Comparing Sea Level Rise Adaptation Strategies in San Diego: An Application of the NOAA Economic Framework

GREATER SAN DIEGO RESILIENT COASTLINES PROJECT

Climate Collaborative SAN DIEGO REGION

NEXUS PLANNING & RESEARCH

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Comparing Sea Level Rise Adaptation Strategies in San Diego: An Application of the NOAA Economic Framework

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Executive Summary

Introduction

Coastal communities in San Diego County face ever-increasing risks from sea level rise, coastal storm events, flooding, and beach erosion. The potential hazards to this vital, vibrant 70-mile stretch of California coastline compel city planners and decision-makers to develop coastal resilience initiatives by conducting vulnerability assessments and considering potential adaptation strategies.

Nexus Planning & Research was tasked with providing a comparative benefit-cost analysis of coastal resilience strategies for participating cities in San Diego County, following the framework outlined in the National Oceanic and Atmospheric Administration's (NOAA) funded study, *What Will Adaptation Cost? An Economic Framework for Coastal Community Infrastructure* (NOAA, 2013). Specifically, we were directed to comparatively assess the trade-offs (spending vs. benefits) of various coastal resilience strategies, as identified by participating jurisdictions. Ultimately, the City of Carlsbad and the City of Del Mar were the two jurisdictions that participated in this study.

We evaluated the potential damage or loss to "at-risk" properties from sea level rise, and the cost of protecting, adapting, or abandoning those properties. The intent of this study is to compare the cost and benefits of sea level rise action scenarios, using benefit-cost ratios.

This report is part of a larger, multifaceted project led by the San Diego Regional Climate Collaborative, a partnership of local and regional agencies and groups. The project, "Connecting the Dots and Building Coastal Resilience in the San Diego Region," was funded through the NOAA Coastal Resilience Grants Program, a federally funded opportunity for coastal communities to prepare for changing sea levels and extreme storm events.

Our study expressly followed the NOAA framework with the intent of: 1) Testing the methodology, 2) Utilizing the participating jurisdictions as case studies, and 3) Providing lessons learned. While the NOAA framework focuses on coastal flooding, we also evaluated bluff erosion and chronic inundation where applicable. (We did not evaluate river flooding.) In addition, the analysis incorporated a high-level overview of potential fiscal impacts to the participating cities.

The purpose of the NOAA framework is to provide benefit-cost ratios for comparing multiple sea level rise adaptation strategies or scenarios. Following that approach, the intent of this study was to compare action scenarios for a specified geographic area consisting of one or more sea level rise adaptation strategies.

The strategies within the action scenarios fall into three categories: natural or engineered protection (beach nourishment or armoring with structures), accommodation (raising structures), and managed retreat (removing structures). We collected existing units and construction costs for selected adaptation strategies, developed cost estimates for the action scenarios, and applied them temporally as indicated by the respective jurisdictional schedules. The project life for the economic analysis depends on the adaptation strategy employed within the action scenario.

Results of the Cost-Benefit Study

A primary output of this study is the comparative assessment of the trade-offs (spending vs. benefits) of the action scenarios as identified by participating jurisdictions. To evaluate the trade-offs, we first developed cost inputs to the model, including:

1. Monetized baseline risk primary and secondary impacts, which represent the maximum damages prevented, or the "no action" scenario
2. Monetized impacts resulting from action scenarios
3. Implementation costs of adaptation strategies
4. Benefits of each action scenario (damages prevented)
5. Capital and maintenance costs of action scenarios

After inputting the costs into the model, we calculated the net benefits and benefit-cost ratios for the action scenarios. The benefit-cost ratio is the net present value (NPV) of total benefits divided by NPV of total costs. The benefit-cost ratio is used for comparing action scenarios and determining whether the benefits outweigh the cost.

The following section details the outcome of the benefit-cost comparison. For more information about each action scenario, see the “Assess What You Can Do Differently: Adaptation Scenarios and Strategies” chapter in this report.

As shown in Table 1 and Table 2, the net benefits are the NPV of total benefits, minus the NPV of total costs. For Carlsbad and Del Mar, all of the benefit-cost ratios are higher than 1, meaning the benefits are greater than the costs.

Table 1: Net Benefits and Benefit-Cost Ratios
Selected Study Area Planning Zone 1, Carlsbad, CA

	NPV of Total Benefits ($million)	**NPV of Total Costs ($million)**	**NPV Benefits ($million)**	**Benefit-to-Cost Ratio**
Scenario 1	$817.7	$11.2	$806.5	72.88
Scenario 2	$722.6	$25.7	$696.9	28.12
Scenario 3	$817.7	$14.4	$803.3	56.97

Table 2: Net Benefits and Benefit-Cost Ratios
North Beach Del Mar, CA

	NPV of Total Benefits ($million)	**NPV of Total Costs ($million)**	**NPV Benefits ($million)**	**Benefit-to-Cost Ratio**
Scenario 1a	$2,843.2	$335.4	$2,507.8	8.48
Scenario 1b	$2,601.2	$363.0	$2,238.2	7.17
Scenario 2	$2,805.2	$567.3	$2,237.9	4.94

For Carlsbad, Scenario 1 has the greatest return on investment. For every $1.00 spent, there is a return of $72.88. Scenario 2 has a return of $28.12 for every dollar spent, and Scenario 3's return in $56.97. These ratios assume that the three action scenarios are equally effective at preventing damages. This assumption is varied in the sensitivity analysis.

For Del Mar, Scenario 1a has the greatest return on investment. For every $1.00 spent, there is a return of $8.48. Scenario 1b has a return of $7.17 for every dollar spent, and Scenario 2's return in $4.94. Again, these ratios assume that the three action scenarios are equally effective at preventing damages. The robustness of these results is tested in the sensitivity analysis.

While we did not incorporate qualitative considerations into our analyses, city planners and decision-makers would want to consider the implications of non-monetized benefits or costs. Additionally, per the NOAA framework, each city should consider funding feasibility when deciding among action scenarios.

Sensitivity Analysis

We conducted sensitivity analysis to test the robustness of our results. That is, even if we modified some of our assumptions, would Scenario 1 and Scenario 1a still have the most return on the investment? We tested assumptions related to the following: equal effectiveness of action scenarios, discount rate, loss of property tax revenue in Del Mar Scenario 2, and loss of beach tourism and city tax revenue. We found that our results were robust to all of the assumptions, except those related to effectiveness and the discount rate.

Effectiveness (Protection Factor)

We found that for both cities, the initial results were not robust to assumptions about effectiveness. The protection factor was varied using 25 percent, 50 percent, and 75 percent effectiveness levels and compared to the results at a 100 percent effectiveness level. We assumed that each action scenario prevented damages equally by setting a protection factor of 100 percent, i.e., it prevents against all baseline risk damages. However, as Figure 1 and Figure 2 show, if Carlsbad Scenario 1 and Del Mar Scenario 1a are not as effective as the other action scenarios, then they might not be the most cost-effective choice.

Figure 1 shows that while Carlsbad Scenario 1 (beach nourishment and groins) initially appears to be the best choice, that ranking depends upon its effectiveness. For example, if Scenario 1 is less effective, e.g. 75 percent effective at preventing baseline damages, and Scenario 3 (beach nourishment, raise/improve seawalls and revetments) is 100 percent effective, then Scenario 3 has the higher benefit-cost ratio (56.97 versus 54.66).

In Del Mar, we find a similar circumstance (Figure 2). Scenario 1a (beach nourishment and groins) has the highest benefit-cost ratio when all scenarios are assumed to have the same effectiveness. However, if Scenario 1a is less effective, e.g. 75 percent effective at preventing damages and Scenario 1b is 100 percent effective, then Scenario 1b is more cost-effective (7.17 versus 6.36).

Figure 1: Varied Effectiveness Assumption
Selected Study Area Planning Zone 1, Carlsbad, CA

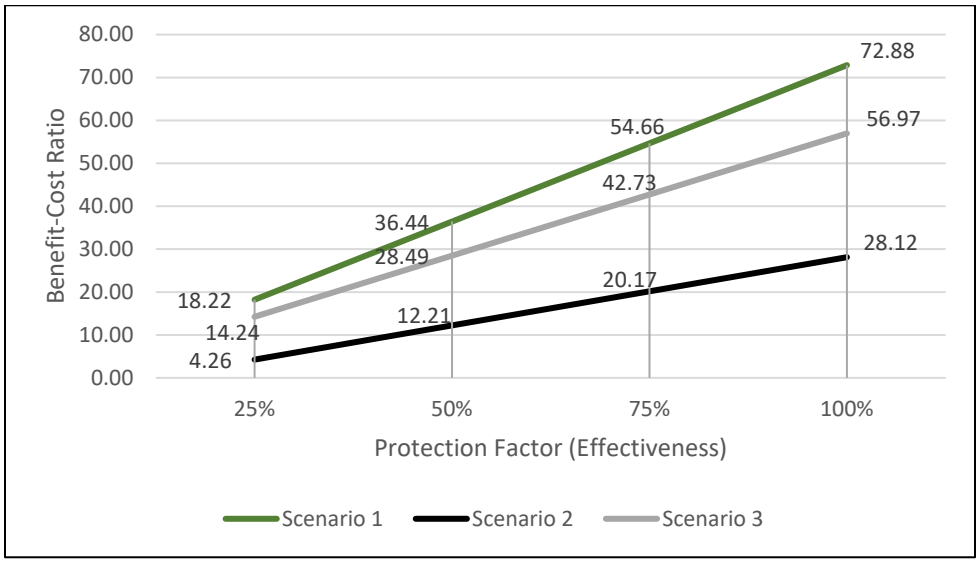
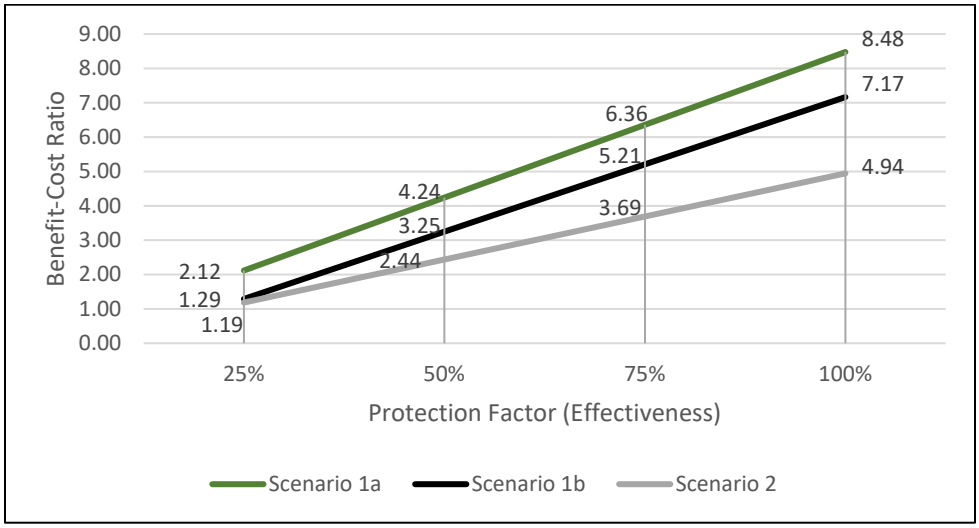


Figure 2: Varied Effectiveness Assumption
North Beach Del Mar, CA



Discount Rate

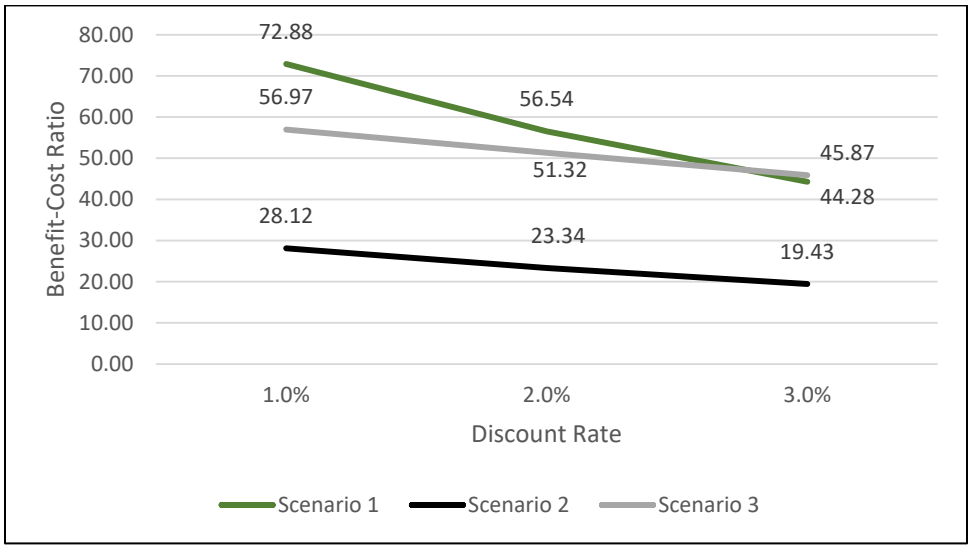
Because action scenarios could incur costs on different timeframes, various discount rates could also alter study results. When cities undertake similar analyses with adaption strategy implementation of distinct timelines that extend in the far future, they should carefully consider which discount rate to apply, or conduct similar sensitivity analysis before making a decision.

We assumed a one percent discount rate, (as found in other similar studies,) however, because the timeline of the adaptation strategies and negative benefits differed by action scenarios, it was pertinent

to test our discount rate assumption. Discount rates of two percent and three percent were compared to the results at a one percent discount rate.

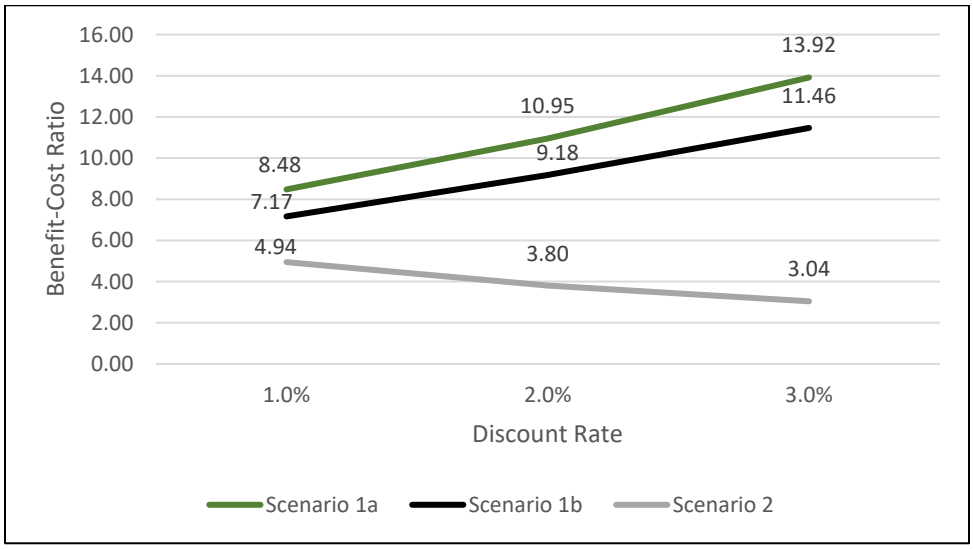
In Carlsbad, we found that our initial results were not robust to the discount rate assumption (Figure 3). While the Scenario 1 benefit-cost ratio (72.88) is the highest when assuming a one percent discount rate, Scenario 3's ratio (45.87) is higher than Scenario 1's ratio (44.28) when the discount rate is three percent. This ranking change is due to Scenario 1 having the higher implementation costs early on, while Scenario 3's costs are spread out across decades.

Figure 3: Varied Discount Rates
Selected Study Area Planning Zone 1, Carlsbad, CA



Del Mar's initial results, on the other hand, are robust. As shown in Figure 4, the sensitivity analysis of the discount rate does not change the ratio rankings. Scenario 1a has the highest benefit-cost ratio across all three discount rates.

Figure 4: Varied Discount Rates
North Beach Del Mar, CA



Ultimately, cities will need to consider benefit-cost ratios for each of their action scenarios, as well as their own city's culture and character. In Carlsbad, Scenario 1 and Scenario 3 both show strong returns on investment, but planners might be inclined to choose Scenario 3 if they are concerned that the groin construction in Scenario 1 could negatively impact local surfing. Del Mar could select to engineer groins, as in their Scenario 1a, over Scenario 1b's raising or improving their seawalls, even though the results were not robust to effectiveness assumptions. For both cities, coastal resiliency choices should not only weigh short-term and long-term cost, but also reflect the communities' values and identity.

Lessons Learned

The intent of these "Lessons Learned" is to provide future practitioners with additional information and guidance that may help focus and refine their implementation of NOAA's framework for greater efficiency and effectiveness.

NOAA's framework offers different approaches to the benefit-cost analyses based on factors such as the goals of a study, technical knowledge and expertise, and data availability. While this study followed one general approach provided in NOAA's framework, we did take additional steps to modify the methodology or verify data accuracy when specific information was not available or directly applicable. The "Lessons Learned" attempts to capture our professional experience with implementation of NOAA's framework, and the information revealed during application of the additional steps.

1. The NOAA Framework.

We found the broad, flexible approach of the NOAA Framework adaptable to meet each of our city's needs, however, the trade-off was a lack of specificity. As such, it provides little direction regarding assumptions that are specific to a city's unique characteristics or needs. For example, post-flood clean-up costs may be additional costs to the city or incorporated into the existing budget.

Practitioners attempting to apply the NOAA framework will need to make decisions about the most appropriate dollar values to apply, or the size and location of specific adaptation strategies (see #2 below).

Additionally, the NOAA framework is presented as a linear process, but in practice, performing the tasks is a nonlinear endeavor. Utilizing multiple team members, different tasks can be performed simultaneously as some tasks do not need to occur in the same order as presented in the framework. However, we recommend practitioners have the technical knowledge and expertise to adjust and revise the approach.

