Title
Rising Resilience: Quantifying the Benefits of Nature-Based Solutions to Sea Level Rise in Imperial Beach, California

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Rising Resilience: Quantifying the Benefits of Nature-Based Solutions to Sea Level Rise in Imperial Beach, California

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Abstract

In light of anthropogenic climate change and increasing global temperatures, coastal flooding and erosion from sea level rise are becoming more prevalent. Historically, adaptation techniques to protect the coastline have focused on gray infrastructure; however, nature-based solutions (NBS) are rapidly emerging as a viable long-term approach for successful adaptation. Due to the relative novelty of the climate adaptation field as a whole and nature-based solutions specifically, barriers to their implementation include a lack of funding and general support. Thus, quantifying and communicating the benefits of NBS is crucial to their successful widespread implementation. This report addresses this issue in the specific context of NBS to sea level rise in Imperial Beach, California. It aims to create a framework that adequately quantifies the benefits of NBS to sea level rise and expresses them in a manner that allows for seamless implementation. A cost-benefit analysis is used, which consists of five steps: (1) project identification, (2) project attributes identification, (3) cost summary, (4) benefits summary, and (5) comparative analysis. The Bayshore Bikeway Resiliency Project and beach nourishment events are considered highly cost-effective solutions based on key findings. Dune restoration, however, is not considered a cost-effective method, given only the current quantitative benefits. If the broader range of additional benefits is included, the City may still designate this project as a plausible response to sea level rise. The most cost-effective method of adaptation considered in this study is beach nourishment. However, a single-project approach is not recommended in climate adaptation. A hybrid adaptation approach is usually the most effective and beneficial as there is no “one-size-fits-all” procedure to planning. Future studies may expand upon this research by utilizing a similar framework for other NBS in different jurisdictions. The City may also utilize this information to further the planning process of climate adaptation projects as they and many other cities work to build resilient communities in the presence of climate change.

Keywords: Climate change, sea level rise, City of Imperial Beach, San Diego, nature-based solutions, living shoreline, Bayshore Bikeway Resiliency Project, beach nourishment, cost-benefit analysis

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1. Introduction

In light of anthropogenic climate change and increasing global temperatures, coastal flooding and erosion from sea level rise are becoming more prevalent. In California, over 2,600 establishments, 49,000 jobs, $8.0 billion in sales, and $6.1 billion of San Diego County's GDP are at risk with just two meters of sea level rise (Colgan et al., 2018). Given the severity of these impacts, proactive climate adaptation and resilience planning are becoming increasingly imperative for local governments to protect public health and safety, the local economy, and the habitat. Historically, adaptation techniques to protect the coastline have focused on gray infrastructure; however, nature-based solutions (NBS) are rapidly emerging as a viable long-term approach for successful adaptation. In planning for and building resilient communities, garnering both financial and general community support is vital to the success of these projects. Due to the relative novelty of the climate adaptation field as a whole and nature-based solutions specifically, comprehensive and detailed information on the performance and co-benefits of NBS remains limited and can be a barrier to implementation. Thus, quantifying and communicating the benefits of NBS is crucial to fostering widespread support and garnering the resources necessary for more widespread implementation. This report addresses this issue in the specific context of NBS to sea level rise in Imperial Beach, California.

1.1. Sea Level Rise - A Primer

Sea level rise is a direct consequence of anthropogenic global warming, meaning that as greenhouse gas emissions and temperatures continue to rise, so will the sea level, threatening coastal infrastructures, habitats, and communities around the globe. Since the end of the last ice age, sea levels have risen approximately 120-135 meters, demonstrating that sea level rise is not a new phenomenon. However, the rate at which inundation occurs has changed. After the industrial revolution and the influx of greenhouse gasses into the atmosphere, sea levels rose at a rate of 1.2 to 1.7 mm per year. Since 1990, this rate has more than doubled and continues accelerating (Griggs & Reguero, 2021). Two main processes drive sea level rise: thermal expansion of seawater and land ice glacier melt. In addition to a small amount of land subsidence, these processes have induced a sea level rise of 8 to 9 inches (21 to 24 centimeters) since 1880 (Lindsey, n.d.). Based on different possible future Intergovernmental Plan on Climate Change (IPCC) pathways for global warming, three scenarios for sea level rise are utilized to analyze potential impacts: 0.5 meters, 1 meter, and 2 meters of inundation as compared to levels in the year 2000. (Lindsey, n.d.). The potential detrimental impacts predicted from just 1 meter of sea level rise prompt immediate action (Griggs & Reguero, 2021).

Coastal inundation impacts communities in three main ways: flooding, erosion, and loss of habitat and beaches. First, beaches and other coastal habitats risk extreme flooding during storm and non-storm conditions. Storm events, such as El Niño years on the California coast, and hurricanes, cyclones, and typhoons in other areas around the country, contribute to coastal flooding, given the increased wave energy and height during these events. The winter of 1997-1998 brought one of the most ferocious El Niño years to date. Boasting some of the heaviest amounts of rainfall, this season was one of the wettest on record across all of California and resulted in approximately $850 million in flood damages statewide (Null, 2023). Increased flooding has also been seen outside of El Niño years. For example, flooding during January 2023, which was not an El Niño year, caused approximately $1 billion in flooding and storm damages across the state (Null, 2023). Global warming increases the occurrence of large storms, meaning the wind and wave action that materialize from these storms will impact coastlines at accelerating rates, mirroring the increasing intensity of climate change. A less studied but equally as crucial type of flooding is “sunny day” or nuisance flooding. This is a “minor” type of flooding driven by sea level rise and high tides. The result is flooded roads, overloaded stormwater systems, and other inconveniences and infrastructure damage. Based on 70 years of observations, a report found that the total number of nuisance flooding events has increased exponentially, with 27% more nuisance floods occurring in 2019 since the beginning of the study (Griggs & Reguero, 2021). With sea levels expected to rise, flooding will consequently increase in frequency.

A second impact of sea level rise is seen in the erosion of cliffsides and beaches. Paired with abnormally high tides, increased wave height and energy initiated by global warming cause increased erosion of coastlines. Rock coasts, which account for nearly half of the world’s coastlines, are expected to retreat at increasingly rapid rates (Brogan, 2022). Third, increased erosion and inundation of coastal areas degrade wetlands, beaches, and other critical habitats for resident species of birds, plants, and other organisms, many of which are endangered (Griggs & Reguero, 2021). A 2015 study concluded that by the year 2100, 60 of the 88 rare coastal plant species across California's central and southern coasts will be threatened by sea level rise (Garner et al., 2015). With sea level rise projected to increase, suitable habitats for these species will either shift or disappear, threatening their survival. In addition to native wildlife losing habitat and resources, sea level rise threatens human communities. Across the California coast, the cumulative effects of coastal flooding and erosion will potentially place nearly 140 schools, 34 police and fire stations, 55 healthcare facilities, 330 hazardous waste sites, 3,500 miles of roads and highways, and 280 miles of railways at risk (Heberger et al., 2009). In the presence of rising sea levels, action must be taken for cities to properly prepare for and respond to the inundation.

