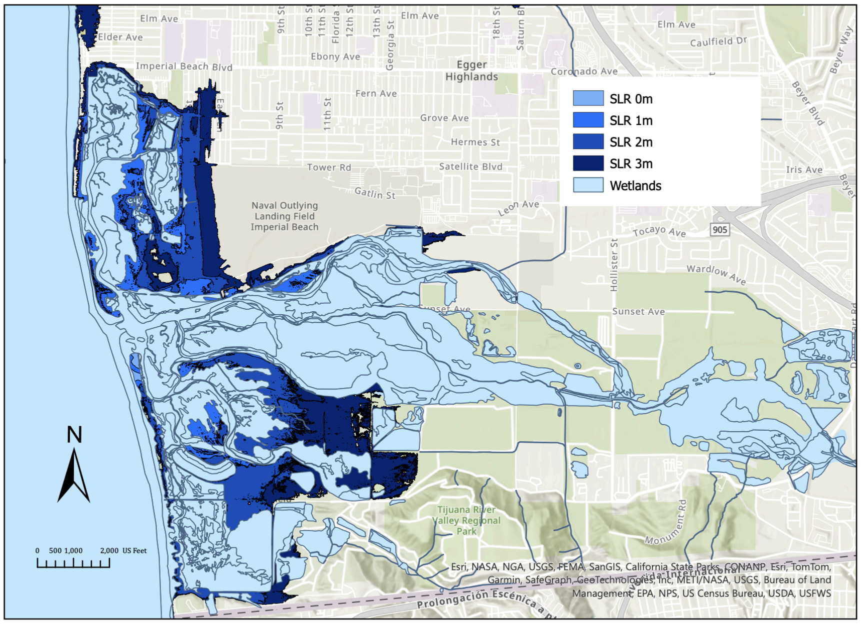


Figure 26. Wetland map with marine and tidal inundation (classified by SLR amount)

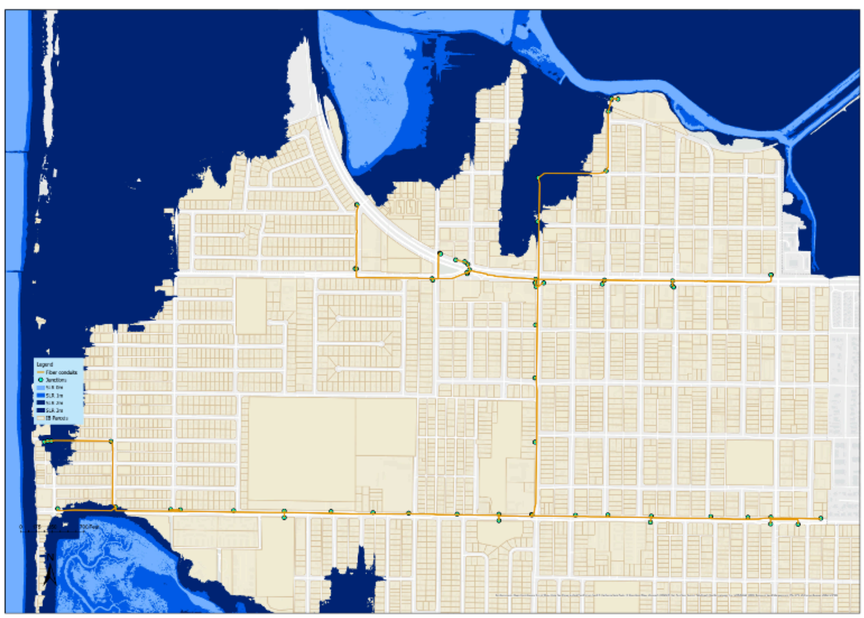


Figure 27. Fiber optic infrastructure with marine and tidal inundation (classified by SLR amount)

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