2. Project and site-specific information is necessary to provide more detailed cost estimates.

Adaptation strategies are dependent on geographic and oceanic conditions specific to an area. As a result, options for adaptation strategies can vary widely depending on existing conditions and the goals of the adaptation strategy. Additionally, labor, materials and seasonal considerations will inevitably vary, nationally. We found historic city expenditures and quoted estimates from local resources and vendors to be better cost indicators than those obtained via out-of-region projects, other studies or generic software packages.

3. The value of GIS and parcel level information versus geographically aggregated approach.

The NOAA framework provides different methods for evaluating impacts, ranging from broad, geographically aggregated approaches such as FEMA's Hazus MH Flooding or the COAST (Coastal Adaptation to Sea Level rise Tool) model. However, we found the use of more site-specific information obtained via parcel level information (obtained using GIS or through primary data collection) provided more precise information regarding costs and potential impacts. We believe the additional time and cost to use this approach is worthwhile.

4. The value of "ground-truthing" and on-the-ground site inspection.

The vulnerability assessments rely upon CoSMoS flooding and inundation GIS layers overlain on city parcel maps and satellite imagery. Ground-truthing, the process whereby GIS layers and images are compared to what is on the ground in reality, is necessary to verify the contents of the image and, in this case, the output of the vulnerability assessments.

On-the-ground inspections resolved real and perceived conflicts in the data. In addition, site inspections revealed differences not captured by the GIS analyses alone. While the NOAA Framework can be performed as a desktop effort, we recommend practitioners be, or become, familiar with actual conditions on the ground.

5. The value of collaboration with appropriate agencies.

Adaptation planning and analyses, including benefit-cost analysis, is best performed as a collaborative, iterative process. Through open dialogue with local, state, and federal agencies, practitioners can collect and analyze the most relevant information. Periodic feedback from participating agencies contributes to an output with better defined parameters. We also found the

collaboration necessary and vital to the project schedule, and setting (or resetting) project expectations.

Study Limitations

City planners and decision-makers should only use the benefit-cost ratios in this study to *comparatively rank* which scenario has the greatest return on investment. Total net benefits, which can be used comparatively as well, should not be used as individual estimates of return on investment. Our analysis represents a high-level approximation for the study areas, with generic structure and infrastructure replacement or repair costs that may not reflect actual costs and specifications in the event of a real loss.

The action scenario cost estimates are intended to provide an approximation of total project costs and do not represent conceptual level of design costs or preliminary design costs. The actual project descriptions for adaptation strategies (and construction costs) may differ substantially from what is provided herein. It is recommended that financial feasibility not be assessed until any preliminary design is accomplished, based on a more thorough consideration of coastal processes, regulatory and environmental opportunities and constraints, and engineering.

The fiscal impact analysis (FIA) contains an analysis of recurring revenues and costs to the jurisdiction from potential loss of property and services. The FIA is based on estimates, assumptions, and other information developed from our research, interviews, telephone discussions with the jurisdictions and County of San Diego staff, and information from our database collected through fiscal impact analyses previously prepared by us and others. It is not considered to be a “financial forecast” nor a “financial projection” as technically defined by the American Institute of Certified Public Accountants. The word “projection” used within this report relates to broad expectations of future events or market conditions.

The analysis also does not consider sea level rise impacts on public health, socio-economic issues, ecosystems and nature habitats, threatened or endangered species, or environmental damage, e.g., oils spills and discharge of pollution.

The sources of information and basis of the estimates are stated herein. While we believe the sources of information are reliable, we do not express an opinion or any other form of assurance on the accuracy of such information. The analyses are based on estimates and assumptions that are inherently subject to uncertainty and variation depending on evolving events. Some assumptions inevitably will not materialize, unanticipated events and circumstances may occur, and actual results may vary from the projections. Therefore, we cannot represent that the results presented here will definitely be achieved.

Introduction

Coastal communities in San Diego County face ever-increasing risks from sea level rise, coastal storm events, flooding, and beach erosion. The potential hazards to this vital, vibrant 70-mile stretch of California coastline compel city planners and decision-makers to develop coastal resilience initiatives by conducting vulnerability assessments and considering potential adaptation strategies.

This report examines the benefit-cost of various coastal resilience strategies as part of a larger, multifaceted project led by the San Diego Regional Climate Collaborative, a partnership of local and regional agencies and groups. The project, "Connecting the Dots and Building Coastal Resilience in the San Diego Region," was funded through the National Oceanic and Atmospheric Administration's (NOAA) Coastal Resilience Grants Program, a federally funded opportunity for coastal communities to prepare for changing sea levels and extreme storm events.

Nexus Planning & Research was tasked with providing a comparative cost-benefit analysis of coastal resilience strategies for participating cities in San Diego County, following the framework outlined in the NOAA-funded study, *What Will Adaptation Cost? An Economic Framework for Coastal Community Infrastructure* (NOAA, 2013). Specifically, we were directed to comparatively assess the trade-offs (spending vs. benefits) of various coastal resilience strategies as identified by participating jurisdictions. We evaluated the potential damage or loss to "at-risk" properties from sea level rise, and the cost of protecting, adapting, or abandoning those properties. The intent of this study is to compare the cost and benefits of sea level rise action scenarios, using benefit-cost ratios.

In addition, the analysis incorporates a high-level overview of potential fiscal impacts to the participating cities. Ultimately, the City of Carlsbad and the City of Del Mar were the two jurisdictions that participated in this study.

Our study expressly follows the NOAA framework with the intent of: 1) Testing the methodology, 2) Utilizing the participating jurisdictions as case studies, and 3) Providing lessons learned. While the NOAA framework focuses on coastal flooding, we also evaluated bluff erosion and chronic inundation, where applicable. We did not evaluate river flooding.

Vulnerability Assessments

The City of Carlsbad and the City of Del Mar both provided sea level rise and coastal flooding vulnerability assessments. However, each city applied different methodological approaches. Del Mar evaluated impacts based on a projection of more frequent coastal flooding events in the future, applying damages from historical storms. Carlsbad focused on increased water depths and expected damages due to those increases. This study describes our process for incorporating both types of vulnerability assessments into the NOAA framework.

Action Scenarios

Del Mar provided a plan outlining action scenarios to prevent future sea level rise damages. Each action scenario identified one or more combined sea level adaptation strategies. The purpose of the NOAA

framework is to provide benefit-cost ratios for comparing multiple sea level rise adaptation strategies or scenarios. Del Mar provided multiple action scenarios for only one area located between the Solana Beach border to the north and 29th Street to the south, known as North Beach. Therefore, we were only able to assess the North Beach area. As only a single bluff erosion action scenario was provided in the Del Mar Adaptation Plan, it was not included in our analysis. As previously mentioned, we were not tasked with evaluating the river flooding action scenarios.

At the time of this study, Carlsbad had not completed an adaptation plan, and therefore was unable to provide action scenarios or adaptation strategies unique to its jurisdiction. Through discussion with Carlsbad city planners, we were directed to adapt and apply Del Mar's North Beach action scenarios to the northern portion of Carlsbad's beach area: Planning Zone 1. While Buena Vista Lagoon is within Planning Zone 1, the city asked us to exclude the lagoon from our analyses. Therefore, the Carlsbad analysis focuses on only the coastal area of Planning Zone 1, referred to as the "Selected Study Area, Planning Zone 1."

The Del Mar and Carlsbad action scenarios contain different variations of the following adaptation strategies:

1. Beach Sand Nourishment
2. Groins
3. Seawalls
4. Revetments
5. Elevate Structures (Del Mar only)
6. Remove Structures – Acquisition/Demolition (Del Mar only)

Background

Participating Jurisdictions

Carlsbad

Carlsbad, California is an incorporated coastal city in northern San Diego County located approximately 87 miles south of Los Angeles, and 35 miles north of downtown San Diego. It is bordered on the north by the City of Oceanside, to the east by the cities of Vista and San Marcos and unincorporated areas of San Diego County, to the south by the City of Encinitas, and to the west by the Pacific Ocean.

Nicknamed, "The Village by the Sea," Carlsbad is a resort community that features seven miles of beach and coastal bluffs, inland hills, and a semi-arid Mediterranean climate. Carlsbad's total area of 39.1 square miles is comprised of 37.7 square miles of land, and 1.4 square miles of water due to its three lagoons and one lake, and has an elevation of 52 feet above sea level. The majority of residences in Carlsbad consist of single-family homes and newer, high-end planned communities. According to realtor.com, the median closing price for all home types in Carlsbad, as of March 2017, was $745,000.

According to the California State Department of Finance (DOF), Carlsbad's population is estimated to be 112,930 as of January 1, 2016, with a density of 2,995 people per square mile. According to the 2015 1-year American Community Survey, 73.1 percent of Carlsbad households are families, 46.4 percent of which have children under 18. The racial composition is mostly non-Hispanic White (76 percent), followed by 11 percent Hispanic or Latino, 9 percent Asian, approximately 3 percent Pacific Islander or other races, respectively, and less than 1 percent African American. More than half of Carlsbad residents are young Baby Boomers and Generation X: Almost 53 percent are 25 to 64 years old. Forty percent of all residents have a bachelor's degree or higher and the median household income is $96,300, with almost 30 percent of households earning $150,000 or more.

In addition to its coastline, Carlsbad has an abundance of natural recreation resources include the southern shore of Buena Vista Lagoon, the Agua Hedionda lagoon, Batiquitos Lagoon, 13 community parks, and over 50 miles of hiking trails across more than 6,000 acres of permanent nature preserves and areas. Other leisure attractions include LEGOLAND California theme and water parks, three golf courses, and the downtown "Village" district of shops and restaurants, making tourism a major contributor to Carlsbad's economy.

City of Carlsbad Sea Level Rise Vulnerability Assessment

Understanding Carlsbad's vulnerability to sea level rise provides city planners and decision-makers with the knowledge needed to lessen the city's exposure to coastal hazards. Planning for future coastal events is complex and highly predictive; therefore, the *City of Carlsbad Sea Level Rise Vulnerability Assessment* draft (City of Carlsbad, 2016) (Carlsbad Assessment) uses high and low sea level rise estimates to account for a range of scenarios.

The United States Geologic Survey's (USGS) Coastal Storm Modeling System (CoSMoS) was used to define and visualize three types of hazard zones for 2050 and 2100 planning horizons. According to the

Carlsbad Assessment, “The CoSMoS 0.5m and 2.0m sea level rise scenarios roughly align with the projected high sea level rise from the 2012 National Research Council’s report for the same planning horizons.” Therefore, the 2050 and 2100 sea level rise scenario results were used as the basis for the Carlsbad Assessment.

We considered three types of hazard zones:

1. **Inundation**: An area that will be subject to recurrent "wetting and drying" as higher daily tides advance inland.
2. **Coastal Flood**: In addition to rising tidal hazards, some areas will experience event flooding due to extreme wave action caused by coastal storms. A 100-year storm event (a storm with a statistical 1% chance of occurring in any given year) was used to define this zone. The use of 100-year storm events has historical precedence in sea level rise literature when considering physical impacts from sea level rise from extreme events and storms (California Coastal Commission, 2015; NOAA, 2010).
3. **Bluff:** Carlsbad's shoreline includes coastal bluffs where rising sea levels will cause contact with daily tides or exposure to increased wave action, resulting in erosion.

The Carlsbad Assessment divided the Carlsbad shoreline into three Planning Zones (Zones) to create manageable areas of examination. The length of shoreline within the Zones ranged from 1.4 to 2.4 miles, with each zone containing one of the three lagoons within Carlsbad city limits: the southern portion of Buena Vista Lagoon, Agua Hedionda Lagoon, or Batiquitos Lagoon. The Carlsbad Assessment provides an inventory of potentially affected assets including beaches, public works infrastructure, transportation infrastructure, state parks, environmentally sensitive lands, public access ways, and residential parcels. These assets were rated low, moderate, or high for their hazard exposure, impact sensitivity, and adaptive capacity.

City of Carlsbad Sea Level Rise Adaptation Strategies and Study Area

At the time of this study, Carlsbad had not selected action scenarios or adaptation strategies. Through discussion with Carlsbad planners, we were directed to adapt and apply Del Mar’s North Beach action scenarios. Our study includes the following adaptation strategies, which fall within one or more action scenarios. More information about the specifics of each strategy can be found in the "Assessing What You Can Do Differently" chapter.

- Beach nourishment for near-term protection
- Sand retention measures such as groins
- Raising/improving the existing sea wall and revetments

Our analysis includes the coastal portion of Carlsbad’s beach area: Planning Zone 1. While Buena Vista Lagoon is within Planning Zone 1, it was not included per the city’s direction. Therefore, the Carlsbad analysis focuses on only the coastal area of Planning Zone 1, referred to as the “Selected Study Area, Planning Zone 1.” The study area is shown in Figure 5.

Figure 5: City of Carlsbad Planning Zones and Selected Study Area

moffatt & nichol

Adapted from *City of Carlsbad Sea Level Rise Vulnerability Assessment* draft, by City of Carlsbad, June 2016.

Del Mar

The City of Del Mar is a small beach city located on the Pacific coast in northern San Diego County. Long and narrow with an elevation of 112 feet above sea level, Del Mar's 18.1 square miles include approximately 2.5 miles of coast and an inland width of less than one mile at its widest point.

Del Mar has a small downtown village and three beaches. North Beach (commonly known as Dog Beach) is adjacent to the Scripps Bluff Preserve at the San Dieguito River outlet. North Del Mar Beach features two oceanfront public parks, whereas south Del Mar Beach is characterized by steep, high coastal bluffs and undeveloped stretches.

Del Mar has a Mediterranean-subtropical climate with warm, dry summers and mild winters. Del Mar is also the home of the Del Mar Fairgrounds, host of the Del Mar Races, the San Diego County Fair, and other large regional events.

According to California DOF, Del Mar's population is estimated to be 4,274 (236 people/square mile) as of January 1, 2016. According to the 2011-2015 American Community Survey its population is 84 percent non-Hispanic white, 13 percent Hispanic or Latino, 2 percent Asian, and less than 1 percent of all other surveyed races, each. Of Del Mar's 2,125 households, 15 percent have children under 18-years-old living in them. Over 60 percent of Del Mar residents are 25 to 64 years old, making late Baby Boomers and Generation X the two largest demographic groups. Sixty-four percent of all residents have a bachelor's degree of higher and the median household income in Del Mar is $107,000, more than double the national median income for the same year.

The majority of Del Mar residences are single-family homes, many of which are beachfront properties. Due to its small size, Del Mar is essentially "built-out" with little room for further development. According to realtor.com, the median closing price for a home in Del Mar was over $1.6 million, as of March 2017.

Because of its shape, location and size, the City of Del Mar is especially impacted by coastal and river flooding, and beach and bluff erosion. The northern portion of the city, which includes the Del Mar Fairgrounds, lies within the San Dieguito River floodplain. Sea level rise will likely increase the severity and frequency of such risks.

City of Del Mar Coastal Hazards, Vulnerability, and Risk Assessment

Del Mar's *Coastal Hazards, Vulnerability, and Risk Assessment* draft (City of Del Mar, 2016a) (Del Mar Assessment) provides a detailed analysis of the city's vulnerabilities and risk from three coastal hazards: coastal flooding, coastal erosion (referred to as chronic inundation in our study), bluff erosion, and river flooding. The Del Mar Assessment examined various asset categories, such as parcels, city structures, and roads.

Coastal flooding and erosion vulnerabilities were examined using historical storm event and damage data, and estimated the increased likelihood of greater and more frequent damage, in accordance with upper-end sea level rise scenarios for 2030, 2050, 2070, and 2100, and preliminary data from the US Geological Survey's Coastal Storm Modeling System (CoSMoS) v3.0 predictions for a 100-year (1% chance of occurring) extreme coastal flood. Beach elevations and widths, and still water levels were also examined. To forecast future erosion to Del Mar's coastal bluffs, historic bluff retreat measurements

were examined, and CoSMoS v3.0 was used to project cliff top retreat rates in 2100, for mid and high sea level rise scenarios.

Coastal hazards were mapped and classified:

- **Significant Coastal Flooding**: Considered a current 10-year storm event, extent and vulnerabilities are based on the historical 2016 storm.
- **Extreme Coastal Flooding:** Considered a current 100-year storm event, extend and vulnerabilities are based on the historical 1983 storm.

City of Del Mar Sea-Level Rise Adaptation Plan and Study Area

The *City of Del Mar Sea-Level Rise Adaptation Plan* draft (City of Del Mar, 2016b) (Del Mar Adaptation Plan) serves as the city's long-range planning guide to address future sea level rise and its effects on storm surge and coastal flooding and erosion. The Del Mar Adaptation Plan draws on the Del Mar Assessment guidance provided by the City's Sea-Level Rise Stakeholder Technical Advisory Committee (STAC), and the California Coastal Commission's *Sea Level Rise Policy Guidance* (California Coastal Commission 2015) for addressing sea level rise in cities' Local Coastal Plan.

The Del Mar Adaptation Plan provides a framework for Del Mar to manage risks and take actions based on specific triggers and monitoring of sea level rise and its effects.[1] It provides action scenarios intended to manage risks, rather than proscribing a specific plan of action. The Del Mar Adaptation Plan assumes project-level planning and approvals will be required to further develop and implement the adaptation measures.