1.2. Adaptation Measures

When confronted with sea level rise, there are generally four solutions: do nothing, take preventative action, engage in managed or unmanaged retreat, or regulate and restrict new developments. While each of these solutions has positive and negative attributes, managed and unmanaged retreat can be politically not viable as it is commonly critiqued as limiting the way of life for residents of coastal areas. Taking the form of zoning changes, removing or relocating developments, or the implementation of buyout programs, this option has been described by homeowners as the "kiss of death" (Rott, 2018). Given the intense backlash to this option, retreat is not usually considered a viable form of adaptation. Regulation and restriction of new developments garners similar, yet less intense, reactions from communities. By restricting new developments, cities can ensure that any new project is not located in a potential flood zone. This option does seem promising. However, this will primarily protect new developments, leaving existing developments at risk (*Responding to Rising Seas*, 2019). While boasting low upfront costs, the "do nothing" approach carries the greatest risk of potential consequences as no proactive measures to reduce risk are taken, making this another suboptimal approach in coastal communities (Griggs & Reguero, 2021). Therefore, preventative action has become the most common response to sea level rise. This includes actions such as armoring the shoreline with sea walls and other "gray" infrastructure or the use of natural "green" infrastructure (also referred to as NBS), including living shorelines and beach nourishment (Griggs & Reguero, 2021). Depending on an area's specific geography, politics, population, and other attributes, one adaptation measure may be desired over another.

The process of adaptation planning is complex and requires cross-industry communication and collaboration. Good adaptation planning will consider and respond to the city's vulnerabilities and assess how different measures might be used to alleviate these impacts. Challenges to adaptation planning lie in collaboration, communication, gaining support, and funding needed for the projects. This paper aims to alleviate these barriers by exemplifying a framework to quantify the benefits of NBS adaptation measures. Effectively communicating the identified benefits of projects will aid in securing the necessary support and funding for the project's completion.

1.3. Local Context: The City of Imperial Beach

Located in San Diego County on the border of Mexico, the City of Imperial Beach (City) is the southernmost city in California. As a primarily residential area, the city holds a population of approximately 26,000, with its 1.5 miles of coastline drawing many more tourists throughout the year (*U.S. Census Bureau QuickFacts,* 2022). As demonstrated in Figure 1, this area is unique as it is surrounded on three sides by water; the San Diego Bay to the north, the Pacific Ocean to the west, and the Tijuana River Estuary to the south (*2016 City of Imperial Beach*, 2016).

Figure 1. City of Imperial Beach Map

In recent years, the communities of Imperial Beach have experienced frequent flooding events. Utilizing the three aforementioned sea level rise scenarios of 0.5-2 meters, in 2016, the City completed a vulnerability assessment which concluded that tidal inundation already impacts key stormwater outlets, 800 feet of wastewater pipes, five wastewater pump stations, 1.7 miles of roads, and all of the beach access points and coastal properties. The inundation has impacted and will continue to affect land use, roads, public transportation, wastewater, stormwater, schools, and hazardous materials (*2016 City of Imperial Beach*, 2016). Figure 2 demonstrates the extent of these impacts.

a) 0.5 meters of SLR b) 1 meter of SLR c) 2 meters of SLR

Figure 2. Imperial Beach Inundation Map

The City has made efforts to implement various green and gray adaptation measures. The first of these projects was the construction of groins (horizontal rock structures perpendicular to the shoreline) in the City's north. Out of the proposed five groins, only two were constructed. The groins, designed to catch sediment and reduce erosion, were ineffective at trapping the sand, and the project was abandoned (*2016 City of Imperial Beach*, 2016). Any further alterations to the groins would require complicated collaboration between multiple stakeholders. Considering the complexity and uncertainty of projects such as the groins, individual property owners have taken a parcel-by-parcel approach to adaptation and have constructed assorted forms of coastal armoring in front of their properties. Engineered sea walls, revetments, and random rip rap armor much of Imperial Beach's coastline. The City has also opted into beach nourishment projects, the most recent being the San Diego Regional Beach Sand Project II in 2012. Despite the failed groins, beach nourishment and coastal armoring (rip rap and sea walls) have proven somewhat successful at maintaining beach width, stabilizing beaches, and protecting infrastructure from wave run-up (*2016 City of Imperial Beach*, 2016).

2. Project Aims and Methodology

As the City looks to longer-term, cost-effective solutions to sea level rise, NBS are emerging as a strong contender because they promote the construction and preservation of healthy ecosystems which have proven to limit greenhouse gas emissions, protect people and nature from the impacts of climate change, and build resilient coastlines. To overcome the challenges of adaptation planning and garner widespread support for the implementation of these projects, each project's entire value, both financial and social value, must be quantified and communicated. This project aims to create a framework that adequately quantifies the benefits of NBS to sea level rise and expresses them in a manner that allows for seamless implementation.

Figure 3. Zone identification map

A cost-benefit analysis is used to quantify the benefits of the potential NBS that can be implemented in each area. The cost-benefit analysis consists of five steps: (1) project identification, (2) project attributes identification, (3) cost summary, (4) benefits summary, and (5) comparative analysis. Given the complex nature of the City of Imperial Beach's geography, no one solution can be implemented across its entire jurisdiction. Therefore, Imperial Beach has been divided into three zones for easy analysis for this project, each shown in Figure 3. The three zones were chosen because the City consists of three distinct ecosystems that call for various adaptation and resilience planning forms.

Zone one encompasses the northern shores along San Diego Bay. This area includes the southern section of the San Diego Bay and the Bayside Neighborhood. The ecology of this region includes the flood plains and salt ponds in the south of San Diego Bay, which serve as crucial habitats for many species of birds and other plants and animals (*South San Diego Bay Coastal Wetland Restoration,* n.d.). The adjacent community, the Bayside Neighborhood, is characterized as a disadvantaged community that, in the past, has lacked the resources to respond aggressively to climatic changes (*2016 City of Imperial Beach*, 2016). Zone two consists of the western shorelines along the Pacific Ocean.

This region is characterized by sand and cobble beaches, dunes, and upland scrub covering the entirety of the coastline. Plenty of species, such as clapper rail, utilize these beaches and dunes as crucial habitats (*2016 City of Imperial Beach*, 2016). Finally, zone three includes the southern border with the Tijuana River Estuary. This area is publicly managed as part of the Tijuana River National Research Reserve (TRNERR), which is a partnership between California State Parks, the National Oceanic and Atmospheric Administration (NOAA), and US Fish and Wildlife Service (USFWS). This area serves as one of Southern California's largest coastal wetland systems. It is comprised of a contiguous beach, dune, salt marsh, riparian, and upland ecosystem (*2016 City of Imperial Beach*, 2016).

After discussing with the local city planners, it is apparent that any projects that reside within zone three are technically not included in the City's jurisdiction, so those projects should not be incorporated in the cost-benefit analysis. This is because while the City may reap some benefits from any restoration project in this area, they will not be burdened with any costs and not be the principal agent tasked with implementation. Therefore the only zones further included in this analysis are zones one and two.

Utilizing these different zones allows for a separate cost-benefit analysis to be completed for each zone, enabling a more direct comparison of each project, given that they all possess unique characteristics. The cost-benefit analyses are performed on a projected timeline of the year 2020 to 2100 to align with the IPCC's projections of end-of-century climate change predictions. This timescale also aligns with the City's planning timelines as they evaluate their plans on a worst-case scenario of 2 meters of sea level rise by the year 2100.

Discounting

Since this analysis extends from 2020 to 2100, future costs and benefits must be discounted appropriately to depict the data in present value terms. Discounting translates future monetary amounts into equivalent current sums, adjusting future values to undo the effects of compound interest. Past projects from the City demonstrate the appropriate discount rate to utilize in this study. Their analyses use a discount rate of 1%, reflecting the findings of a 2001 paper by Weitzman, which states that a 1% discount rate should be utilized for projects with timelines exceeding 75 years (*2016 City of Imperial Beach*, 2016). Considering that this report analyzes projects on a time scale reaching from 2020 to 2100, a discount rate of 1% is also used in this report. Using the formula below, the discount factor for each year is calculated, where t represents years from 2020, i.e. 2020 = 0. 2021 = 1, etc.

$$Discount\ factor = 1/((1 + 0.01)^{t}$$

When appropriate, multiplying the future value costs and benefits by the respective discount factor results in the present value costs and benefits of each project which serve as an accurate representation of the project's value.