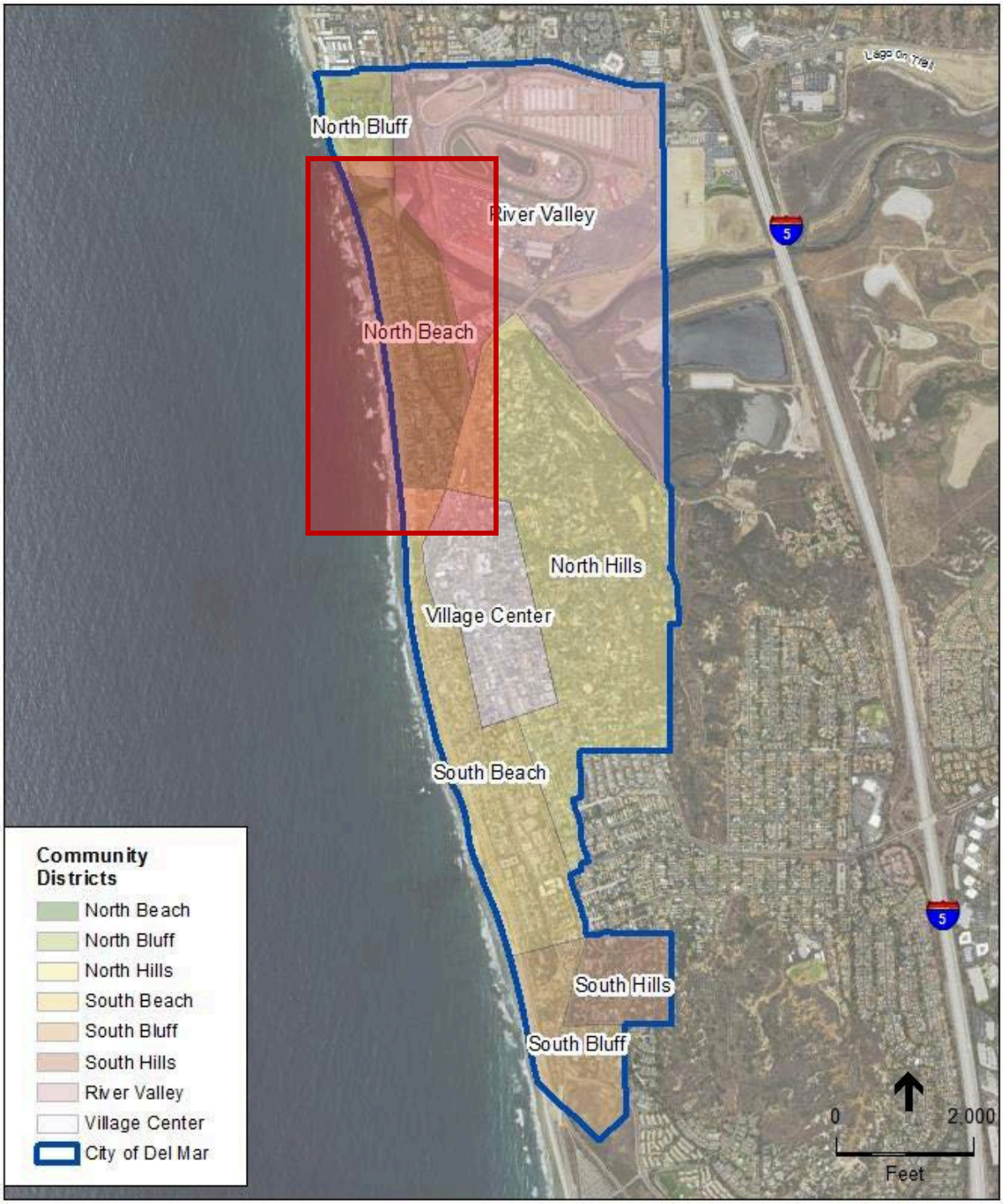
Our study includes the following adaptation strategies, which fall within one or more action scenarios. More information about the specifics of each strategy can be found in the "Assessing What You Can Do Differently" chapter.

- Beach nourishment for near-term protection
- Sand retention measures such as groins
- Raising/improving the existing sea wall and revetments
- Raising infrastructure and structures
- Removing structures

As previously stated, the intent of our study is to compare cost-benefit ratios for multiple action scenarios. Del Mar provided multiple action scenarios for only one area: North Beach. Therefore, this study only assesses the North Beach action scenarios. We were not tasked with evaluating river flooding action scenarios. The study area is shown in Figure 6.

[1] At the time this study was initiated, the STAC had not yet given their formal recommendations on the above North Beach flooding and erosion adaptation measures and scenarios. This study does not attempt to account for future revisions to measures and scenarios.

Figure 6: City of Del Mar Community Planning Districts, North Beach Study Area



Adapted from *City of Del Mar Sea-Level Rise Adaptation Plan* draft, by ESA, September 2016.

NOAA Framework

This study's primary purpose is to apply the NOAA methodology described in their report, *What Will Adaptation Cost? An Economic Framework for Coastal Community Infrastructure* (NOAA, 2013). The report, included in the appendix, provides a framework for comparing the cost and benefits of adaptation strategies that would lessen the coastal flooding impacts of current and future seal level rise. In applying their framework, our objective is to present and demonstrate a methodology that other cities can follow when doing similar studies. This chapter describes the broad components of the NOAA framework.

Figure 7 shows the framework's components and tasks. We found this broad approach flexible and adaptable enough to apply to various cities; however, the trade-off was a lack of specificity. As such, they provide little direction regarding assumptions specific to our cities' needs. Anyone attempting to apply the NOAA framework will need to make decisions about the most appropriate dollar values to apply, or the size and location of particular adaptation strategies, because these assumptions will be unique to each city. Our report provides the assumptions we made for Carlsbad and Del Mar, and consequently, attempts to provide paradigm guidance for other cities. These details are found in the ensuing chapters.

Key Framework Components

The NOAA framework has four key components, shown in Figure 7. Each section is broken down into tasks and more detailed steps. By following NOAA's process, city planners and decision-makers can compare the costs and benefits of various adaptation scenarios to reduce the effects of sea level rise. In this chapter, we broadly describe each component of the framework, along with a brief description of our approach. We provide more detailed account of the tasks and our application in the following chapters.

Definitions of Terms

Sea Level Rise Scenarios: Projected increases of sea level rise, typically compared to mean sea level in 1992. Usually defined as low, intermediate, or high scenarios for analysis.

Coastal Flooding: Flooding caused by increase in ocean's sea level rise and storm events.

Chronic Inundation[1]: Shoreline change resulting from an increase in ocean's sea level rise.

Bluff Erosion[1]: Wearing away of sediment at the bluff's edge

Primary Impacts: Includes directly impacted property or infrastructure, such as homes or roads.

Secondary Impacts: Includes indirect impacts, such as business interruption or cleanup costs.

Adaptation Strategy: An individual measure that reduces the impacts of flooding or storm events.

Action Scenarios: A compilation of one or more adaptation strategies.

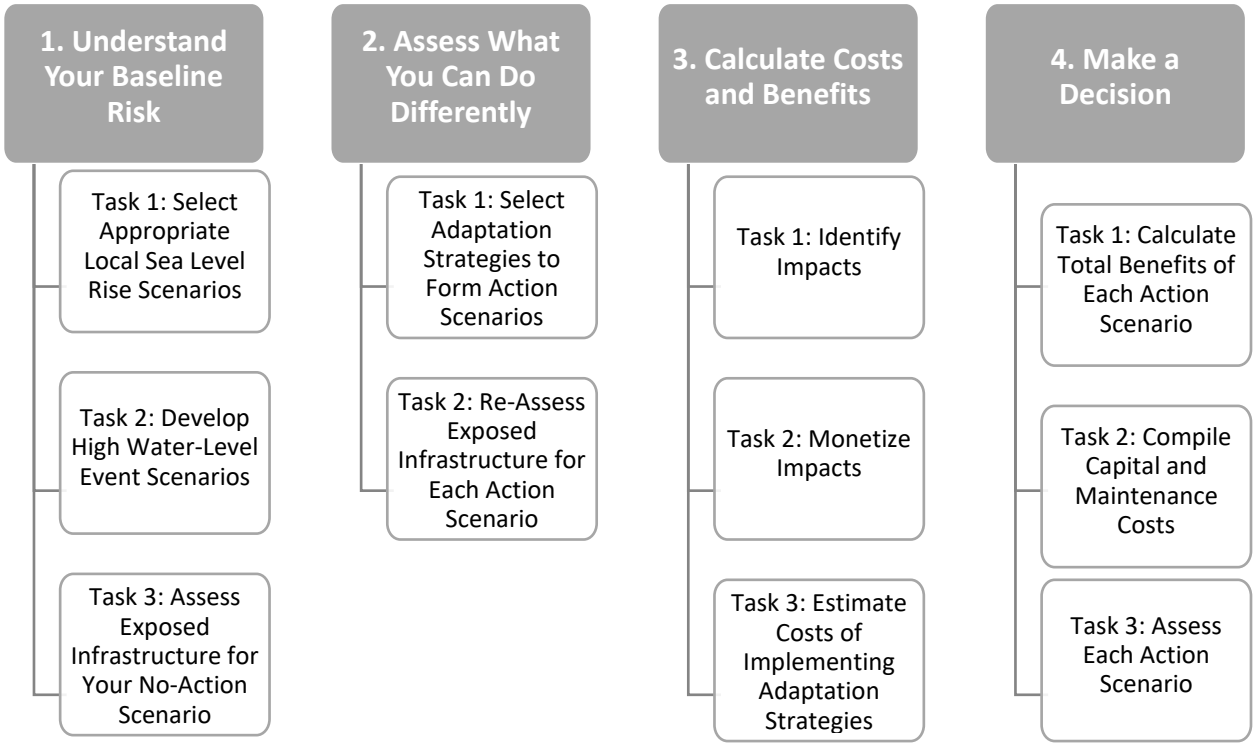
Baseline Risks: The damages that would result if no adaptation strategies were in place.

Benefits: Monetary benefits gained by implementing action scenarios. Also known as damages prevented.

Costs: Monetary cost of implementing action scenarios.

[1] Not discussed in the NOAA framework.

Figure 7: NOAA Framework



Adapted from *What Will Adaptation Cost? An Economic Framework for Coastal Community Infrastructure*, by NOAA, 2013.

According to NOAA, their framework can be used for assessing impacts on a city's infrastructure in two ways. It can be used for assessing infrastructure broadly throughout the city, or a portion thereof, which is known as the *holistic* approach. Or, it can be used on one specific piece of infrastructure, such as a power plant. This is known as the *priority infrastructure* approach. We follow the holistic infrastructure approach because we are evaluating impacts to multiple infrastructures within specific geographic areas of the city.

The NOAA framework also has an *impact assessment* and *risk assessment* option. Each city should choose which option to pursue before beginning their analysis. Per the framework, the impact assessment estimates coastal flooding damages only using water depth, while the risk assessment uses water depth plus the probability of flooding events occurring, i.e., 10-year storm event. We follow the risk assessment approach because we wanted to incorporate the probability of events occurring. Also, it was our only option in Del Mar because we did not receive water depth data.

Understanding Your Baseline Risk

The first component of the NOAA framework is understanding the baseline risk. This includes selecting a sea level rise scenario(s), i.e., low, medium, or high, projecting high-water-level increases for future years, and assessing potentially exposed land, property, and infrastructure under these future sea level rise scenarios. This initial geographic extent assessment, along with the more detailed primary and secondary impacts developed in the "Costs and Benefits" chapter answers the question, "What would

happen if no adaption measures were put in place to mitigate or protect against future sea level rise?" This is the “no action” scenario when evaluating costs and benefits.

To be consistent with each city’s documents, we selected the sea level rise scenario and hazard impacts identified in their vulnerability assessments.[2] We did not conduct any separate hazard modeling. We also incorporated the modeled damages due to chronic inundation (Carlsbad and Del Mar) and bluff erosion (Carlsbad). Our analysis of Del Mar only included coastal flooding and beach loss due to chronic inundation for the North Beach area because it was the only area with multiple action scenarios that fell within the scope of this project.[3]

Assessing What You Can Do Differently

Once a city identifies its baseline risk, it can establish adaptation strategies and action scenarios. Adaptation strategies are those tactics that a city can employ to lessen or protect against sea level rise damages. An action scenario is a combination of one or more adaptation strategies. For example, in one of its action scenarios, Del Mar chose to raise or improve their seawall, replenish the beach’s sand, and eventually, remove the impacted residential and commercial structures. These three strategies combine to create one action scenario.

We opted to be consistent with each city’s plans and not release a study that could be misconstrued as an alternative plan. As Carlsbad did not have an adaptation study or plan from which to draw, we coordinated with Carlsbad planners and followed their direction for the selection of adaptation scenarios and geographic application. As already stated, we only analyzed the cost and benefits for those geographic areas with more than one action scenario, in adherence with the NOAA’s framework to compare two or more scenarios, rather than establish the net benefits of one.

The next step in NOAA’s process is to reevaluate the city’s impact from sea level rise with each action scenario in place. Since environmental modeling of coastal sea level rise impacts fell outside of the scope of this project and our expertise, we were unable to reassess impacts. Rather, the final cost-benefit model incorporates a protection or effectiveness factor, ranging from 0 - 100 percent, that can be altered using information provided by experts. For example, this factor could be set to 100 percent if the action scenario is expected to prevent all sea level rise impacts, or it could be set to 75 percent if it is expected to prevent most, but not all, impacts. This protection factor allows analysts to compare action scenarios based on their assumed effectiveness. For our analyses, we set that factor to 100 percent for all action scenarios because we did not have the expertise to make a judgment about each action scenario’s effectiveness. However, we tested the robustness of the effectiveness assumption in our sensitivity analysis (described later in the "Sensitivity Analysis" chapter).

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[2] The NOAA framework focused on coastal flooding hazards. We also incorporated chronic inundation and bluff erosion hazards from each city’s vulnerability assessment.

[3] Bluff erosion only included one action scenario, and thus could not be compared to another one. River flooding fell outside the scope of this project.

Calculating Costs and Benefits

The purpose of this component is to monetize (assign a dollar value) the baseline (no action scenario), then re-assess impacts for each action scenario and estimate the costs of implementing each adaptation strategy within the action scenarios. These data will be used in the "Making a Decision: Results" chapter to compute benefit-cost ratios that compare relative return on investment for each action scenario, including the baseline scenario with no action.

Identifying impacts was the first task in this process. Using each city's vulnerability assessment, we created a list of primary and secondary impacts within the predetermined asset categories that fell in the hazard zones. After the city identified their action scenarios, we also considered any additional positive or negative impacts associated with one action scenario over another. For example, Del Mar selected an action scenario that protected the beach across all years, and another where the beach was lost in later years. We accounted for these different impacts in the benefits side of the ratio.

Next, we assigned monetary values to the primary and secondary impacts. While we primarily quantified the costs to the city, we also estimated costs to residential and commercial property owners. See the "Costs and Benefits" chapter for a detailed description of the resources used for each primary and secondary impact.

While we followed NOAA's risk assessment methodology (versus their impact assessment method), the process was different for each city because each had different challenges associated with estimating future damages by storm type. Our adaptations are described in more detail in the "Costs and Benefits" chapter.

Lastly, we estimated the costs for implementing each adaptation strategy within the action scenarios. Data were gathered from a variety of sources, such as construction companies and the San Diego Association of Governments (SANDAG). See the "Costs and Benefits" chapter for more detail.

Making a Decision

After all data are compiled, we aggregated to calculate the benefit-cost ratios. The chosen discount rate should also be incorporated into the analysis to calculate net present value (NPV) of benefits and costs. Because a dollar is worth more today than it will be in the future, future net benefits and costs are calculated in today's dollars. This conversion is called "discounting," and NPV is the net value in today's dollars.

As Carlsbad action scenarios did not start until 2050, we evaluated the planning horizon years 2050 to 2100. In Del Mar, the action scenarios began in 2030 and we evaluated the years 2030 to 2100. City planners and decision-makers can compare these ratios to determine the best option for their community.

The first task was to assemble the total benefits of each action scenario. This step began with compiling the benefits, or potential damages prevented, from the baseline risk (no action scenario.) For both Carlsbad and Del Mar, we followed the process for the risk assessment option as it incorporated the probability of flooding occurrences into the calculations. From the baseline, annual expected damages were calculated for each action scenario by incorporating the annual probability of storm events, e.g., a

10-year storm. The NOAA framework provides the equations and step-by-step process for calculating and discounting expected annual losses.

After determining the total benefits of each action scenario, the next step required compiling the adaptation strategy costs within each action scenario, and then discounting the cost to present value. For this step, the implementation timeline for each strategy must be determined, with the capital and maintenance costs specified by year (2030, 2040, etc.). Because the costs are incurred in different years, they must all be discounted back to present value to get the NPV. We followed the specified timelines given by each city.

Finally, the last task was to assess each action scenario by calculating net benefits and benefit-cost ratios. City planners and decision-makers can use these measures to determine which action scenario has the highest return on investment. They should also consider other relevant information that cannot be quantified in monetary terms, such as whether the loss of their beaches would change the culture or identity of their community. We developed benefit-cost ratios for each city and conducted sensitivity analysis to determine the robustness of our results. These are described in the "Sensitivity Analysis" chapter.

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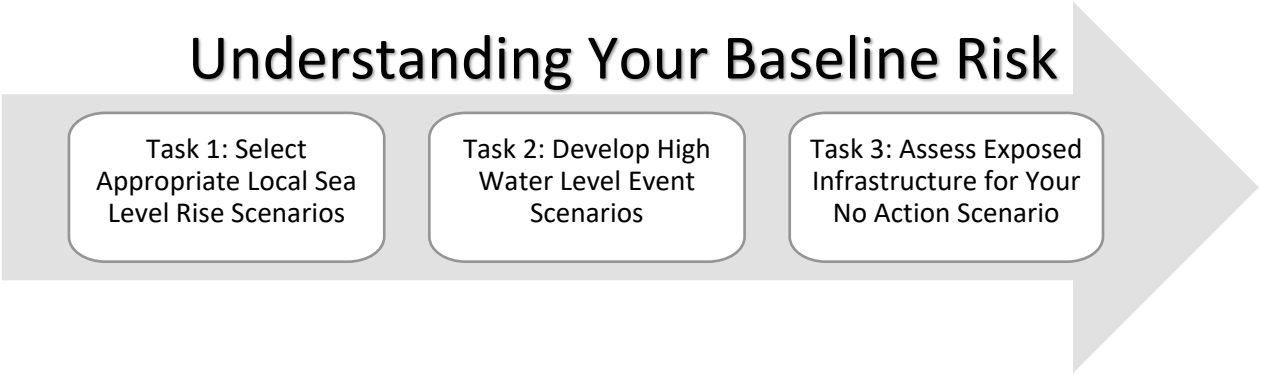
Baseline Risks



In this chapter, we focus on the NOAA Framework's "Understanding Your Baseline Risk" component. This chapter describes our specific baseline risk methodology and adjustments we made to fit each city's approach. To make our process easier to replicate, we situated our methodology within the NOAA framework.

The Carlsbad Assessment projected future flooding impacts by modeling the *water level increases* over time. The Del Mar Assessment, on the other hand, projected the increase in *flooding occurrences* over time by referencing past flooding events and flooding return probabilities. Both approaches provided the opportunity to apply NOAA's baseline risk component in these two distinct circumstances. Carlsbad's approach was more aligned with the NOAA's high water level event scenarios (NOAA Chapter 1, Task 2). Del Mar's approach did not necessitate incorporating high water level event scenarios. These differences and adaptations are described in this chapter.

We also expand upon the NOAA framework by including chronic inundation and bluff erosion hazards in our analyses. The specific hazards determine which, and how, baseline risks are identified. The Carlsbad study area in Planning Zone 1 assessed impacts causes by coastal flooding, chronic inundation, and bluff erosion. The Del Mar study area in North Beach, on the other hand, only included coastal flooding and chronic inundation. Thus, each baseline risk scenario incorporates different sources of the impacts, with Del Mar excluding bluff erosion.

NOAA Methodology Adjustments

Table 3, on the next page, shows the modifications by task and city. Most of these tasks were conducted as part of each city's vulnerability assessment. We acquired those assessments and relevant GIS layers to incorporate into this study. The Carlsbad Assessment identified two sea level rise scenarios using CoSMoS v3.0. Per their report, they selected 0.5 meters (1.64 ft.) and 2.0 meters (6.56 ft.), which roughly parallels the forecasted high sea level rise from the 2012 National Research Council's report for the 2050 and 2100 planning horizons (City of Carlsbad, 2016). To be consistent with the Carlsbad Assessment hazard modeling, we chose the high sea level rise scenario with the 2050 and 2100 planning horizons.

The Del Mar Assessment differed in its approach by projecting the increase in flooding occurrences over time, instead of the water level increases like those used by Carlsbad. The Del Mar Assessment used flooding return probabilities and damages from past storm events to predict future impacts of coastal flooding. This required us to adapt NOAA's methodology, and as a result, there was no need to conduct Task 2 (Develop High-level Water Event Scenarios) in this section because future damages were not based on water depths.

Table 3: Understanding Your Baseline Risk: Adjustments to NOAA Methodology by Task and City

Understand Your Baseline Risk	**Carlsbad Adaptations**	**Del Mar Adaptations**
Task 1: Select appropriate sea level rise scenarios	City vulnerability assessment selected high sea level rise scenario from CoSMoS v3.0. City selected 2050 and 2100 as their planning horizon years, which roughly corresponded with 0.5 meter and 2.0 meter sea level rise from the National Research Council projections (2012). They only provided forecasts for those two years. We predicted intermittent 5-year points using the high USACE curve to fit a quadratic curvilinear regression, and benchmarked the sea level rise curve to the 2050 and 2100 values (0.5m and 2.0m).	City vulnerability assessment selected a high sea level rise scenario. They did not project water-level increases. Rather, they used historical coastal flooding events to project the extent of future coastal flooding caused by storm events. Significant flooding equaled today's 10-year storm event. Extreme flooding was considered today's 100-year storm event. They projected future damages by increasing the probability of similar storm occurrences between now and 2100.
Task 2: Develop high water level event scenarios	None. We contacted NOAA directly to obtain exceedance probability curve data because the referenced website did not provide data in table format.	Did not conduct because future damages were based on increased frequency of current storm events, not increased water depth.
Task 3: Assess exposed infrastructure for the no action scenario	Conducted as part of the city vulnerability assessment. They provided us with GIS layers showing extent of coastal flooding. We also considered chronic inundation and bluff erosion.	Conducted as part of the city vulnerability assessment. They provided us with GIS layers showing extent of coastal flooding. We also considered chronic inundation.

While in some ways utilizing Carlsbad and Del Mar's existing modeling made the cost-benefit analyses simpler, it also yielded challenges when applying the NOAA framework. For example, the Carlsbad Assessment only provided two time points, and both Carlsbad and Del Mar Assessments only considered one sea level rise scenario (high). Thus, we were limited to only comparing action scenarios under the high sea level rise scenario and could not make comparisons under the low or intermediate scenarios. Similarly, since we only possessed modeled impacts for 100-year storm events in 2050 and 2100 in Carlsbad, we had to interpolate damage estimates between years and storm types. Furthermore, since

the first time-point modeled was 2050, we did not have information regarding potential impacts before 2050; thus, our analysis in Carlsbad starts at 2050. In Del Mar, we were limited to projecting future damages based on historical events as their modeled layers did not account for future increased water depth. Additionally, we chose to use NOAA's risk assessment option for both cities to incorporate storm event probabilities.

Carlsbad

At the direction of city staff, the study area was limited to the coastal area of Carlsbad's Planning Zone 1, delineated by Buena Vista Lagoon to the north, and Tamarack Avenue to the south. The lagoon itself was not included in the study area.

Applying the Method

Task 1: Select Appropriate Local Sea Level Rise Scenarios

The Carlsbad Assessment only selected the high sea level rise scenario for analysis, using the CoSMoS v3.0 sea level rise scenarios to project 0.5 meter (1.64 ft.) and 2.0 meter (6.56 ft.) rises. These two values roughly corresponded with the 2050 and 2100 planning horizon years from the National Research Council's (NRC) high range (City of Carlsbad, 2016).

The Carlsbad Assessment only provided sea level projections for 2050 and 2100. Consequently, we had to generate local high water level event scenarios for the 5-year intermittent periods. We first used the U.S. Army Corps of Engineers (USACE) Sea Level Change Curve Calculator to obtain the high sea level projections for the years in-between 2050 and 2100. As the Carlsbad Assessment provided values for 2050 and 2100 and their modeled impacts, we used these two dates as anchor points and refit the sea level rise curve from the nearest NOAA tide gauge (La Jolla, CA) using curvilinear regression with a quadratic equation. The NOAA framework recommended utilizing a quadratic equation because sea level rise is likely to increase at higher rates in the future. Additionally, the USACE curves were non-linear and we aimed to match their growth. We predicted values for each 5-year increment between 2050 and 2100, incorporated the predicted rate of change in sea level rise, and matched the Carlsbad Assessment's two modeled years (Table 4).

Table 4: Projected Mean Sea Level Rise, High Sea Level Rise Scenario
Carlsbad, CA

Year	High Sea Level Rise Scenario (ft.)[1]	Year	High Sea Level Rise Scenario (ft.)[1]
2050	1.64[2]	2080	4.26
2055	2.13	2085	4.78
2060	2.49	2090	5.33
2065	2.89	2095	5.91
2070	3.32	2100	6.56[2]
2075	3.78		

[1] Feet above 1992 sea level.
[2] Source*: Sea Level Rise Vulnerability Assessment* draft, by City of Carlsbad. 2016.

Task 2: Develop High Water Level Event Scenarios

Our second task was to estimate high water level event increases for the 5-year increments by storm types. Again, we chose NOAA's risk assessment and utilized Option B because we wanted to consider the probability of storm events occurring in our analysis. As the Carlsbad Assessment modeled the impacted areas for a 100-year storm in 2050 and 2100, it was not necessary to calculate high water level values to estimate damages. However, we completed this task because the high water level event estimates allowed us to interpolate the damages for other years and other storm types, when calculating the average and expected monetized damages prevented by year (NOAA Chapter 4 Task 1, Table 4.2), described later in this report. Thus, we calculated the high water level events here so we could apply NOAA's methodology later.[4]

The NOAA framework provided direction to use the NOAA Extreme Water Levels map "Exceedance Probability Curves" for the closest station; in our case, La Jolla CA. Unfortunately, the charts referenced by NOAA did not provide enough detail to identify each storm type's mean higher high water (MHHW) value. Instead, we contacted NOAA directly and obtained the data behind the charts. The data for numerous storm types provided by NOAA is shown in Table 5. Then, we followed NOAA's methodology to create a table similar to Table 1.6 in the NOAA framework for the high sea level rise scenario. For each storm type, we added the exceedance probability MHHW (Table 5) to the projected mean sea level rise (Table 4). Our table estimates high water level values for 100-year, 50-year, 10-year, 2-year, and 1-year storm events (Table 6).

Table 5: Exceedance Probability Curves
La Jolla, CA Tide Gauge Station

Storm Type	Meters Above MHHW	Feet Above MHHW
100-year	0.69	2.26
50-year	0.68	2.23
10-year	0.63	2.07
2-year	0.55	1.80
1-year	0.42	1.38

Source: NOAA Exceedance Probability Curves.

[4] This logic applies to Carlsbad only. For Del Mar, we did not calculate high water level events because they projected damages for today's 10-year and 100-year event storm, and then forecasted how the frequencies of those events would increase over time. Water depths were not provided in their vulnerability assessment.

Table 6: Projected High Water Level Increases (ft.) by Storm Event and Year
Carlsbad, CA

High SLR Scenario	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
100-year	3.90	4.39	4.76	5.16	5.58	6.04	6.53	7.05	7.59	8.17	8.82
50-year	3.87	4.36	4.73	5.12	5.55	6.01	6.49	7.01	7.56	8.14	8.79
10-year	3.71	4.19	4.56	4.96	5.39	5.84	6.33	6.85	7.40	7.97	8.63
2-year	3.44	3.93	4.30	4.70	5.12	5.58	6.07	6.59	7.13	7.71	8.36
1-year	3.02	3.51	3.87	4.27	4.70	5.15	5.64	6.16	6.71	7.29	7.94

Task 3: Assess Exposed Infrastructure for Your No-Action Scenario

The Carlsbad Assessment included a list of parcels impacted by coastal flooding (100-year storm), chronic inundation, and bluff erosion in 2050 and 2100, and GIS layers for each of those hazards, provided by their consultant. Because of this, we did not need to perform this analysis.

We further identified specific impacts, which are discussed in more detail in the "Cost and Benefits" chapter. The following city-owned and non-city asset categories were considered in our analysis:

- City property and structures
- City public infrastructure
- City transportation infrastructure
- Residential property
- Commercial and industrial property
- Beaches

Del Mar

Applying the Method

Task 1: Select Appropriate Local Sea Level Rise Scenarios[5]

The Del Mar Assessment differed in its approach, compared to the Carlsbad Assessment, by projecting the increase in flooding occurrences over time, instead of water level increases. The Del Mar Assessment used flooding return probabilities and damages from past storm events to predict future impacts of coastal flooding. A "significant event" had the same impacts as their 2016 storm, which the Del Mar Assessment considered to be a high sea level rise 10-year storm event. An "extreme event"

[5] Nexus analysis of the City of Del Mar only included coastal flooding and beach loss due to chronic inundation for North Beach; the only area with multiple action scenarios that fell within the scope of this project.

referenced the damages from their 1983 storm and was considered to be a high sea level rise 100-year storm event. Additionally, the Del Mar Assessment used CoSMoS v3.0 to estimate the loss in shoreline due to chronic inundation. Table 7 shows the how the coastal flooding annual probabilities increase over time for the high sea level rise scenario. By 2050, today's 10-year event will be 1-year event. By 2100, today's 100-year event will be a 1-year event.

Table 7: Coastal Flooding Event Annual Probabilities Over Time
Del Mar, CA

	Flood Returns for High Sea Level Rise Scenario				
Type of Coastal Flooding	**Present**	**2030**	**2050**	**2070**	**2100**
Significant (e.g. 2016 storm) 10-year event today	10%	50%	100%	100%	100%
Extreme (e.g. 1983 storm) 100-year event today	1%	5%	15%	50%	100%

Source: *Del Mar Coastal Hazards Vulnerability Assessment* draft, by ESA, 2016.

Task 2: Develop High Water Level Event Scenarios

We did not conduct this task, as future damages in the Del Mar Assessment were based on increased frequency of storms instead of increased depth of water caused by sea level rise; the Del Mar Assessment did not provide projections of future mean sea level rise. Unlike the Carlsbad Assessment where we used NOAA's exceedance probability curves to develop high water level increases, for the Del Mar Assessment, we only had the modeled damages for today's significant and extreme events, and the predicted change in their occurrences between the present and 2100. Although we were unable to estimate the water level increases for North Beach, we were able to adapt the NOAA methodology to project how damages would increase over time by increasing the frequency of storm events. In the "Make a Decision: Results" chapter, we applied the flooding probabilities and timeline shown in Table 7 to estimate how damages would change in the future. The increase in storm occurrences assumes the same extent and reach as the present storms, per the Del Mar Assessment. This approach allowed us to calculate the baseline no action scenario, i.e., damages prevented, without having modeled damages by sea level rise depths, i.e., 2 feet.

Task 3: Assess Exposed Infrastructure for a No-Action Scenario

This task was conducted as part of the Del Mar Assessment. The city's consultant provided us with the GIS hazard layers for coastal flooding and chronic inundation. Per the Del Mar Assessment, these GIS layers illustrated the extent of coastal flooding damages based on historical flooding events caused by the equivalent of today's 10-year and 100-year storms.

We further identified specific impacts, which are discussed in more detail in the "Cost and Benefits" chapter. We included the same property and infrastructure assets that were considered in the Carlsbad analysis. Again, we considered the following asset categories:

- City property and structures
- City public infrastructure

- City transportation infrastructure
- Residential property
- Commercial and industrial property
- Beaches

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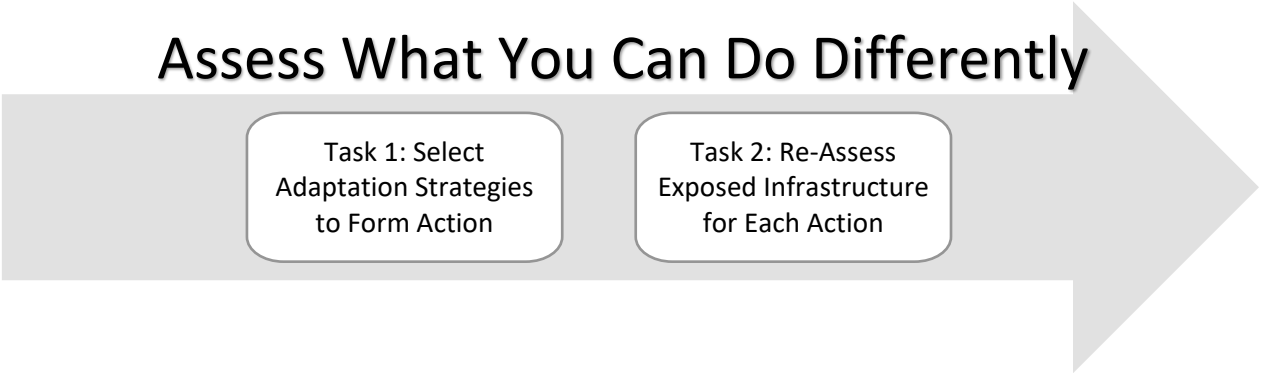
Assess What You Can Do Differently: Adaptation Scenarios and Strategies



After each city identified its baseline risk through their respective vulnerability and risk assessment, they selected action scenarios consisting of various combinations of adaptation strategies to lessen or protect against any potential damages. This chapter describes the adaptation strategies and action scenarios selected by each city.

NOAA Methodology Adjustments

Table 8: Assess What You Can Do Differently: Adjustments to NOAA Methodology by Task and City

Assess What You Can Do Differently	**Carlsbad Adaptations**	**Del Mar Adaptations**
Task 1: Select adaptation strategies to form action scenarios	City of Carlsbad in progress of selecting. Carlsbad requested we use Del Mar strategies and action scenarios for this report.	City of Del Mar selected strategies and actions scenarios.
Task 2: Re-asses exposed infrastructure for each action scenario	We did not re-assess exposed infrastructure. It fell out of the scope of this project due to required additional modeling. Rather, we created a protection or effectiveness factor that ranged from 0 - 100%. We assumed 100% protection for each action scenario, and varied this assumption in sensitivity analysis.	We did not re-assess exposed infrastructure. It fell out of the scope of this project due to required additional modeling. Rather, we created a protection or effectiveness factor that ranged from 0 - 100%. We assumed 100% protection for each action scenario, and varied this assumption in sensitivity analysis.

As we did not conduct NOAA's Task 2 (Table 8), this chapter does not include "Applying the Method" or "Assumptions" sections. The next section describes the action scenarios and strategies selected by the cities.