2.1. Step One: Project Identification

In step one of the cost-benefit analysis, historical records are used to determine which projects have been utilized in the past that could still be considered for implementation in the future. In addition, collaboration and interviews with local government officials further identify which projects are preferred to be included in this analysis. Between these two processes, three NBS are identified: living levees, beach nourishment, and dune restoration. Zone one includes the proposed living levee, which is being constructed by the City as a project titled the Bayshore Bikeway Resiliency Project, and zone two includes proposed beach nourishment and dune restoration events.

Living Levee

Zone one encompasses the Bayshore Bikeway Corridor, a popular bike path around San Diego Bay. Given this structure, the project that most closely aligns with this zone is the construction of a living levee. The City has already planned the construction of a living levee as an aspect of the Bayshore Bikeway Resiliency Project. This project includes a living levee to provide flood protection from sea level rise in San Diego Bay. Coined "horizontal levees" or "living levees," these structures elevate the land and then slope off in one direction to mimic the geography of naturally formed coastlines (Mena, 2016). They consist of a hardened structure (in the case of Imperial Beach, this will be the bike path) followed by a wide expanse of natural marsh and vegetation (*Horizontal Levees,* n.d.). The sloping vegetated hillside allows for a natural transition from land to water, absorbing the water and providing flood protection to the land, structures, and adjacent communities. Living levees provide many benefits, including flood protection benefits, water filtration, habitat restoration, and recreational opportunities.

Beach Nourishment

Zone two includes a potential beach nourishment project. This is a popular response to sea level rise in the City and the greater San Diego region for sandy coastlines, such as the coast in zone two. This process involves large amounts of sand being imported and deposited on the beach to maintain width, provide upland protection of structures, and reduce erosion. In addition, the recreational use and aesthetic appeal of wide beaches offer beachgoers the ability to enjoy and appreciate the beauty of coastlines. Multiple renourishment events are necessary to maintain a beach width over time, due to the fact that sand and beaches are eroding at increasing rates due to sea level rise. Nourishment events are viewed as potential long-term solutions to sea level rise, granted that the cost of sand does not increase dramatically and the project continuously aligns with community wants and needs. The City of Imperial Beach and many other San Diego County communities have opted into beach nourishment programs. The San Diego Association of

Governments (SANDAG) has coordinated and completed multiple sand nourishment projects, nourishing beaches along San Diego's 60 miles of coastline (*SANDAG - Beach Sand Replenishment*, n.d.). The City of Imperial Beach has participated in these projects with nourishment events from 1940 to 2005, adding almost 40 million cubic yards to its coastline (*2016 City of Imperial Beach*, 2016). The most recent beach nourishment project, San Diego Regional Beach Sand Project II, added approximately 450,000 cubic yards of sand to combat erosion (*2016 City of Imperial Beach*, 2016).

Dune Restoration

Zone two also includes a potential dune restoration project, as this project most accurately represents the natural dunes of the City in this region. Dune restoration is a highly effective method of adaptation that most closely emulates the natural ecology and structure of the coastline. This process consists of a cobble layer on the beach's coastal side, followed by the construction of a sand dune (*2016 City of Imperial Beach*, 2016). Dunes are beneficial as they provide habitat and natural protection to adjacent upland properties. These dunes serve as nesting grounds and habitats for various species, including some that are endangered. Restoring dunes supports biodiversity in these areas and contributes to species conservation. A unique benefit of dune restorations is their capacity to reduce beach erosion rates. Unlike projects that simply replenish the eroded sand, dune restoration involves the use of cobble berms which experience slower erosion rates than that of sand, making their placement on beaches extremely beneficial. In addition, dunes provide flood protection and create scenic coastlines with many recreational opportunities. These benefits make dune restoration a highly sought-after adaptation strategy.

2.2 Step Two: Project Attributes Identification

After the projects are chosen, their physical attributes are identified. This is a necessary step in the cost-benefit analysis as it allows the scope of the project to be understood, leading to accurate cost and benefit estimates.

2.2.1. Zone 1

The living levee, which is part of the Bayshore Bikeway Resiliency Project, is located in zone one. The City has already considered and thoroughly assessed the scope of the project. Public meetings have been held to discuss this project, which is currently in the planning stage of implementation. Therefore the dimensions and details of this project were provided by the City and found in public domains.

2.2.2. Zone 2

Multiple project dimensions must be considered for beach nourishment and dune restoration. Given that the coastline will erode over time, renourishment events for both projects are necessary to maintain the width of the beach and its benefits. Both sand nourishment and dune restoration require an initial nourishment event and then nine subsequent events that restore the area to the same dimensions as the initial event. This resulted in a total of ten nourishments from 2020 to 2100 (*2016 City of Imperial Beach*, 2016). The number of renourishment events was derived from the City's 2016 City of Imperial Beach Sea Level Rise Assessment. Then, to easily compare the projects, it was assumed that each project is implemented along the entirety of the City's coastline (1.5 miles). Each project (beach nourishment and dune restoration) is analyzed separately, and based on these findings, the City can then consider the implementation of both projects, one project, or potentially neither.

Beach Nourishment

Based on historic beach nourishment projects and information provided by the City, the original 50 ft beach is assumed to be nourished to the ideal width of 150 ft, making the initial nourishment area approximately 2,843 yards long, 33 yards wide, and 9.76 yards deep. Thus, the initial beach nourishment event is a total of 925,000 cubic yards. Then, the subsequent renourishment events were found by applying the sand erosion rates for the respective year to the years between nourishment events and calculating the renourishment dimensions necessary to restore the area to the initial event.

This study utilizes erosion rates calculated by the City that were found using the Digital Shoreline Analysis System (DSAS), a system developed by the United States Geological Survey (*2016 City of Imperial Beach*, 2016). This software utilized a historic erosion rate of 7.48 inches per year as its baseline erosion rate. It then predicted future erosion rates based on existing rates escalated with sea level rise predictions. This resulted in the erosion rates depicted in table Table 1, which are used in this study.

Table 1. Sand and Cobble Erosion Rates

Year	Sand Erosion Rate (ft/year)	Cobble Erosion Rate (ft/year)
2020	1.5	1.35
2025	1.8	1.62
2030	2.1	1.89
2035	2.4	2.16
2040	2.7	2.43
2045	3	2.7
2050	3.3	2.97
2055	3.6	3.24
2060	3.8	3.42
2065	4.1	3.69
2070	4.4	3.96
2075	4.7	4.23
2080	5	4.5
2085	5.3	4.77
2090	5.6	5.04
2095	5.9	5.31
2100	6.2	5.58

Renourishment events actively restore the beach to a width of 150 ft. The volume of each renourishment event is then determined by subtracting the eroded beach width from 150 ft, converting the result to yards, and multiplying that number by a length of 2,843 yards and a depth of 9.76 yards. This process was applied to each of the ten nourishment events from 2020 to 2100.

Dune Restoration

The initial dune restoration project includes a cobble berm at a width of 50 feet, followed by a sand dune nourishment with a width of 30 ft and a height of 20 feet. (*2016 City of Imperial*

Beach, 2016). The cobble and dune measurements were borrowed from past studies completed by the City.

Then, erosion rates were applied to both the cobble and sand dune to calculate the volume of each renourishment event. Utilizing information from the City of Imperial Beach, it was assumed that once the beach erodes to a width of 175 ft, the cobble will begin to erode at a rate of 90% of the sand erosion rates (Table 1). Once the cobble erodes to 25 ft, the sand dune will then begin to erode at the sand erosion rate (*2016 City of Imperial Beach*, 2016). Considering these parameters, the subsequent renourishment widths of cobble and dune sand are calculated.