Carlsbad and Del Mar Action Scenarios

Since Carlsbad did not select their action scenarios by the time of this report, their planning staff directed us to adapt and use Del Mar's three adaptation strategies. Therefore, we applied three action scenarios to both cities composed of one or more of the following adaptation strategies:

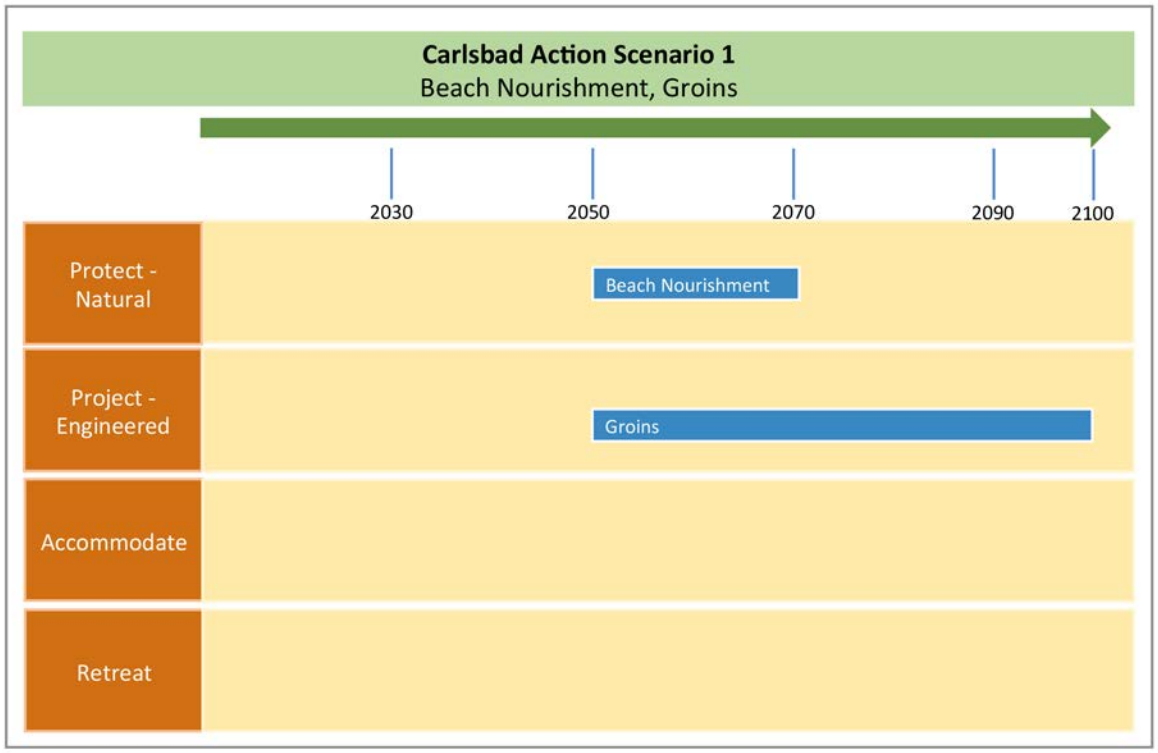
1. Natural Protection: Building up of shorelines through the "soft" armoring with beach nourishment. For this report, we only analyzed beach nourishment to be consistent with other regional nourishment projects (SANDAG, 2001).
2. Engineered Projects: Construction of "hard" physical barriers such as groins, breakwaters, or engineered reefs, or improving/raising existing barriers, i.e., seawalls and revetments. Groins were selected for evaluation instead of breakwaters as the latter tends to "destroy surfing resources" (City of Del Mar, 2016b).
3. Accommodation: Retrofitting of inhabited structures by raising occupied floors above known flood levels to avoid damage without impeding floodwaters.
4. Retreat: Removal of all man-made structures and barriers – homes, buildings, engineered structures – and allowing the shoreline to erode/advance inland without intervention.

Carlsbad Action Scenarios

The following action scenarios for Carlsbad were adapted from the Del Mar Assessment and adjusted to reflect an implementation timeframe that begins in 2050. We intentionally renumbered the Del Mar scenarios for Carlsbad to differentiate them.

Scenario 1 employs the natural protection of beach nourishment over a 20-year period, simultaneous to construction of engineered permanent sand retention with groins for further armoring (with the knowledge that such hard structures could negatively impact surfing conditions immediately) (Figure 8).

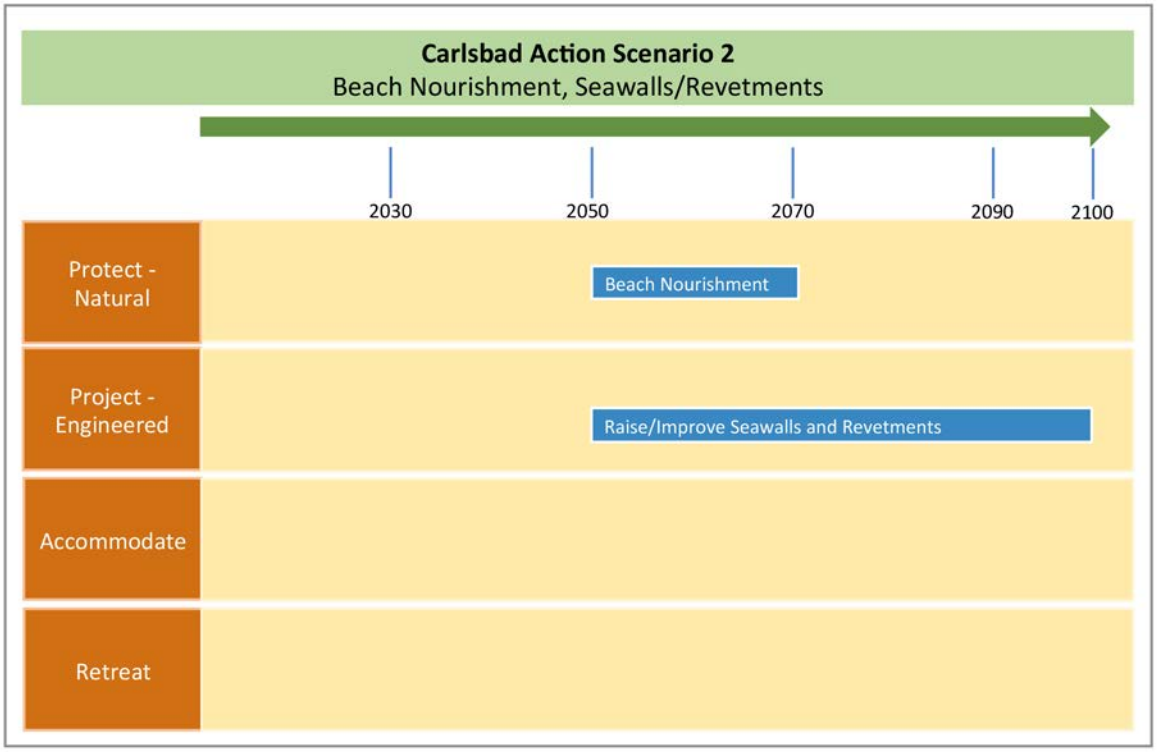
Figure 8: Carlsbad Action Scenario 1 Strategies and Timeline



Adapted from *City of Del Mar Sea-Level Rise Adaptation Plan* draft, by ESA, September 2016.

Scenario 2 uses the same two-prong approach of Scenario 1, but opts to raise and improve seawalls, rather than construct groins. In this scenario, beaches will become vulnerable to erosion and shorelines will migrate inland after nourishment is discontinued (Figure 9).

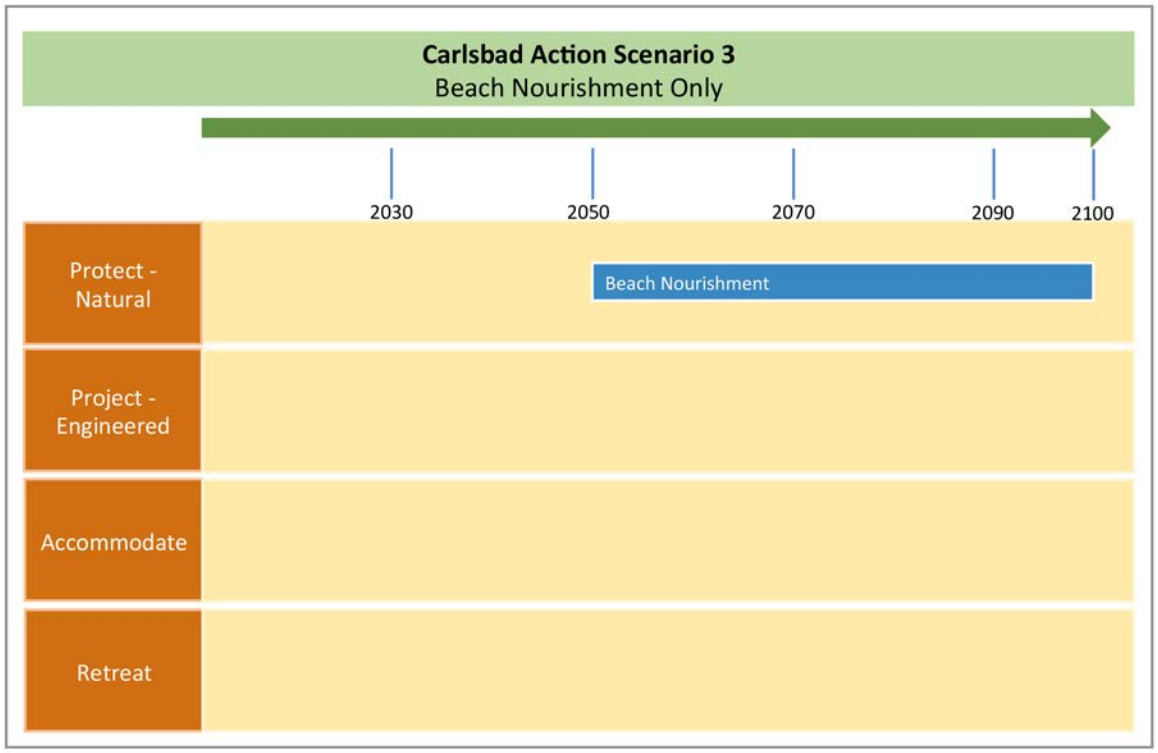
Figure 9: Carlsbad Action Scenario 2 Strategies and Timeline



Adapted from *City of Del Mar Sea-Level Rise Adaptation Plan* draft, by ESA, September 2016.

Scenario 3 relies solely on the natural protection measure of beach nourishment through 2100, with no change to surf conditions (beyond intermittent interruptions during scheduled nourishments) (Figure 10).

Figure 10: Carlsbad Action Scenario 3 Strategies and Timeline

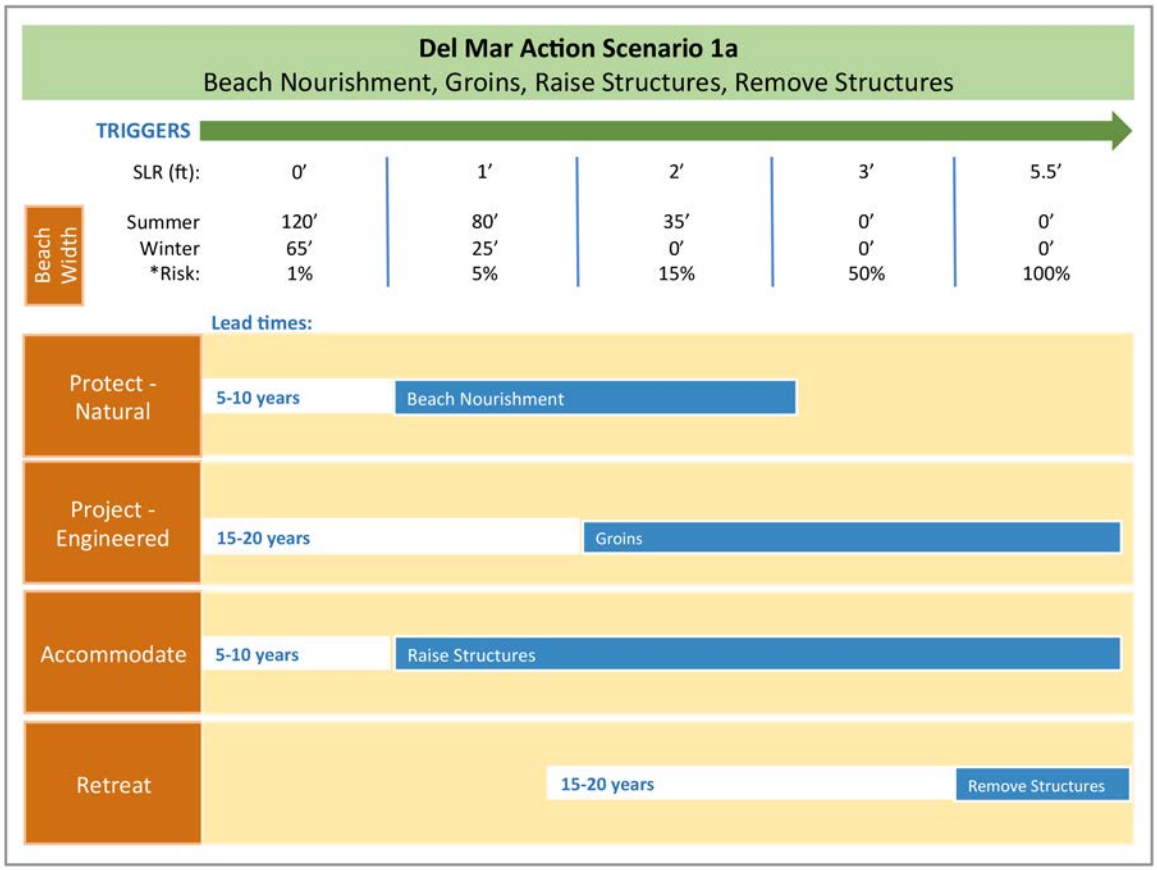


Adapted from *City of Del Mar Sea-Level Rise Adaptation Plan* draft, by ESA, September 2016.

Del Mar Action Scenarios

Scenario 1a uses a combination of natural protection (beach nourishment) and accommodation (raising structures above known flood levels), followed by the addition of engineered projects such as groins for further armoring. We decided to analyze groins because this strategy is least likely to impact surfers (City of Del Mar, 2016b). Retreat is triggered after risk levels exceed 50% (Figure 11).

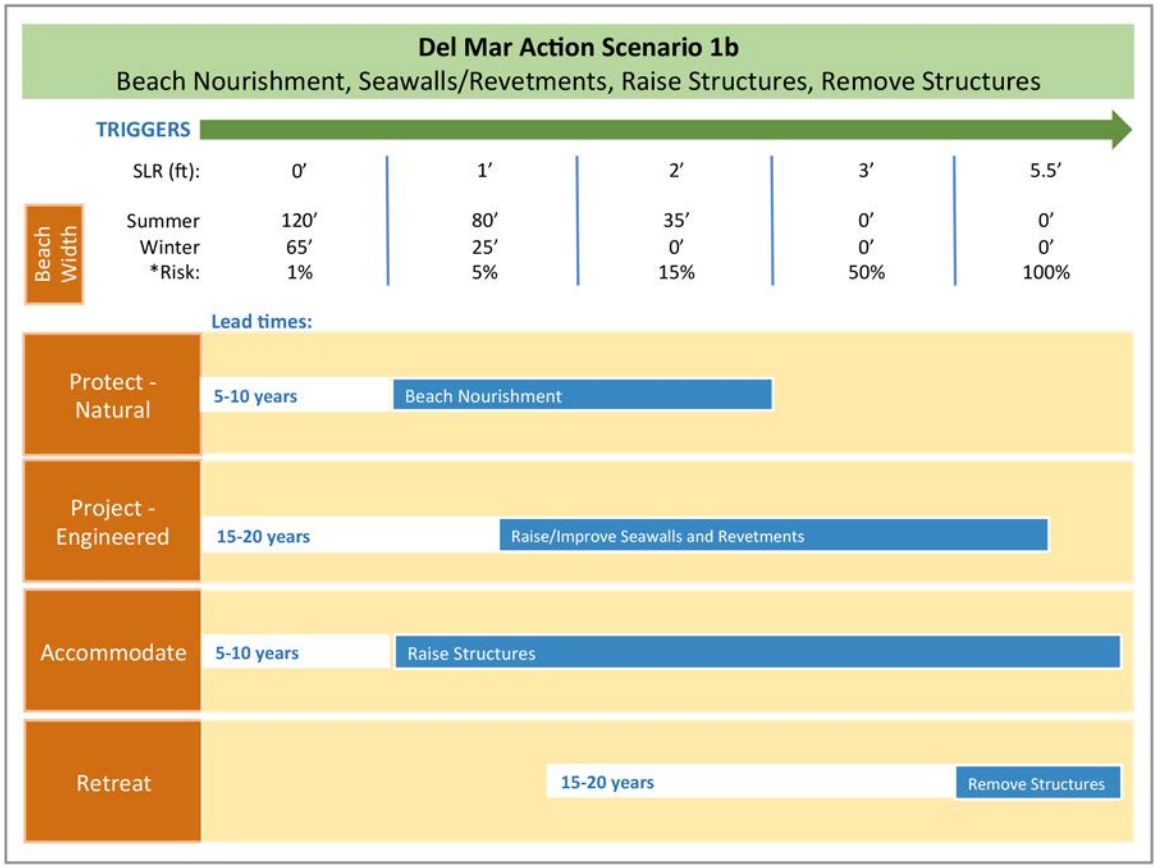
Figure 11: Del Mar Action Scenario 1a Strategies and Timeline



Adapted from *City of Del Mar Sea-Level Rise Adaptation Plan* draft, by ESA, September 2016.

Scenario 1b implements the same plan schedule as Scenario 1a, but foregoes new engineered projects in favor of raising or improving existing sand retention structures (seawalls, revetments). The trade-off in this scenario is the likely loss of beach area over time (Figure 12).

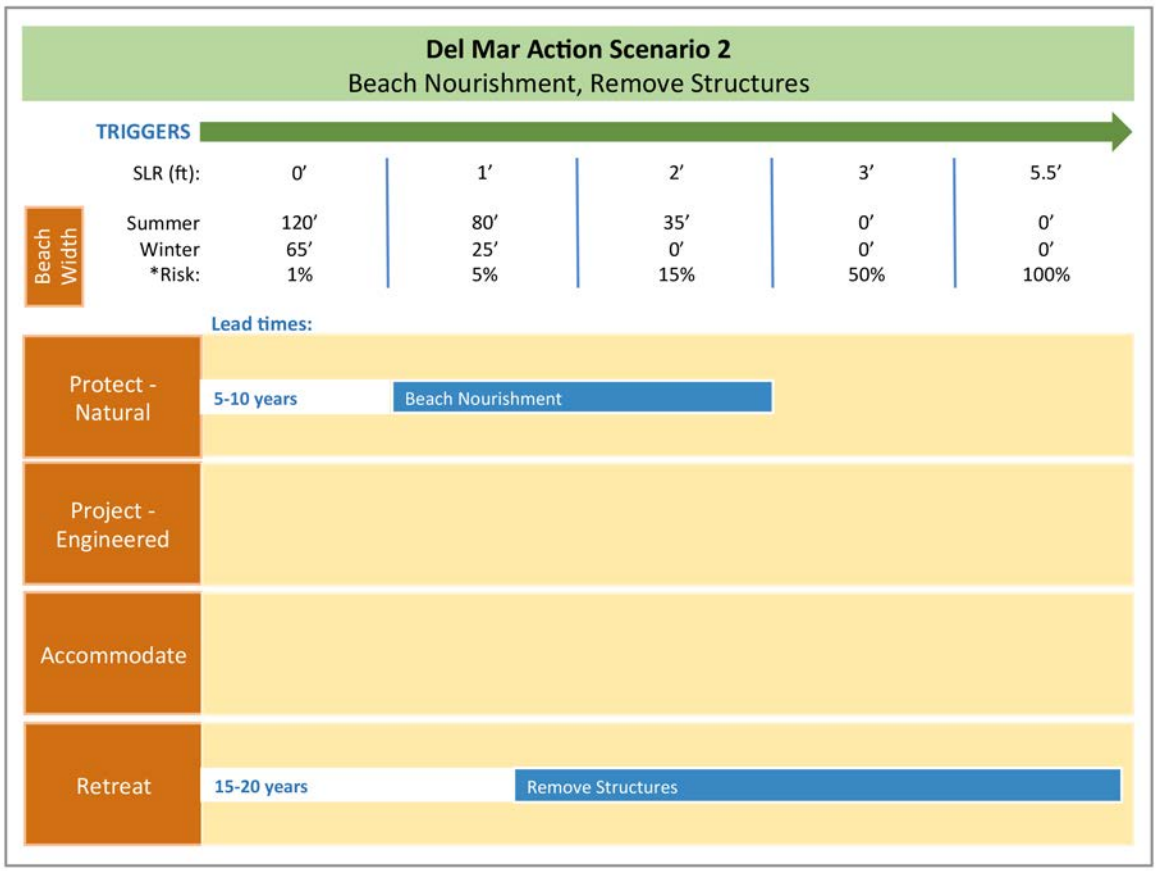
Figure 12: Del Mar Action Scenario 1b Strategies and Timeline



Adapted from *City of Del Mar Sea-Level Rise Adaptation Plan* draft, by ESA, September 2016.

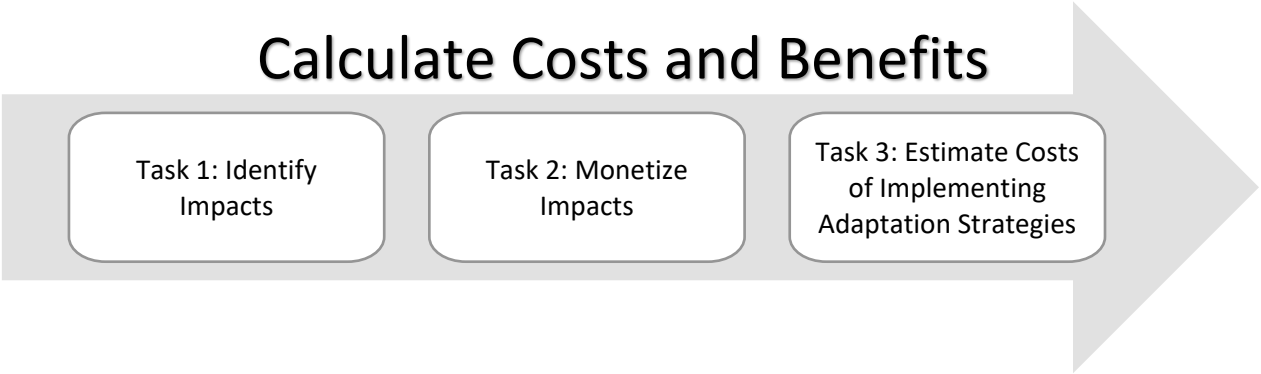
Scenario 2 forgoes all engineered projects and accommodations and only considers two strategies: natural protection through beach nourishment until water depths exceed 15 percent risk, with retreat measures initiated at 5 percent risk, and continued as risk increases to 100 percent. (Figure 13).

Figure 13: Del Mar Action Scenario 2 Strategies and Timeline



Adapted from *City of Del Mar Sea-Level Rise Adaptation Plan* draft, by ESA, September 201

Cost and Benefits



In this chapter, we discuss how we identified specific impacts and applied monetary values to impacted areas described by each city's vulnerability assessment and the previous chapter "Baseline Risks." Lastly, we discuss how we estimated the costs of implementing the adaptation strategies.

As previously mentioned, while we found the NOAA methodology broad enough to allow flexibility for city differences, there was minimal guidance regarding assumptions needed for completing this analysis. This chapter describes our specific methodology for valuing impacts and adaptation strategies, and any adjustments we made to fit each city's approach into NOAA's framework. We provide specific assumptions in detail to help others apply NOAA's framework.

Importantly, we developed values for three inputs into our final model, described in the next chapter. These three inputs were:

1. Monetized baseline risk primary and secondary impacts, which represent the maximum damages prevented, or the no action scenario
2. Monetized negative impacts resulting from action scenarios (We did not have any additional positive impacts.)
3. Costs of adaptation strategies

What does the baseline or no action scenario represent?

The baseline or no action scenario represents the maximum damages that could occur if no strategies were in place to lessen sea level rise impacts. These potential costs represent the *damages prevented* once strategies are in place to mitigate these damages, which is on the benefit side of the cost-benefit model. For each city, the no action scenario serves as the baseline for the benefits of all action scenarios. Depending upon the action scenario, we then account for any additional negative impacts that would reduce the benefits (damages prevented) of the baseline model. The baseline risks depend upon the hazards included in the analysis. For Carlsbad, we included impacts from coastal flooding, chronic inundation, and bluff erosion. Only coastal flooding and chronic inundation were included in Del Mar.

NOAA Methodology Adjustments

Table 9 summarizes the adjustments we made to NOAA's methodology. As shown under Task 2, our primary adjustments to align the steps with the cities' impacted areas and sea level rise projections identified in their vulnerability assessments, including their identified storm events, planning horizons, and extent of damages.

Additionally, we only calculated damages for the no action scenario (baseline risk). We calculated any negative impacts of implementing the action scenarios, which were then applied in the final cost-benefit model discussed in the next chapter, "Making a Decision: Results." We did not have positive impacts associated with each action scenario because we did not re-assess the exposed infrastructure; Task 2 in "Assess What You Can Do Differently" chapter.

Table 9: Calculate Costs and Benefits: Adjustments to NOAA Methodology by Task and City

Calculating Cost and Benefits Tasks	**Carlsbad Adaptations**	**Del Mar Adaptations**
Task 1: Identify impacts	Included impacts from chronic inundation and bluff erosion in addition to coastal flooding	Included impacts from chronic inundation in addition to coastal flooding
Task 2: Monetize impacts	● Used the city's vulnerability assessment to determine which impacts applied at 2050 and 2100. ● Only created one modified table (NOAA table 3.4.) for the no action scenario because each action scenario had the same baseline damages for 2050 and 2100. ●Did not create NOAA table 3.6 because we incorporated storm probabilities into NOAA table 4.2. ● Valued the negative impacts associated with each action scenario, but did not calculate separate damages for each action scenario. Because we were unable to re-assess damages of each action scenario, we applied these negative damages to the final cost-benefit model (found in next chapter).	● Used the city's vulnerability assessment to determine which impacts applied to a 10-year storm event and 100-year storm event. ● Only created one modified table (NOAA table 3.4.) for the no action scenario because each action scenario had the same baseline damages for a 10-year storm event and 100-year storm event. ● Did not create NOAA table 3.6 because we incorporated increased frequency of current 10-year and 100-year event into NOAA table 4.2. ● Valued the negative impacts associated with each action scenario, but did not calculate separate damages for each action scenario. Because we were unable to re-assess damages of each action scenario, we applied these negative damages to the final cost-benefit model (found in next chapter).
Task 3: Estimate costs of implementing adaptation strategies	None	None

Carlsbad

Applying the Method

Task 1: Identify Impacts

We conducted Task 1 in this section in conjunction with Task 3 in "Baseline Risk." That is, we identified each asset category's specific impacts while assessing the exposed areas. We assessed exposed infrastructure by overlaying the vulnerability assessment's hazard areas (flooding, chronic inundation, and bluff erosion) on the city's parcels and infrastructure using ESRI's ArcMap software. Carlsbad provided us the impacted parcel file with hazards already identified by parcel. This file was originally used in their vulnerability assessment.

As previously mentioned, except for private residential and commercial/industrial property, and beaches, all of the other assets in our analysis were city-owned. We assessed primary impacts for the following asset categories, but as noted in Table 10 not all asset categories had impacts in the Carlsbad study area:

- City property and structures
- City public infrastructure
- City transportation infrastructure
- Residential property
- Commercial and industrial property
- Beaches

We also considered the following secondary impacts:

- Loss of beach tourism revenue to businesses
- Loss of beach tourism tax revenue to city
- City cleanup for flooding events
- Emergency response and/or traffic control for flooding events

To identify more specific primary impacts for both 2050 and 2100, we developed an impacted parcels inventory for residential and non-residential properties. We updated the inventory with additional data, such as current market value of structures, number of stories, and square feet. Where relevant for multi-story condominium buildings, we identified ground floor units because we assumed flooding would not damage second floor units, or higher. This required us to view the buildings on Google Earth, Google maps, street view, or, in a few cases, conduct a physical site visit, to determine the unit number ordering scheme and layout, i.e., equal or unequal number of units on each floor. Where we could not ascertain specific first floor units, we assumed the lowest numbered units were located on the ground floor. Additionally, we also visually inspected whether the hazard layer, such as flooding, "touched" the

structure. We created a field with a “yes” or ‘no” tag to identify whether the structure was impacted. It was crucial to use a map-based system to visually identity specific impacts.

We also overlaid the hazard GIS files, using both ArcMap and Google Earth, to identify impacted city infrastructure, such as roads.

See the Assumptions section in this chapter for more information about how we valued these assets for each hazard type and our business rules, where applicable. This section also provides detail about how we estimated applicable secondary impacts.

Table 10 shows the list of primary and secondary impacts we identified and the data sources and methods used to estimate their monetary impacts.

Negative Impacts of Action Scenarios

Per the next step in this task, we considered additional positive or negative impacts that could result from the action scenarios. There were no perceived additional positive impacts for each action scenario. However, the following negative impacts were identified:

- Scenario 1: None.
- Scenario 2: Loss of beach tourism business revenue and city tax revenue for loss of beach starting in 2070.
- Scenario 3: None.

Table 10: Methods for Valuing 2050 and 2100 Primary and Secondary Impacts in Selected Study Area, Planning Zone 1, Carlsbad, CA

Impact Type (2050 and 2100)	Method(s) for Valuing	Data Source(s)
Primary Impacts		
Residential property damages (flooding event)	2050 – no expected damages 2100 – USACE depth damage functions and locally developed parcel inventory	USACE depth damage functions; local assessor parcel data; RSMeans replacement costs
Residential property damages (chronic inundation)	2050 – no expected damages 2100 – current market value and business rules	Zillow and/or Redfin; local assessor parcel data
Commercial/industrial property damages (flooding event)	USACE depth damage functions and locally developed parcel inventory	USACE depth damage functions; local assessor parcel data; RSMeans commercial replacement costs
Commercial/industrial property damages (chronic inundation)	None - no expected damages	N/A
Residential and commercial/industrial property damages (bluff erosion)	None - no expected damages	N/A
City property and structures damages (flooding event, chronic inundation, bluff erosion)	None - no expected damages	N/A
City public infrastructure damages (flooding event, chronic inundation, bluff erosion)	None - no expected damages	N/A
City transportation infrastructure damages (flooding event, chronic inundation)	None - no expected damages	N/A

Continued on the next page.

Impact Type (2050 and 2100)	Method(s) for Valuing	Data Source(s)
Primary Impacts (continued)		
City transportation infrastructure damages (bluff erosion)	2050 – generic infrastructure repair costs for damaged segments of Carlsbad Blvd; generic infrastructure replacement costs for damaged beach pathway and stairways 2100 – generic infrastructure replacement costs for lost segment of Carlsbad Blvd; generic infrastructure replacement costs for damaged beach pathway and stairways	City Capital Improvement Program budget; City Council agenda bills, accepted bids for similar capital improvement projects; City Public Works Department; Local construction companies' estimates
Secondary Impacts		
Loss of business revenue due to loss of beach tourism loss (chronic inundation)	Area-based beach attendance model with benefits transfer day use value	City vulnerability assessment projected beach width loss, beach area measurements using GIS, beach attendance from state, day use value from local study
Loss of city tax revenue due to loss of beach tourism loss (chronic inundation)	Area-based beach attendance model with benefits transfer day use value, fiscal model with local tax rates assuming distribution of lodging	City vulnerability assessment projected beach width loss, beach area measurements using GIS, beach attendance from state, day use value from local study; State of California Board of Equalization for sales tax rate; City of Carlsbad Finance Department for Transient Occupancy Tax rate
Loss of city tax revenue due to business interruption (flooding event)	Applied midpoint of HAZUS-MH physical restoration time by FEMA occupancy class	HAZUS-MH for physical restoration time; City of Carlsbad Finance Department for transient occupancy tax rate
City cleanup (flooding event)	Did not include because flooding does not impact roads in the study area	N/A
Emergency response/traffic control (flooding event)	Did not include because flooding does not impact roads in the study area	N/A

Task 2: Monetize Impacts

Our next task was to monetize the impacts (i.e., assign monetary values). Using the identified impacts for both 2050 (0.5 meters) and 2100 (2.0 meters), we compiled data that allowed us to estimate the value of the various assets.

We then compiled the no action scenario (baseline) tables for 2050 and 2100 following the risk assessment option. As stated in Table 9, we only created one table for the no action scenario because these baseline damages were the same for each action scenario. Thus, it would be redundant to create tables for each one. We also modified NOAA's Table 3.4 to fit the assessment years of 2050 and 2100, and included chronic inundation and bluff erosion hazards (Table 11). Because our baseline damages for coastal flooding were estimated from a 100-year storm event, we did not include other storm event types in this table. However, we do incorporate them when we estimate expected damages from annual storm probabilities (in the next chapter.)

Finally, we did not create NOAA's Table 3.6, which shows the combined monetized damages by storm type. Again, because we only had projected damages for a 100-year storm, we waited until the next chapter to incorporate storm probabilities that required interpolation of monetary damages from a 100-year storm at 2050 and 2100. Rather, we decided to only include the damages estimated from the vulnerability assessment in this chapter's tables. We conduct all of the interpolation in the next chapter. Furthermore, NOAA's Table 3.6 damages are the same damages shown in their average damages column in Table 4.2, which is used to compute the annual expected damages by storm type. Table 4.2 extends Table 3.6 and we found it redundant to create both.

Table 11: Monetized Damages by Hazard Type: Coastal Flooding
Selected Study Area Planning Zone 1, Carlsbad, CA

Storm Type	2050 Damages	2100 Damages
Coastal flooding - 100-year storm event	**Primary:** City structures and infrastructure: $0 Private residential/commercial structures: $1.1 million **Secondary:** City tax revenue loss: $100,000 Private business revenue loss: $1.0 million	**Primary:** City structures and infrastructure: $0 Private residential/commercial structures: $7.6 million **Secondary:** City tax revenue loss: $300,000 Private business revenue loss: $2.5 million

Note: Rounded to the nearest $100,000

Table 12: Monetized Damages by Hazard Type: Chronic Inundation and Bluff Erosion Selected Study Area Planning Zone 1, Carlsbad, CA

Hazard Type	Expected Damages Between 2050 and 2100
Chronic Inundation	**Primary:** Private residential/commercial structures (2100): $37.1 million **Secondary:** Beach tourism business revenue loss: $1,086.1 million Beach tourism city tax revenue loss: $56.4 million
Bluff Erosion	**Primary:** City transportation infrastructure (2050): $5.8 million City transportation infrastructure (2100): $24.5 million

Note: Rounded to the nearest $100,000.

Task 3: Estimate Costs of Implementing Adaptation Strategies

The final task in this section was estimating the implementation costs for the adaptation strategies and action scenarios. We collected data from local sources and other sea level rise studies to estimate the cost of the strategies (Table 13). We also researched the maintenance schedules and costs of each strategy. From these, we developed initial implementation (capital) costs and maintenance costs (Table 14). (Please see Appendix B for unit costs). We used the specifications provided by the city's adaptation plan.