2.3. Steps Three and Four: Cost and Benefits Summary

Given the physical attributes of each project, and information collected from varying literature and documents, the costs and benefits are then considered for each project.

2.3.1. Zone 1 - Costs

As with project attributions, the City has already considered the costs of the Bayshore Bikeway Resiliency Project, and thus no separate calculations need to be made.

2.3.2. Zone 2 - Costs

For beach nourishment and dune restoration, the costs of the projects include material and permitting costs.

Permitting

The permitting process for coastal construction projects is complex, given that the land that will be altered is highly valued by the community and City. In the past, beach nourishment within the City included permits provided by SANDAG. Permitting for this project was complex, with permits coming from several agencies, including USACE, California Coastal Commission, State Lands Commission, Regional Water Quality Control Board, and potentially the California State Parks and Department of Fish and Game (*Coastal Regional Sediment Management Plan,* 2009). The City of Imperial Beach also issued its own local coastal development permit and noise variance approval. Moreover, compliance with the California Environmental Quality Act (CEQA) and National Environmental Protection Act (NEPA) was required for all projects. The costs of these permits were shared by all participating jurisdictions, meaning the City contributed a relative percentage of the costs.

This analysis attempted to include permitting in the cost estimates; however, this information was not easily accessible and could not be identified in the allotted project time frame. Based on other beach nourishment projects in southern California, it is assumed that the cost of permits is relatively minor in comparison to the overall cost of a project. Provided that the following estimated project costs already account for variance in multiple aspects, the permitting costs are omitted. This does not disregard the importance of permitting costs; this project's scope does not allow for this analysis.

Beach Nourishment
According to the City, sand costs $20 USD per cubic yard (*2016 City of Imperial Beach*, 2016). This amount was held constant through each nourishment event and multiplied by the estimated volume of each event to calculate the event's cost. The sum of these totals represents the future value cost of beach nourishment. Finally, discount rates were applied to find the present value cost of nourishment, which accurately represents the costs from 2020 to 2100.

Dune Restoration
The cost of dune restoration is more difficult to calculate. The City provided the cost of cobble and dune sand in a format of $USD per linear foot, given fixed dune restoration dimensions. These numbers are pulled from a study outlining the cost of dune restoration along the entire 1.5 miles coast of Imperial Beach, with 50 feet of cobble width and 30 feet of dune width (*2016 City of Imperial Beach*, 2016). These are the same dimensions utilized in this study. Given that dimensions are held constant throughout the two studies, the cost of each material is divided by the width of nourishment to convert this cost to the proper units. This produces a cost of $USD per foot of nourishment width per foot of beach length. The resulting cost of cobble is $60 USD per foot of width per foot of beach length. Dune sand costs $33 USD per foot of width per foot of beach length. To calculate the total cost of each nourishment event, the added width of the nourished material is multiplied by the price *and* the total length of the beach (9,720 ft). These costs for each nourishment event are added across the entirety of the project's timeline to find the future value cost of dune restoration. Finally, discount rates are applied, resulting in the dune restoration's present value costs.

2.3.3. Zone 1 - Benefits
While the City was able to provide the costs for the Bayshore Bikeway Resiliency Project directly, they did not have the benefits. Therefore, a new framework needed to be created to quantify the benefits of this project. The primary benefit of this project lies in the flood protection benefit to the adjacent neighborhood (census tract 105.02). These benefits are reflected in the potential change in the value of the housing stock that the project will protect. A 2023 study evaluated the effect of climate adaptation infrastructure on housing values in Miami-Dade County by comparing property values before and after the completion of infrastructures similar to the living levee utilized in the Bayshore Bikeway Resiliency Project. This study employs the hedonic model, which values the homes based on their internal characteristics and the outside factors that will affect the home, including the potential reduction in climatic risks due to the presence of climate adaptation measures. They concluded that one year after the project's completion, property values rose 5%, and five years after completion,

property values rose 10% (Kelly & Molina, 2023). These same percentages are used in this study.

To perform this calculation, the total housing stock value of homes in the Bayside community (census tract 105.01) is determined by utilizing housing values from census tract data from the most recent 2021 census count. This value is then multiplied by 53%, representing the estimated percentage of properties within the area the project will safeguard. Those values are then multiplied by 5% and 10% to determine the increase in housing value one year and five years after the completion of the project. Discount rates are not applied to these figures because the hedonic property model assumes that when a home is purchased, the estimated net present value of all future streams of benefits provided by each component of the home is captured in the home's value. Therefore, by increasing the home's value by a certain percentage based on the expected benefits provided by the project, the new housing value will encapsulate the total net present value of the future benefits of the project.

2.3.4. Zone 2 - Benefits

The benefits of the beach nourishment and dune restoration projects in zone two are demonstrated by recreational use and flood protection impacts, respectively.

Beach Nourishment

The goal of beach nourishment is to restore the beach to a width that combats erosion while promoting the area's recreational use. Thus, the benefits of beach nourishment are reflected in the recreational value added to the beach from the project. This is calculated by identifying the additional width of the beach provided by the project, multiplying that by a person's willingness to pay (WTP) to recreate at the beach, multiplying the resulting recreational value by the estimated attendance, and finally applying discount rates.

The value of each additional foot of beach width is demonstrated by a person's WTP to recreate at the beach, which can be deduced using stated preference, revealed preference, and other combined methods. A 2016 study utilized these methods and found that the average value per foot of beach width is $0.29 to $0.86 USD (Gopalakrishnan et al., 2016). The benefits of beach nourishment are calculated using the midpoint between these two numbers ($0.575 USD per additional foot of beach width). The beach width in the absence of nourishment is calculated and compared to the beach width with nourishment. The difference between these two numbers for each year demonstrates the additional beach width the nourishment events provide. Then these values are multiplied by $0.575 to determine that year's recreational value per visit to the beach. This value is then multiplied by the estimated beach attendance for that given year to find the future present value of beach nourishment benefits.

Two numbers were selected to represent beach attendance. A lower bound of 300,000 visits per year was borrowed from a study completed by SANDAG that is often referenced by the City of Imperial Beach (*2016 City of Imperial Beach*, 2016). Researchers completed counts of people recreating at San Diego Beaches from May 2012 to June 2013. Estimates of yearly attendance were then able to be made by multiplying the counts by an attendance multiplier. They concluded that there were approximately 300,000 visitors a year at the shoreline of Imperial Beach. Provided that this estimate's wide range of uncertainty and possible fluctuation, an upper range of 500,000 visits per year was also used. This study uses this as the upper bound because it is the same number used by the City in many of their analyses. In April 2016, the City interviewed Imperial Beach lifeguards to collect data and understand lifeguard counts of beach attendance. Their counts range from approximately 1,000,000 to 3,000,000 people a day. Given that lifeguards are concerned with more than just headcounts of beachgoers, their estimates are expected to be much less accurate than the SANDAG study. Therefore, the City utilized 500,000 visits per year in its studies.

Using these values of beach attendance, the recreational value of the beach per visit is multiplied by 300,000 and 500,000 to calculate the additional beach recreational value provided by the beach nourishment project for each year. The sum of these values demonstrates the future value benefits of beach nourishment. Discount rates are applied to the future value, resulting in the present value benefits of beach nourishment.

Dune Restoration

To evaluate the flood protection benefits of dune restoration, a methodology similar to the Bayshore Bikeway Resiliency project is applied. While dune restoration influences beach width, its primary purpose is flood protection. Flood protection benefits can be quantified by the impact the project has on the value of the housing stock in this area. Housing values in two census tracts, 105.01 and 102.01, were assessed as these tracts are located along the 1.5-mile coastline of Imperial Beach. The value of the housing stock was calculated for both of these census tracts utilizing census data, creating an upper and lower bound for these values. Once the total housing value was found, the impact of the project on housing values could be calculated.