Table 13: Methods for Valuing Cost to Implementation Adaptation Strategies, Selected Study Area, Planning Zone 1, Carlsbad, CA

Strategy	Method(s) for Valuing	Data Source(s)
Beach Sand Nourishment	Benefits transfer method to obtain cost per cubic yard.	SANDAG Regional Beach Sand Project; SANDAG Regional Beach Monitoring Program 2001; SANDAG Regional Beach Sand Retention Strategy 2001
Seawalls (Raise/Replace)	Generic infrastructure cost per linear foot	One-foot cap: EC Constructors 2016 Full replacement: TerraNova 2017
Revetments	Benefit transfer method of cost per linear foot from relevant studies	Replacement phase: NOAA 2005 Replacement cost: Port of San Diego Maintenance: NOAA 2005
Groins	Benefit transfer method of cost per linear foot from relevant studies	SANDAG Regional Beach Sand Retention Strategy 2001

Table 14: Estimated Costs to Implement Adaptation Strategies, Selected Study Area, Planning Zone 1, Carlsbad, CA

Action Scenario	Estimated Costs to Implement Strategies Between 2050 and 2100
Scenario 1	Beach Nourishment: $8.6 million Groins: $8.5 million
Scenario 2	Beach Nourishment: $12.9 million Sea walls and revetments: $28.4 million
Scenario 3	Beach Nourishment: $25.7 million

Note: Rounded to the nearest $100,000.

Del Mar

Applying the Method

Task 1: Identify Impacts

Like Carlsbad, we conducted Task 1 in this section in conjunction with Task 3 in the chapter, "Baseline Risk." That is, we identified primary and secondary impacts while assessing our geographically exposed areas. We assessed exposed infrastructure by overlaying the vulnerability assessment's significant flooding event (10-year storm) and extreme flooding event (100-year storm) GIS layer on the city's parcels and infrastructure using ArcMap. We developed a parcel inventory GIS layer that identified impacted parcels by significant or extreme event. To identify beach erosion impacts, we utilized the city's vulnerability assessment table that showed projected changes in beach width over time.

As previously mentioned, except for private residential and commercial/industrial property, and beaches, all of the other assets in our analysis were city-owned. We assessed primary impacts for the following asset categories, but as noted in Table 15 not all asset categories had impacts in the Del Mar study area:

- City property and structures
- City public infrastructure
- City transportation infrastructure
- Residential property
- Commercial and industrial property
- Beaches

We also assessed the following secondary impacts as well:

- Loss of beach tourism revenue to businesses

- Loss of beach tourism tax revenue to city
- City cleanup for flooding events
- Emergency response and/or traffic control for flooding events

To identify more specific primary impacts for both significant and extreme coastal flooding events, we developed an impacted parcels inventory for residential and non-residential properties. We updated the inventory with additional data, such as current market value of structures, number of stories, and square feet. Where relevant for multi-story condominium buildings, we identified ground floor units because we assumed flooding would not damage second floor units, or higher. This required us to view the building on Google Earth to determine the unit number ordering scheme and layout, i.e., equal or unequal number of units on each floor. Where we could not ascertain specific first floor units, we assumed the lowest numbered units were located on the ground floor. Additionally, we also visually inspected whether the flooding, "touched" the structure. We created a field with a “yes” or ‘no” tag to identify whether structure was impacted. It was crucial to use a map-based system to visually identity specific impacts.

We also overlaid the hazard GIS files, using both ArcMap and Google Earth, to identify potentially impacted city infrastructure, such as roads. However, per Del Mar Public Works staff, floods rarely impact city infrastructure because the city's topography is somewhat sloped and floodwaters tend to drain away quickly. We considered cleanup costs and road damage for extreme events based on historical data. Table 15 shows the list of primary and secondary impacts we identified and the data sources and methods used to estimate their monetary impacts.

Negative Impacts of Action Scenarios

Per the next step in this task, we considered additional positive or negative impacts that could result from the action scenarios. We relied upon on Del Mar’s Adaptation Plan and their description of action scenarios because we did not re-assess exposed infrastructure, as noted in the previous chapter. There were no perceived additional positive impacts for each action scenario. However, the following negative impacts were identified:

- Scenario 1a: Loss of tax revenue for removed structures starting in 2100.
- Scenario 1b: Loss of beach tourism business revenue and city tax revenue for loss of beach starting in 2070; loss of tax revenue for removed structures starting in 2100.
- Scenario 2: Loss of tax revenue for removed structures starting in 2040.

Table 15: Methods for Valuing Primary and Secondary Impacts in North Beach, Del Mar, CA

Impact Type (Significant and Extreme)	Method(s) for Valuing	Data Source(s)
Primary Impacts		
Residential property damages (flooding event)	USACE depth damage functions and locally developed parcel inventory	USACE depth damage functions; local assessor parcel data; RSMeans replacement costs
Commercial/industrial property damages (flooding event)	USACE depth damage functions and locally developed parcel inventory	USACE depth damage functions; local assessor parcel data; RSMeans commercial replacement costs
Commercial/industrial property damages (chronic inundation)	None - no expected damages	N/A
City property and structures damages (flooding event)	USACE depth damage functions and locally developed parcel inventory	USACE depth damage functions; local assessor parcel data; RSMeans commercial replacement costs
City public infrastructure damages (flooding event)	None - no estimated repairs needed based on historic events	City Department of Public Works
City transportation infrastructure damages (flooding event)	Significant - no expected damages Extreme - applied historical estimated damages from similar event	City Department of Public Works
City property and structures damages, public infrastructure damages, transportation infrastructure damages (chronic inundation)	None - no expected damages	N/A

Continued on the next page.

Impact Type (Significant and Extreme)	Method(s) for Valuing	Data Source(s)
Secondary Impacts		
Loss of business revenue due to loss of beach tourism loss (chronic inundation)	Area-based beach attendance model with benefits transfer	City vulnerability assessment projected beach width loss, beach area measurements using GIS, beach attendance from state, day use value from local study
Loss of city tax revenue due to loss of beach tourism loss (chronic inundation)	Area-based beach attendance model with benefits transfer day use value, fiscal model with local tax rates assuming distribution of lodging	City vulnerability assessment projected beach width loss, beach area measurements using GIS, beach attendance from state, day use value from local study; State of California Board of Equalization for sales tax rate; City of Del Mar Finance Department for Transient Occupancy Tax rate
Loss of city tax revenue due to business interruption (flooding event)	Applied midpoint of HAZUS-MH physical restoration time by FEMA occupancy class	HAZUS-MH for physical restoration time; State of California Board of Equalization for sales tax rate; City of Del Mar Finance Department for transient occupancy tax rate
City cleanup (flooding event)	City budgeted amount per event	City Department of Public Works
Emergency response/traffic control (flooding event)	None – Did not include because costs are included in their normal operating budget	City Department of Public Works

Task 2: Monetize Impacts

Our next task was to monetize the impacts, i.e., assign dollar values. Using the specific identified impacts for both the significant and extreme events, we compiled data that allowed us to estimate the value of the various assets.

Then, we compiled the no action scenario (baseline) tables for both the significant and extreme coastal flooding event, following the risk assessment option. As previously shown in Table 9, we only created one table for the no action scenario because these baseline damages were the same for each action scenario. We also adapted NOAA's Table 3.4 to show damages for the significant and extreme event instead of planning horizon years, and added another table to show expected chronic inundation damages from 2030 to 2100 (Table 16 and Table 17). We did not include other storm event types in Table 16 because we only calculated damages for the significant (10-year) and extreme (100-year).

Table 16: Monetized Damages by Hazard Type, per Coastal Flooding Event
North Beach Del Mar, CA

Hazard Type	Significant (Current 10-year) Expected Damages per Event	Extreme (Current 100-year) Expected Damages per Event
Coastal flooding	**Primary:** City structures and infrastructure: $200,000 Private residential/commercial structures: $1.3 million **Secondary:** City tax revenue loss: $300,000 Private business loss: $8.1 million	**Primary:** City structures and infrastructure: $1.7 million[1] Private residential/commercial structures: $46.7 million **Secondary:** City tax revenue loss: $400,000 Private business loss: $12.9 million

[1] Also includes infrastructure cleanup costs. Note: Rounded to the nearest $100,000.

Table 17: Monetized Damages by Hazard Type, 2030 - 2100
North Beach, Del Mar, CA

Hazard Type	Expected Damages Between 2030 and 2100
Chronic Inundation	**Primary:** None **Secondary:** Beach tourism business revenue loss: $2,227.5 million Beach tourism city tax revenue loss: $115.7 million

Note: Rounded to the nearest $100,000.

Finally, we did not create NOAA's Table 3.6, which shows the combined monetized damages by storm type. We did not have estimated damages for other current storm event types, e.g., 1-year or 2-year, because Del Mar's vulnerability assessment projected future damages by increasing the frequency of a current 10-year and 100-year storm event (described in the "Baseline Risks" chapter). Rather, we increased the probability of the current 10-year and 100-year storm events to project more damages resulting from sea level rise. These computations are shown in the next chapter in our table that is analogous to NOAA's Table 4.2, and used to compute the annual expected damages by storm type.

Task 3: Estimate Costs of Implementing Adaptation Strategies

The final task in this section was estimating the implementation costs for the adaptation strategies and action scenarios. We collected data from local sources and other sea level rise studies to estimate the cost of the strategies. Our methods for valuing and data sources are shown in Table 18. We also researched the maintenance schedules and costs of each strategy. From these, we developed initial implementation (capital) costs and maintenance costs (Table 19). (Please see Appendix B for unit costs). We used the specifications provided by Del Mar's Adaptation Plan.

Table 18: Methods for Valuing Cost to Implementation Adaptation Strategies, North Beach, Del Mar, CA

Strategy	Method(s) for Valuing	Data Source(s)
Beach Sand Nourishment	Benefits transfer method to obtain cost per cubic yard.	SANDAG Regional Beach Sand Project; SANDAG Regional Beach Monitoring Program 2001; SANDAG Regional Beach Sand Retention Strategy 2001
Seawalls (Raise/Replace)	Generic infrastructure cost per linear foot	One-foot cap: EC Constructors 2016 Full replacement: TerraNova 2017
Revetments	Benefit transfer method of cost per linear foot from relevant studies	Replacement phase: NOAA 2005 Replacement cost: Port of San Diego Maintenance: NOAA 2005
Groins	Benefit transfer method of cost per linear foot from relevant studies	SANDAG Regional Beach Sand Retention Strategy 2001
Elevate Structure	Generic construction cost and benefit transfer method of cost per square foot raised from relevant studies	Burrus Coastal Engineering, 2000; Army Corp of Engineers, 1990
Remove Structure	Generic construction cost per square foot of demolition; Generic acquisition cost based on current market conditions	Dependable Demolition, 2016; Building Journal 2016; Zillow.com

Table 19: Estimated Costs to Implement Adaptation Strategies, North Beach, Del Mar, CA

Action Scenario	Estimated Costs to Implement Strategies Between 2030 and 2100
Scenario 1a	Beach Nourishment: $14.3 million Groins: $8.5 million Raise structures: $16.2 million Remove structures: $711.2 million
Scenario 1b	Beach Nourishment: $17.9 million Sea walls and revetments: $52.1 million Raise structures: $16.2 million Remove structures: $711.2 million
Scenario 2	Beach Nourishment: $17.9 million Remove structures: $711.2 million

Note: Rounded to the nearest $100,000.

Baseline Primary and Secondary Impacts: Assumptions and Data Sources

This section describes how we valued the primary and secondary impacts in our baseline (the no action scenario) for each asset category. Specific unit values are found in Appendix B. It is important to note a single asset could have two different values, depending upon the hazard type. For example, the costs to a homeowner for a temporary flood would be different than that for chronic inundation. In the case of a temporary flooding, the homeowner would incur partial damage and/or cleanup costs to the structure, while in the case of chronic inundation; the homeowner would likely lose the entire structure and use of the property.

Importantly, we assumed current conditions for all of our estimates. That is, we estimated future property values and future beach attendance on today's figures. While we could potentially project population changes, other factors, such as future housing market prices would be difficult to accurately predict. Our analytical strategy emphasizes relative cost and benefits *across* scenarios rather than the cost and benefits of a particular scenario. Our decision to consistently apply the assumption of current conditions to the cost and benefit estimates allows for valid cross scenario comparison.

Residential Properties- Bluff Erosion and Inundation

In general, residential properties located in bluff erosion or inundation hazard zones are at risk for experiencing not only a loss of the structure, but also a loss of the land upon which it sits. When that land no longer exists (a collapsed bluff), or is no longer accessible (area is inundated with water), it is assumed the lost structure cannot be rebuilt. The resulting financial consequence is the total loss of investment to the homeowner and the loss of property tax revenue to the city.

Neither study area in Carlsbad or Del Mar was impacted by residential bluff erosion. However, there were residential properties impacted by chronic inundation in Carlsbad, (but not Del Mar). The

economic value of these residential properties was defined by their estimated real estate market value and Carlsbad property tax assessments.

For estimated market values of single-family homes and multi-family units, we collected data from two real estate websites: zillow.com and redfin.com. Zillow estimates ("Zestimates®") are calculated from public and user-submitted data, entered into Zillow's proprietary formula. Redfin calculates their estimates using comparable home listings and sales records culled from the "MLS," the multiple listing service used by real estate agents. We gathered the residential property values in late 2016 and early 2017, with the acknowledgement that real estate markets fluctuate with corresponding sales data. For any residential property (single-family, multi-family, or vacant lot) where a market value was not available, we identified a comparable property's estimate, calculated the price per square foot, and applied that rate to arrive at an estimate for the missing data.

For condominiums, individual units' market values were collected, but the value of associational common elements such as outer walls, lobbies, clubhouses, pool houses, gyms, etc., was not calculated.

There were no large scale, multi-unit rental apartments (5 or more units) in bluff hazard and inundation zones for Carlsbad, and those in Del Mar were only considered for flooding.

Similar to previous studies, we applied business rules to determine when the property was no longer inhabitable (Table 20). We visually checked ESRI imagery and Google Earth to conclude whether the hazard touched the structure or not. The business rules also accounted for the multiple hazard types, occurring at different times. For instance, if a parcel was predicted to be lost to chronic inundation in 2050, we did not also assume temporary flooding damages in 2050 or 2100. Additionally, when estimating land loss only, we approximated market value of the land by applying the assessor’s ratio of land value to total value.

Table 20: Business Rules, Chronic Inundation Impacts to Residential Properties Selected Study Area Planning Zone 1, Carlsbad

Circumstance	Business Rule
Parcel impacted by flooding and chronic inundation	If 10% or less of the parcel[6] is lost due to chronic inundation and the structure is hit by flooding, then the parcel is only assigned flooding damages. If more than 10% of the parcel is lost due to chronic inundation, then the parcel is assigned chronic inundation damages.
Partial parcel impacted by chronic inundation	If more than 10% but less than 50% of the parcel is impacted by chronic inundation AND the structure is not impacted, then 50% of the estimated land value (ratio of assessor land value to assessor total value multiplied by market value) If more than 50% of the parcel is impacted and/or the structure is impacted, then 100% of the estimated market value.
Parcel impacted by chronic inundation in 2050 and 2100	If the same geographic area within the parcel was impacted in both years, we only included the 2050 impacts once in 2050. We did not include again in 2100.

Residential Properties- Flooding

Flooding is temporary and is not assumed to damage the lands. However, it does damage the structure. We used USACE depth damage functions (USACE, 2003; USACE, 2006) and RSMeans replacement costs (RSMeans Online, 2016b) to estimate the damages associated with flooding. Depth-damage functions or curves predict the percentage of damage that is caused to a structure and its contents due to flooding. The estimated damage is a function of the depth of flooding. We estimated structure damages using the structure without basement curves (since very few if any homes in coastal areas have basements, but did not address loss of contents (personal property.) For small apartment buildings (4 units or fewer), we applied the values from single-family functions because these structures were similar. We estimated damages to larger apartment buildings (5 or more units) using commercial functions that approximate the structure type (USACE, 2006).

[6] Because these properties were on the beach, we assumed that the slightly smaller beachfront width would not impact property values.

Using depth-damage functions to approximate the amount of structure damage, we calculated the value of the damage to the property owner. We valued damages using replacement cost which is similar to the method used in previous studies (Nature Conservancy, 2016). Using the square footage of the structure, and the cost per square foot to build a comparable new home in the San Diego region from RS Means, we applied the percentage of structure damage to arrive at a monetary estimate of damages.

City-owned Open Space and Undeveloped Public Lands - Bluff Erosion and Chronic Inundation

There were no city-owned public lands (open space or undeveloped property) that were impacted by bluff erosion and inundation in Carlsbad or Del Mar.

City-owned Open Spaces and Undeveloped Public Lands- Flooding

Because flooding is temporary with water receding naturally, there are no estimated damages associated with flooding of open spaces or undeveloped lands.

Commercial and Industrial Properties- Bluff Erosion and Chronic Inundation

Within the Carlsbad and Del Mar study areas, there were no commercial or industrial properties in the bluff erosion or chronic inundation hazard zones.

Commercial and Industrial Properties- Flooding

Commercial and industrial properties affected by flooding have the added complication of business interruption or loss, which also have an economic value. But defining the economic values of hotels, motels, restaurants, retail businesses, service industries, and offices would require an in-depth financial analysis of the establishment and its real estate, making it prohibitively difficult to determine "what it's worth." Therefore, we utilized replacement costs for the structure alone, using depth-damage functions and RSMeans (RSMeans Online, 2016a). Using the commercial functions (USACE, 2006), we applied the same method as described in the residential flooding. There were commercial flooding impacts in Del Mar, but not in the Carlsbad study area.