A study completed in 2017 utilizes the hedonic property model and estimates the economic impact of large-scale investment in dune restoration to be a housing stock value increase of 3.6% (Dundas, 2017). Therefore, the housing stock value of the two census tracts was multiplied by 3.6%, and their value change represents the benefits of dune restoration in Imperial Beach. Discount rates were not applied to these numbers for the same reason as the benefits of the Bayshore Bikeway Resiliency Project.

2.4. Step Five: Comparative Analysis
To accurately compare the economic impacts of each project, their net present values were calculated. This calculation provides the sum of the future stream of benefits minus the present discounted value of the future stream of costs. This was done by subtracting the sum of the present value costs from the sum of the present value benefits for a given project. All projects could then be compared with each other for further analysis.

3. Results

The results of this study include the calculated physical attributions, costs, benefits, and net present value of each potential project in zone one and two.

3.1. Zone 1 - Bayshore Bikeway Resiliency Project

Physical Attributions
The Bayshore Bikeway Resiliency Project encompasses a 1.2-mile segment of the Bayshore Bikeway Corridor, extending along the San Diego Bay perimeter (Figure 4). This project will result in the elevation of the Class 1 Bikeway using a living levee and ecotone slope, along with a flood control structure/outlet to manage floodwater and control stormwater discharge into the bay (*Public Access Concepts*, 2022). The project area is divided into three sections. Segment one includes an area that wraps around Pond 10A, segment two stretches from 7th Street to 8th Street, and segment 3 runs along 8th Street to 10th Street (*Public Access Concepts*, 2022).
The City considers this a mid-term project within the larger scope of climate adaptation planning.

Figure 4. Bayshore Bikeway Resiliency Project parameters

Costs
The City has previously estimated the costs of the Bayshore Bikeway Resiliency project. The estimated costs total $21,658,479.00 USD. A breakdown of the costs is outlined in Table 2.

Benefits

The benefits of the Bayshore Bikeway Resiliency project are quantified by the increase in housing value of the homes that the levee will protect from flooding damages. The total housing stock value of census tract 105.02 is $949,876,200.00 - $1,320,720,315.07 USD. Given that the project will protect an estimated 53% of homes from flooding, the total value of the housing stock that the project will protect is $503,434,386.00 - $699,981,766.99. As previously discussed, the value of these homes is predicted to rise by 5% one year after the project's completion and by 10% five years after the project's completion (Kelly & Molina, 2023). Therefore, one year after the project's completion, the value of the homes will increase by an estimated $25,171,719.30 - $34,999,088.35 USD. Five years after the project's completion, the housing value is expected to increase by an estimated $50,343,438.60 - $69,998,176.70 USD. The total increase in housing value serves as the quantification of benefits.

Table 2. Bayshore Bikeway Resiliency Project Costs

Project Aspect	Cost ($USD)
Project management	1,022,924
Phase 1	
1. Procurement	15,000
2. Design	1,235,000
3. EHP: CEQA, NEPA, FEMA consultation	807,500
4. Permitting	427,500
Submit phase 1 deliverables to cal OES/FEMA	15,000
Phase 2	
1. Procurement	15,000
2. Construction Management	1,645,960
3. Demolition	613,733
4. Earthworks	9,226,097
5. Site work	2,527,222
6. Utility installation	4,092,543
7. Grant Closeout	15,000
Totals	**21,658,479**

Net Present Value

The project's net present value is calculated by subtracting the costs from the estimated benefits one year after the project's completion and five years after the project's completion. The resulting net present value is $3,513,222.30 USD - $13,340,591.35 USD one year after the project's completion and $28,684,941.60 USD - $48,339,697.70 USD five years after completion.

3.2. Zone 2 - Beach Nourishment

The City has completed multiple beach nourishment projects in the past, the most recent being the San Diego Regional Beach Sand Project II in 2012. Projects such as these have shaped the analysis in this report. Beach nourishment is a preferred adaptation method as it protects from sea level rise while creating recreational opportunities and allowing upland structures to remain.

Physical Attributions
In this study, the beach is assumed to have started at 50 ft wide and been nourished to a width of 150 feet. This gives the initial nourishment width of 100 ft, a depth of 9.76 yards, and a length of 2,843 yards. A renourishment event was assumed to occur every 10 years. The erosion rates were applied to the years leading to each renourishment event, and the volume of each renourishment event was then calculated by finding the volume that would need to be added to restore the beach width to 150 feet, keeping the depth and length constant throughout the study. The volumes of each nourishment event are listed in Table 3.

Costs
The costs of beach nourishment are representative of the sum of the cost of the initial nourishment event and each subsequent renourishment. The volume of each nourishment event was converted to cubic yards and multiplied by $20 USD per cubic yard. The total cost of beach nourishment from the year 2020 to 2100 was found to be $48,434,234.97 USD. The breakdown of costs is outlined in Table 3.

Table 3. Volumes and Costs of Beach Nourishment Events

Year	Nourishment Volume (cy)	Cost of Sand ($/cy)	Future Value Total Costs ($USD)	Present Value Total Costs ($USD)
2020	924958.67	20	$18,499,173.36	$18,499,173.36
2030	138757.68	20	$2,775,153.52	$2,512,310.28
2040	188710.44	20	$3,774,208.79	$3,093,131.94
2050	238663.20	20	$4,773,264.05	$3,541,394.00
2060	288615.97	20	$5,772,319.32	$3,876,996.40
2070	330243.27	20	$6,604,865.38	$4,016,014.58
2080	380196.03	20	$7,603,920.65	$4,185,575.20
2090	430148.80	20	$8,602,975.91	$4,286,990.70
2100	480101.56	20	$9,602,031.18	$4,331,648.52
		Totals	**$68,007,912.16**	**$48,343,234.97**

Benefits
The benefits of beach nourishment are quantified through the recreational value provided by the additional width of the beach. Multiplying the additional footage of the beach by the aforementioned value of each additional foot of the beach resulted in the recreational value of the beach for a given year. The recreational value was then multiplied by 300,000 and 500,000 annual estimated visits. Discount rates were applied, and the benefits of beach nourishments were found to be $640,299,862.84 - $1,067,166,439.73 USD.

Net Present Value

Subtracting the costs from the estimated benefits results in a net present value of $591,956,627.87 - $1,018,823,204.76 USD. While these are seemingly high net benefits, the processes used to determine the costs and benefits are synonymous with processes previously performed by the City.

3.3. Zone 2 - Dune Restoration

Dune restoration was selected as a potential solution to sea level rise. This process will emulate the coastline before human development and intense erosion due to climate change.

Physical Attributions

Two measurements must be utilized to calculate the cost of dune restoration: the width of the cobble and the width of the dune sand. The cobble is nourished to a width of 50 ft, and the dune sand is nourished to a width of 30 ft. The depth of the projects was not needed as the cost estimates already account for a given depth. The cobble and dune sand erosion rates were then applied to the dune during the years between nourishment events, and every 10 years, the dunes are restored to their original width. Therefore, the difference between the eroded dunes and the renourished dunes provides the measurements of each nourishment event. Measurements are described in Table 4.

Costs

The width of cobble and dune sand added in each nourishment event was multiplied by their respective costs and the length of the beach in which they were nourished. After the cost of each nourishment event was added and discount rates were applied, it was found that the total present value cost of dune restoration from the year 2020-2100 is estimated to be $136,196,703.02. A breakdown of these costs is described in Table 4.

Table 4. Measurements and Costs of Dune Restoration

Year	Added Width of Cobble (ft)	Added Width of Dune Sand (ft)	Cost of Cobble ($USD/ft of width/ft of beach length)	Cost of Dune Sand ($USD/ft of width/ft of beach length)	Present Value Total Cost ($USD)	Future Value Total Cost ($USD)
2020	50	30	60	33	$38,880,000.00	$38,880,000.00
2030	13.5	0	60	33	$7,873,200.00	$7,127,505.25
2040	18.36	0	60	33	$10,707,552.00	$8,775,315.03
2050	23.22	0	60	33	$13,541,904.00	$10,047,048.93
2060	28.08	3.6	60	33	$17,542,656.00	$17,782,579.97
2070	32.13	8.2	60	33	$21,395,016.00	$13,009,000.38
2080	36.99	14.1	60	33	$26,140,968.00	$14,389,285.80
2090	41.85	21.2	60	33	$31,275,720.00	$15,585,155.92
2100	46.71	29.5	60	33	$36,799,272.00	$16,600,811.74
					Total	**$136,196,703.02**

Benefits

The benefits are quantified by the impact the flood risk reduction will have on the value of housing stock in the adjacent neighborhoods. The estimated housing stock value of census tract 105.01 is an estimated $296,088,000.00 USD - $557,369,600.00 USD. The estimated housing stock value of census tract 102.01 is estimated to be $690,609,600.00 USD - $1,291,567,200.00 USD. Provided that the estimated impact of dune restoration on housing values is 3.6%, the values of the housing stocks were summed and multiplied by 3.6% to calculate a total housing stock value increase of both census tracts 105.01 and 102.01. The estimated benefits of dune restoration are estimated to be $35,521,113.60 - $66,561,724.80 USD.

Net Present Value

The net present value of dune restoration is calculated by subtracting the costs of the project from the potential benefits. This results in a negative net present value of -$100,675,589.42 USD - -$69,634,978.22 USD. This negative balance suggests that dune restoration is not considered a cost-effective adaptation measure. However, other additional benefits of dune restoration are present, which may impact the City's decision of whether or not to continue with implementation.

4. Additional Benefits

Quantifying the costs and benefits for these various projects is a significant step in the planning and implementation process. However, there are also additional benefits that cannot currently be adequately quantified in this project's timeframe, given their complexity. This, however, does not diminish their value, as they can provide significant benefits and are a crucial aspect of the argument as to why a NBS project should be implemented. Different benefits might be quantified based on the desires and needs of a specific jurisdiction. While this project's analysis does omit some benefits, it is meant to demonstrate that it is possible to quantify different types of benefits.

4.1. Zone 1

Bayshore Bikeway Resiliency Project

While the Bayshore Bikeway Resiliency Project will notably reduce flood damages to the Bayside Community, it will also provide recreational and environmental benefits. The Bayshore Bikeway is a popular recreational trail for cyclists, providing views of Coronado, Downtown San Diego, and Silver Strand Beach (*San Diego's Bayshore Bikeway*, n.d.). Flooding on the bikeway has inhibited its use in the past, but elevating the path will allow for ease of recreational activities, which is beneficial for the physical and mental health of the community. In addition, by elevating the path and incorporating a living levee, the park adjacent to the Bayside Elementary School will be protected from flooding, providing another access point to recreation for the community (*Public Access Concepts*, 2022).

The benefits to the community members are expansive, as are the benefits to the wildlife that reside in the area. Living levees and transitional habitat lands will lie adjacent to the bike path, enhancing habitat by restoring the tidal marsh. This will increase tidal flushing in Pond 10A, providing a habitat for wildlife. A multitude of species will benefit from this project, including animals such as waterfowl and endangered plants such as the salt marsh bird's beak (*San Diego Bay National Wildlife Refuge*, n.d.).

This project most directly impacts the Bayside community in Northern Imperial Beach, an area that is historically slower to adapt to climate impacts due to a lack of resources. With an average per capita annual income of $27,835 USD and a median household annual income of $60,000, this community is a largely low-income, disadvantaged community, increasing the necessity of this project and emphasizing the importance of the potential benefits that it will provide (*Census profile,* n.d.). Restoring the bikeway and adjacent habitat will provide the community with recreational and educational opportunities while protecting their homes, roads, schools, and other infrastructures from severe flooding.

4.2. Zone 2

Beach Nourishment and Dune Restoration

While the main flood protection and recreational benefits of beach nourishment and dune restoration are included in their respective benefit quantifications, other benefits, such as habitat restoration and erosion control, cannot be quantified, yet should be considered. California beaches, including that of Imperial Beach, are crucial habitats and spawning areas for a number of species, many of which are endangered, such as the Ridgeway Rail and Clapper Rail (*2016 City of Imperial Beach,* 2016). Via the Endangered Species Act, local governments are required to protect these species, making these projects even more beneficial to the beach and dune ecosystems. Supporting the abundance and survival of these species will also increase this region's biodiversity, ultimately providing additional benefits. The Federal Government has acknowledged the importance of protecting biodiversity through the *America the Beautiful* initiative. This is a call to action to conserve and restore 30% of the United State’s lands and waters by 2030 (Claes et al., 2020). The projects included in zone two will provide crucial habitats for many of the resident and migratory plants and animals that contribute to this initiative by expanding beach and sand dune ecology and biodiversity.

Beach and dune ecosystems also have a certain level of existence value. While the dunes and beach will provide tangible, monetary value, a value is added to the projects purely by citizens just knowing that these ecosystems exist. The inclusion of this value in cost-benefit analyses has been heavily debated. The Army Corps of Engineers have displayed reluctance in the use of existence value in analyses because it shifts the value of the benefits to be higher than even recreational values. Other studies argue that the project’s magnitude will be greatly understated if its existence value is not included in analyses (Silberman et. al., 1992). Regardless of the outcome of this debate, the fact that there is an argument about the inclusion of existence value demonstrates that it is a critical aspect to consider when quantifying and communicating the value of climate resilience projects.

An additional benefit to both nourishment events and dune restoration is the restoration quality or the project’s closeness to the natural ecosystem (Nguyen et al., 2023). The level to which a restored area emulates the natural ecosystem will change the success and consequential benefits of the project. If done correctly, beach restoration and dune nourishment will restore the beach ecosystem to a pre-developed state, unlike gray infrastructures, which lead to further erosion. Thus NBS such as these offer additional benefits in the fact that they provide the ability to restore the ecosystem back to its original state.

4.3. Zone 1 and 2

The Bayshore Bikeway Resiliency Project and dune restoration also provide benefits to the City as the increased property value initiated by flood protection benefits will increase the property tax revenue of these homes. Property taxes serve as the financial backbone of local governments as they are a significant revenue source for public education, police and fire departments, parks, and other services (Zhu & Pardo, 2020). The City of Imperial Beach lists property tax revenue as the largest category of their general funds' revenue to be received from 2022 to 2023 (*CITY OF IMPERIAL BEACH 2022‑23, 2023*). This demonstrates the importance of property taxes to the local government and the potential benefits that this may provide. While increased property values can lead to higher property tax revenue for the City, it is also important to acknowledge the affordability challenges it poses for some residents. The City will need to consider certain measures, such as affordable housing initiatives or tax-relief programs, to mitigate the potential impacts of rising property taxes on lower-income residents. These measures will ensure that the projects are able to be implemented in a way that only benefits the local residents rather than driving them out of the neighborhoods due to increased housing costs and property taxes.

An additional benefit for all projects in zone one and zone two is the potential educational opportunities for students to connect with nature. With seven public schools in the City, a large population of school-age children will benefit from these outdoor spaces. Multiple studies have outlined the benefits of outdoor learning and the utilization of outdoor classrooms. These benefits include more unstructured playtime that promotes creativity, higher standardized test scores, higher grade point averages, decreased behavioral problems, and reduced symptoms of ADHD (Benefits of Outdoor Classrooms, n.d.). These benefits are in addition to the more general benefits of spending time outside, such as reduced blood pressure, better sleep, reduced obesity, decreased stress, and more (Benefits of Outdoor Classrooms, n.d.). Potential sea level rise, flooding, and erosion will make the outdoor spaces in zone one and two unavailable for educational purposes. However, if the proposed projects are implemented, the areas will be preserved, allowing students and even general community members to utilize these spaces for educational opportunities and gain the corresponding benefits.

5. Project Comparison

The wide range of benefits, both quantitative and additional benefits mentioned above, are important to consider when choosing how to respond to climatic changes. Quantifying the benefits of each project allows for their comparison. These calculations and many other factors, including local vulnerabilities, project impacts, and already existing protection, are leveraged to make an informed decision. Thus, as the final step of the cost-benefit analysis, a comprehensive comparison of all projects in this cost-benefit analysis is outlined in Table 5.

Table 5. Comparison of all projects' costs and benefits

	Zone 1	Zone 2	
Project	Bayshore Bikeway Resiliency Project	Beach Nourishment	Dune Restoration
Present Value Costs	$21,658,497.00 USD	$48,343,234.97 USD	$136,196,703.02 USD
Present Value Benefits	$25,171,719.30 - $34,999,088.35 USD $50,343,438.60 - $69,998,176.70 USD	$640,299,862.84 - $1,067,166,439.73 USD	$35,521,113.60 - $66,561,724.80 USD
Net Present Value	$3,513,222.30 - $13,340,591.35 USD $28,684,941.60 - $48,339,697.70 USD	$591,956,627.87 - $1,018,823,204.76 USD	-$100,675,589.42 - -$69,634,978.22 USD
Additional Benefits	- Recreation - Benefits disadvantaged community - Habitat restoration - Educational opportunities	- Existence value - High restoration quality - Habitat restoration - Educational opportunities	- Existence value - High restoration quality - Habitat restoration - Potential recreation - Educational opportunities

6. Discussion

The State of California has recently prioritized green NBS in climate adaptation as they have proven to be potential long-term solutions to climatic impacts. In October 2020, Governor Newsom issued Executive Order N-82-20, which outlined an agenda to expand the use of NBS utilization across the state (*Expanding Nature-Based Solutions,* n.d.). This Executive Order acknowledges the often underutilized opportunity to harness natural resources to build resilient coastlines and protect communities from the impacts of sea level rise. For NBS to become a widely utilized form of adaptation, its benefits must be explained clearly to all participating parties.

Following project recommendations and guidelines from the City of Imperial Beach, this study provides a framework of how to quantify the benefits of NBS to sea level rise in a local context. Utilizing physical changes in the beach and the economic impacts of each project, the costs and benefits are able to be weighed, which provides a way of comparing and understanding complex and newly-emerging projects.

Based on the key findings above, the Bayshore Bikeway Resiliency Project and beach nourishment events are considered highly cost-effective solutions. The benefits of these projects heavily outweigh the costs, even without including a consideration of the identified additional benefits. Dune restoration, however, is not considered a cost-effective method, given only the current quantitative benefits. If the broader range of additional benefits is included, the City may still designate this project as a plausible response to sea level rise.

The most cost-effective method of adaptation considered in this study is beach nourishment. However, a single-project approach is not recommended in climate adaptation. A hybrid adaptation approach is usually the most effective and beneficial as there is no “one-size-fits-all” procedure to planning. In reality, zone one and zone two possess differing vulnerabilities, necessitating varying forms of resilience project implementation. Thus, it is recommended that the City emphasize the implementation of multiple projects in a phased approach to adaptation.

The information gathered from this study can be leveraged in the planning stage of adaptation. The cost-benefit analysis framework utilized is a useful process to perform for two reasons. First, it allows decision-makers to value each project and decide which project type to move forward with. From a business perspective, it is crucial to accurately value future projects to ensure that the project in question is feasible, given the available funding and resources. Secondly, by clearly stating each cost and benefit and giving them a monetary value, the information is transparently communicated to the public. Many City officials have shared that one of the barriers to the implementation of climate resilience projects, specifically NBS, is the lack of community and governmental understanding. By quantifying these project’s benefits in a dollar amount rather than adaptation planning jargon, the project’s value is clearly communicated to the average citizen, allowing them to understand the project's value comprehensively. This, in turn, facilitates the process of garnering greater support and funding. Consequently, citizens can also make informed decisions, actively participate in discussions, and make public comments regarding the projects in question. Ultimately, this process fosters a more inclusive and successful planning process.

To promote the use of this framework in other jurisdictions, a comprehensive flowchart was created of the process utilized in this study (Appendix A). Local planners are encouraged and able to follow the same steps used in this study to quantify the value of NBS to aid in widespread implementation efforts.

6.1. Potential Sources of Error

It is important to note that the results of this study are only estimations and hold a certain amount of potential error.

Bayshore Bikeway Resiliency Project

For the Bayshore Bikeway Resiliency project, there are few sources of errors in the cost estimation, given that they were provided directly by the City. The benefits, however, utilize a number from a 2023 study that evaluated the effect of living levees on housing values in Miami-Dade County. While the project structure is similar, this study had to assume that the housing markets in Miami-Dade County and the City of Imperial Beach are comparable in their response to climate adaptation infrastructure. If time permitted, a similar study to the Miami-Dade County study could have been conducted for the City of Imperial Beach or a neighboring jurisdiction. However, this was not possible due to time and resources constraint, and therefore a degree of assumptions had to be made. However, these assumptions are rightfully made, and the numbers provided in this study remain quality estimates of the benefits of the Bayshore Bikeway Resiliency Project.

Beach Nourishment

While this study was meticulously completed, there are some inevitable sources of error within the calculations. First, the beach erosion rates, width, and renourishment cycles were increased at a given rate throughout the study's timeline of 2020 to 2100. These highly unpredictable values will inevitably shift depending on climate change, erosion rates, storm surges, and other factors. However, these values were estimated using official studies from the City and have been approved by officials.

A second potential source of error is the estimated beach attendance for the coastline of Imperial Beach. The variation in this number greatly impacts the amount of benefits that this project will provide. Beach attendance is highly variable due to the difficulty in completing accurate counts of beachgoers and the unpredictable nature of beach visitations. This unpredictable nature has been exacerbated by an increase in water pollution due to sewage spillover from Tijuana. The frequency of beach closures has risen due to this pollution, with the City of Imperial Beach experiencing 249 days of sewage contamination warnings in 2019 (Smith, 2023). Increasing sewage contamination days will undoubtedly reduce the total annual beach attendance. However, the planned construction of hotels and businesses and the promise of a renovated pier will potentially increase beach visitations. Thus, a range of attendance was utilized in this study, allowing for a greater understanding of the possible benefits considering the highly variable beach attendance estimates.

Another apparent source of error is the limitations of the equipment and programs used to complete this study. Previous studies completed by the City have used the California Sediment

Benefits Analysis Tool (CSBAT). This is a benefits transfer model that performs estimates of the gains and losses in the recreational value of a beach as the width increases or decreases. The precision of this model allows for highly specific measurements and results. While this model is potentially the preferred method of analysis, this study was unable to use it given time and resource restrictions. However, the methods employed in this study were meticulously performed and are sound in their reasoning.

Dune Restoration

Three main potential sources of error can be found in these calculations. First, as with the analysis of beach nourishment, the erosion rates for both cobble and dune sand were assumed to increase at a certain rate and then remain constant for a period of time. As explained, these values will inevitably experience some variability provided the unpredictable nature of climate change and storm surges, but there is no way to accurately predict this, so the methods used in this study are acceptable.

Second, the dune sand and cobble cost had to be deduced from limited information. As mentioned earlier, the costs of dune sand and cobble that were provided were given in $USD per linear foot of restoration. To accurately correlate the price of the material to the additional width of nourishment, the dimensions of the dunes were kept constant between this study and the city's, and the price was divided by the width of the respected material nourishment. This process allowed units to be kept constant and made calculations as accurate as possible. There are still some potential sources of error within these calculations; however, these methods are acceptable due to the limited information.

The third and final source of error is within the estimated housing value stock. If time were to permit, instead of taking the aggregate housing stock value of all homes within census tracts 105.01 and 102.01, only the values of homes that would be protected by flooding would be included in this total. This would be done by overlaying a projected sea level rise inundation map onto a parcel data map and then taking a parcel-by-parcel approach to find the total housing stock value. The allotted time frame for this project did not permit this process to be completed, so the total housing value stock was used.

While these findings were calculated as precisely as possible given this project's time and resource constraints, it is important to understand the limitations of this study and the assumptions made. These limitations and assumptions offer the opportunity for further in-depth analysis.

7. Conclusion

Climate adaptation planning is a complex and emerging process filled with many barriers, causing some projects to take decades to implement. Given the speed at which global temperatures are rising, and the climate is changing, time is a luxury that many cities do not possess in regard to adapting. A framework, such as the one demonstrated in this paper, provides city and adaptation planners with the necessary tools and resources to properly explicate a project's benefits and demonstrate the information to others.

Future studies may expand upon this research by utilizing a similar framework for other NBS in different jurisdictions. This is an in-depth case study into the City of Imperial Beach, so while there will be differences between jurisdictions, the structure and methodology of cost-benefit analysis remain transferable. The City may also utilize this information to further the planning process of climate adaptation projects as they and many other cities work to build resilient communities in the face of climate change.

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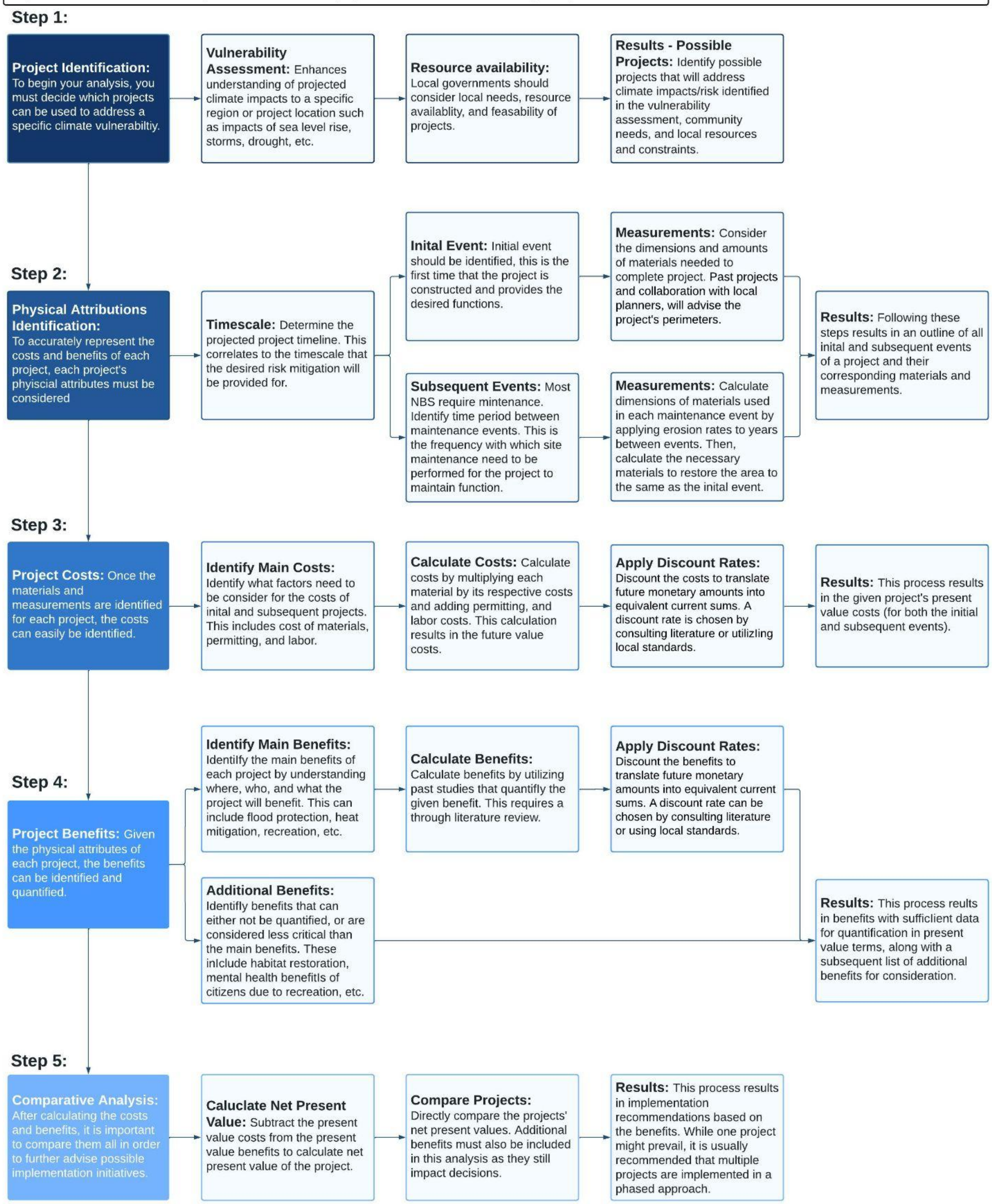
Appendix A: Capstone Deliverable

This report is a case study on the City of Imperial Beach. However, this same framework can be utilized in different jurisdictions to aid in the implementation of different NBS to differing climate vulnerabilities. To allow for ease of completion, the following flow charts were created to allow other jurisdictions to easily follow the process followed in this report. The first flow chart outlines the general process, while the second serves as an example of how to complete the quantitative analysis.

Capstone Deliverable: Cost-Benefit Anlysis of Nature-Based Solutions

When faced with the impacts of climate change, cities must adapt and build resilient communities. As cities are looking for long-term, cost-effective solutions to climate change impacts, nature-based solutions (NBS) are emerging as a viable approach. In planning for and building resilient communities, garnering both financial and general community support is vital to the success of these projects. Due to the relative novelty of the climate adaptation field as a whole and NBS specifically, comprehensive and detailed information on the performance and co-benefits of NBS remains limited and can be a barrier to implementation. Thus, quantifying and communicating the benefits of NBS is crucial to fostering widespread support and garnering the resources necessary for more widespread implementation. The benefits are quantified by completing a cost-benefit analysis of NBS. This flowchart serves as a summary of the cost-benefit analysis of NBS to sea level rise in the City of Imperial Beach, California. While this process was utilized for a specific case study, this same process can be followed to quantify the benefits of NBS for other climatic changes in various jurisdictions. To use this flowchart, first identify which climatic change is being addressed and then follow each step. The results include the net present value of each project, which can then be directly compared and communicated.



Using the methods oulined above, NBS to sea level rise (SLR) in the City of Imperial Beach (further refered to as the City) were analyzed. The full analysis looked at living levees, beach nourishment, and dune restoration projects. The following flow chart outlines the process for quantifying the benefits of beach nourihsment to serve as an example for how the process described in the above chart can be used in varying NBS analyses in different jurisdictions.