City Transportation and Public Infrastructure - Bluff Erosion and Chronic Inundation

We overlaid flood area GIS files, using both ArcMap and Google Earth, to identify and measure impacted city infrastructure. In Carlsbad, Carlsbad Boulevard, the street-adjacent beach pathway, and beach access stairways were the only impacted infrastructure that fell into the bluff erosion area. None fell into the chronic inundation area. We estimated the road repair costs of Carlsbad Boulevard (2050) between Pine Avenue and Tamarack Avenue by using costs per linear foot estimates from the city's Public Works Department. For the Carlsbad Boulevard replacement costs, we gathered the generic cost per linear foot of constructing a similar road from their 2016-17 Capital Improvement Program budget. Because the damages to the beach path and access stairways would most likely result in substantial repairs or full replacement, we valued both their 2050 and 2100 damages using replacement costs. For the top pathway, we obtained the historical estimate of constructing that actual pathway between Pine and Cherry Avenues in 1989, and inflated to current dollars. We applied this estimate to that same section, and used estimates for a similar sidewalk for the segment between Pine and Tamarack Avenues. For the stairways, we applied an estimate from a local construction company that specializes in this type

of build. We assumed three stairways would be replaced in 2050 and five would be replaced in 2100. We also applied a factor 1.27, computed from a similar Capital Improvement Program project, to account for any additional study, design, and environmental cost to the city. Del Mar did not have any impacts.

City Transportation and Public Infrastructure - Flooding

No roads in the Carlsbad study area were affected by flooding. Per Del Mar Public Works staff, their roads typically require cleanup only, and rarely require repair after large storm events. So, we assumed that Del Mar only has cleanup costs after significant events, but in the case of extreme events, may have a road repair similar to that caused by a storm event in January 2016. Estimates were gathered from their Public Works Department.

Beach Visitor Revenue

The loss of beach was valued based on the revenue generated from visitors. These data were also used to calculate lost city tax revenue due to the shoreline eroding. Ecological value of beach land was not calculated.

CoSMoS v3.0 provided projections of shoreline loss that were incorporated into each city's vulnerability assessment. For the City of Carlsbad, we were provided with GIS layers showing the projected change in shoreline for 2050 and 2100.[7] The Del Mar Assessment provided a table with projected width change over time (Table 21). We used these values to estimate Del Mar's beach loss for the high sea level rise scenario. For both cities, we assumed an annual linear loss of beach for missing years, which followed Del Mar's pattern for the existing years until it reached zero (2010 to 2060). We applied linear interpolation between the specified years (2010, 2020, 2030, etc.), with 2015 serving as the base at the 2010 value.

We calculated the loss of beach tourism revenue using an area-based model (Engel et al., 2015, p. A-41). The area-based model calculated an attendance density factor based on current attendance and beach area. This factor was multiplied by annual projected beach loss to estimate the loss of beach visitors each year. Then, the annual loss of visitors was multiplied by a day use value to project loss of beach revenue. We assumed the day use value did not change as the beach narrowed. In actuality, the day use value may decrease as the beach width narrows because visitors prefer wider beaches (Engel et al., 2015), but we did not employ an amenity-based model that changes the day use value as the function of beach width. While an amenity-based model was considered, such as the USACE's Coastal Sediment Benefits Analysis Tool (CSBAT) model, we decided to pursue a more parsimonious approach. Our primary rationale for this decision was that we did not have the inputs needed for the CSBAT model. We did not believe approximating inputs would gain us any benefit over the simpler area-based model. We also did not have any data to adjust the day use value per changes in beach width. To account for this, we varied the day use values in sensitivity analysis to check the robustness of our results.

[7] Carlsbad's Vulnerability Assessment calculated that there were 6 acres of beaches exposed to erosion in 2050 and 66 acres exposed in 2100. However, they still deemed these areas able to "provide recreation and storm protection" benefits. Therefore, we used their chronic inundation shoreline GIS layers to estimate beach loss impacts.

Table 21: Projected Beach Widths over Time (High SLR), Del Mar, CA

Year	Projected Beach Width (ft.)
2010	95
2020	69
2030	53
2040	34
2050	12
2060	0
2070	0
2080	0
2090	0
2100	0

Source: *Coastal Hazards, Vulnerability, and Risk Assessment* draft, ESA 2016.

For the area-based model, we used current annual beach attendance data compiled by the California State Parks and United States Lifesaving Association (USLA), and the day use value from *The Economic and Fiscal Impacts of Carlsbad Beaches: A Survey and Estimate of Attendance* (King, 2005). As we did not conduct our own beach surveys, we deemed this value most relevant. The 2005 value was inflated to 2015 values using the CPI. The current areas of both cities' beaches were calculated using GIS and Google Earth.[8] From this, we calculated an attendance density factor that was applied to the estimated loss of beach associated with erosion or chronic inundation.

Since a guiding assumption throughout this study was to assume current conditions, we applied the 2015 attendance as our base for all years. While we concede that the San Diego region's population is forecasted to grow (SANDAG, 2013), we preferred to remain consistent in our guiding assumption. However, as noted earlier, baseline assumptions were applied equally to each action scenario; thus, any underestimation resulting from this assumption would not result in any change to baseline comparisons. Beach attendance could potentially affect the negative impact values of Carlsbad's Scenario 2 and Del Mar's Scenario 1b. Because of this, and that other studies have noted that attendance counts are frequently overestimated (King & McGregor, 2012; Engel et al., 2015), we tested the sensitivity of our cost-benefit model results to Scenario 2's and Scenario 1b's negative impacts values.

[8] While we recognize that beach width varies seasonally, and depending on other conditions, we deemed this the best option since collecting precise measurements fell outside of the scope and schedule of this project. Because these approximations are applied consistently to each action scenario's base model and sensitivity analysis tested this negative impact of Scenarios 2 (Carlsbad) and 1b (Del Mar), potentially imprecise beach measurements do not impact the study's conclusions.

Loss of beach tourism city tax revenue due to chronic inundation

Included in fiscal analysis description.

City road cleanup for flooding events

No flooding was projected to impact roads in the Carlsbad study area. In Del Mar, the city's Department of Public Works provided an estimate of the cost to cleanup storm events, which is included in their normal operating budget as an additional expected seasonal cost.

Emergency response and/or traffic control for flooding events

No flooding was projected for impact roads in the Carlsbad study area. In Del Mar, the Department of Public Works is responsible for expenses related to road closures, which is part of their normal operating budget. Since no additional costs are incurred, we did not include any.

Fiscal Analysis of City Tax Revenue Lost: Assumptions and Data Sources

Negative impacts from coastal flooding and inundation to existing development and services brings with it a decrease in local government revenues through the loss of taxes and fees, and consequently, a potential corresponding decrease in demand for government services and infrastructure. This fiscal impact analysis describes an approach to analysis of these decreased revenues. As the study areas are small, relative to their respective jurisdiction, we did not evaluate fiscal impacts to public services.

This analysis focuses on impacts to the city's General Funds, which represent the portion of municipal and district budgets that help finance the ongoing provision of basic services. To pay for these services, the city's General Fund and operating funds are dependent on discretionary revenue sources such as property taxes, sales taxes, transient occupancy taxes (TOT), and various local taxes, as well as revenues allocated by the State of California and the federal government[9].

Annually Recurring General Fund Revenues

The properties and business operations in the study areas generate revenue for Carlsbad and Del Mar. This analysis calculates the loss of sales and use tax revenue, property tax revenue, TOT revenue, and vehicle licensing fee in-lieu of property tax revenue. These four tax sources account for over 90 percent of all tax revenue for the cities. While the cities also receive revenue from the sales tax in lieu of property tax, franchise tax, business license tax, and a tax on real property transfer, they are not

[9] Removal of structures results in more than the loss of property tax, sales tax, TOT tax, and ILVLF revenues (Vehicle owners pay the fee on an annual basis, in lieu of paying property taxes on vehicle ownership). The study does not make assumptions regarding future sales turnover of properties and therefore does not attempt to estimate property transfer taxes. As it is unknown whether displaced residents or businesses will relocate in the affected jurisdiction, this study did not evaluate fiscal impacts from changes to the service population. Finally, cities receive various other revenues, including franchise, license, and permit revenues; fees, fines, and forfeitures; and penalties and cost delinquency taxes; and other miscellaneous revenues. The intent of this analysis was to focus on the capturing that largest tax revenue generators.

calculated herein. As the structures to be removed occur at the end of the study period (2100), an estimate of turnover rates and loss of this revenue was not estimated.

It was assumed that structures affected by long-term inundation would not be rebuilt upon removal, leading to an annual loss of property tax, vehicle licensing fee in-lieu of property tax revenue, sales tax, and/or TOT revenue.

Carlsbad

The Carlsbad Assessment did not reveal long-term losses to tax revenue-generating properties. Therefore, we only estimated the fiscal impacts of temporary losses to services resulting from increased coastal flooding and chronic inundation of the beach in the study area.

Specifically, the analysis focused on the loss of sales and use tax (from the purchase of goods) and TOT revenue from hotel/motel expenditures in the selected study area, Planning Zone 1. Our analysis specifically addresses revenue impact to the city's General Fund resulting from:

- Potential interruptions of business operations caused by short- to medium-term coastal flooding
- Loss of city tax revenue associated with loss of beach

Del Mar

Scenarios 1a and 1b in the Del Mar Adaptation Plan recommend removal of the first row of structures directly adjacent to the beach, starting in 2100. Scenario 2 recommends removal of homes starting in 2040.

We estimated the fiscal impacts of temporary and/or long-term loss of real property and associated services resulting from increased coastal flooding and chronic inundation of North Beach. The analysis focused on the loss of tax revenue generators, specifically property tax, sales and use tax (from the purchase of goods), TOT revenue from hotel/motel expenditures, and vehicle license in-lieu fees. Our analysis specifically addresses revenue impact to the city's General Fund resulting from:

- Potential interruptions of business operations caused by short- to medium-term coastal flooding
- Loss of city tax revenue associated with loss of beach
- The removal of the first row of homes and commercial establishments directly adjacent to the beach

Loss of Beach Tourism City Tax Revenue Due to Chronic Inundation

For Carlsbad and Del Mar, we calculated the loss of beach tourism revenue from chronic inundation using an area-based model. Total visitor spending was then distributed among lodging, spending subject to sales tax, or spending not subject to sales tax (King, 2005). Lodging expenditures were then multiplied against the local TOT rate. Expenditures subject to sales tax were multiplied against the local sales tax rate.

Temporary Business Interruption

Carlsbad

Intermittent storm events may temporarily interrupt business operations.

2050 100-Year Storm Event

Following FEMA Hazus-MH methodology (FEMA, 2016), it is assumed that a temporary loss from a 100-year storm event in 2050 would require 10 months of physical restoration time.

2100 100-Year Storm Event

Following FEMA Hazus-MH methodology (FEMA, 2016), it is assumed that a temporary loss from a 100-year storm event in 2100 would require 25 months of physical restoration time.

Del Mar

Significant and extreme storm events may temporarily interrupt business operations. Because we did not have high-water depths data, we used Table 2 of the Del Mar Adaptation Plan and the high 100 percent risk value for significant and extreme events to select corresponding levels of sea level rise.

Significant Event

Following FEMA Hazus-MH methodology (FEMA, 2016), it is assumed that a temporary loss from a significant event would require 10 months of physical restoration time.

Extreme Event

Following FEMA Hazus-MH methodology (FEMA, 2016), it is assumed that a temporary loss from an extreme event would require 16 months of physical restoration time.

Sales and Use Tax

Carlsbad

Carlsbad receives sales tax revenues from purchases made by visitors to the local retail establishments. According to the State Board of Equalization (2016a), the city receives sales tax revenues equal to 0.95 percent of the local taxable expenditures that occur within city limits. Although the Bradley-Burns Local Sales and Use Tax (California State Board of Equalization, 2016b) specifies that one percent of the total sales tax is distributed to the local jurisdiction, cities within many California counties, including San Diego County, share five percent of sales tax revenues with the county government to cover administrative and other costs, retaining 95 percent of the one percent sales tax, or 0.95 percent of total taxable sales, for themselves.

There are no commercial establishments directly affected by coastal flooding and/or inundation.

Del Mar

Like Carlsbad, Del Mar would receive sales tax revenues from purchases made by visitors to the local retail establishments. According to the State Board of Equalization (2016a), the city receives sales tax revenues equal to 0.95 percent of the local taxable expenditures that occur within the city limits.

There are two commercial restaurants in North Beach. Under California law, foods eaten on the premise of an eatery are taxed, while the same item taken "to-go" is not. Estimates for sales tax revenue for the restaurants assume all food is consumed on the premises, and therefore subject to sales tax.

Transient Occupancy Tax

The transient occupancy tax (hotel, motel, campground, or bed tax) is authorized under State Revenue and Taxation Code, Section 7280 as an additional source of non-property tax revenue to local government.

Carlsbad

Carlsbad levies a transient occupancy tax at a rate of 10 percent of room rental revenue. The study area includes one 48 -room hotel, the Beach Terrace Inn.

Our research indicates that non-holiday asking rates at the Beach Terrace Inn are approximately $285 per night for a standard room. We have projected transient occupancy tax assuming a 65 percent occupancy rate.

Del Mar

The transient occupancy tax (hotel, motel, campground, or bed tax) is authorized under State Revenue and Taxation Code Section 7280 as an additional source of non-property tax revenue to local government. Del Mar levies a transient occupancy tax at a rate of 12.5 percent of room rental revenue. North Beach includes one 43-room limited service motel, the Del Mar Motel.

Our research indicates that non-holiday asking rates at the Del Mar Motel range from approximately $169 to $209 per night for a standard room. We have projected transient occupancy tax assuming a 65 percent occupancy rate and an average daily rate (ADR) of $189.

Property Taxes

Del Mar

Property taxes are a key source of Del Mar's General Fund revenues, as well as the primary revenue source for a number of special districts. Property taxes are applicable to real property, defined as land and the buildings attached to it, and certain types of personal property, including furniture, fixtures, and equipment (FF&E) owned by businesses.[10] Property in California is subject to a base 1.0 percent property tax rate, which is shared among various local jurisdictions including the county, city, and special districts, as well as the state, which is allocated a portion of funds known as Education Revenue Augmentation Funds (ERAF). The County of San Diego Controller's Office is the responsible agency for calculation of property tax assessment and corresponding allocation of revenues. Shifting of ERAF funds is performed by the county and therefore not recalculated here.

[10] All San Diego County businesses with personal property worth $100,000 or more are required to file an annual personal property tax statement.

In addition to the base 1.0 percent property tax rate, North Beach is subject to supplemental property taxes to pay for bonds issued for parks and recreation, school district, and community college district purposes. Supplemental property taxes are restricted for specific uses and apply only to real property, and not to business personal property. This analysis focuses on the city's General Fund revenues and does not calculate supplemental taxes for non-discretionary services.

The potential loss of tax revenue generated by at-risk Del Mar residential coastal property represents an accurate and meaningful way to quantify the tangible costs of increased coastal flooding caused by sea level rise. Property taxes comprise an average of about 34 percent of all revenue collected by the City (City of Del Mar, 2015). North Beach is located in Tax Rate Area (TRA) 011001 and is allocated 14.78 percent of the 1.0 percent property tax revenue for 2016-2017 (San Diego County, 2016-2017). For example, the loss of a coastal property in TRA 011001 assessed at $1 million; therefore, would result in an annual loss of $1,478 (2015$) in property tax revenue to the city.

Property Tax In-Lieu of Vehicle License Fees

Beginning in FY 2005-2006, the State ceased to provide "backfill" funds to counties and cities in the form of a Motor Vehicle In-Lieu Fees (ILVLF). As a result of the complicated financial restructuring enacted as part of the State's budget balancing process, counties and cities now receive revenues from the State in the form of what is known as property tax in-lieu of vehicle license fees, or ILVLF. This state-funded revenue source is tied to a city's total assessed valuation. In FY 2005-2006, former VLF revenues were swapped for ILVLF revenues, which set the local jurisdiction's ILVLF "base." The base increases each year thereafter in proportion to the increase in total assessed valuation within the jurisdiction. For example, if total assessed valuation increases by five percent from one year to the next, the ILVLF base and resulting revenues would increase by five percent.

In order to calculate the incremental decrease in ILVLF revenues that would result from the removal of the first row of residential structures, we first determined the total assessed value within the city, and the city's current ILVLF revenues. The analysis then determined the percentage by which the removal of structures would decrease the city's assessed valuation, and applied the percentage to the current ILVLF revenues in order to determine the incremental amount of ILVLF attributable to the removal of structures.

The adaptation scenarios 1a, 1b, and 2 would generate a 3.4 percent decrease in the city's total assessed value, which would result in adaptation scenario-generated ILVLF revenue of an equivalent reduction.

Costs of Implementing Adaptation Strategies: Assumptions and Data Sources

This study evaluated three categories of strategies: natural or engineered protection (beach nourishment, or armoring with structures), accommodation (raise structures), and managed retreat (remove structures). The purpose of armoring with structures is to protect buildings and infrastructure, not beaches (Kraus and McDougal, 1996). Groins and beach nourishment are the common methods by which eroding beaches are expanded, both of which are fundamentally different than armoring.

Armoring is constructed to halt erosion of cliffs, bluffs, and other lands that have buildings on or behind them, or to protect a building built on the backshore (above the high tide line) (NOAA, 2005).

We collected existing construction costs for selected adaptation strategies. The unit costs in 2015 dollars for action scenarios are shown in Appendix B. We developed cost estimates for the action scenarios and applied them temporally as indicated by the respective jurisdictional schedules. The project life for the economic analysis depends on the adaptation strategy employed.

Beach Sand Nourishment

Beach sand nourishment maintains beach widths, protecting environmental and recreational resources. We assumed scheduled beach sand nourishment and not opportunistic nourishment. We assumed the beach sand size is equivalent to the size applied during historical beach nourishment in the same area or close by, but do not make assumptions regarding location of sand sources or potential for future scarcity. While previous studies escalate the cost of beach sand over time to represent progressive scarcity for beach nourishment, this study assumes constant price per cubic yard for future replenishments. We estimated the sand cost and required sand volume from the following sources:

- 2012 Regional Beach Sand Project, average cost per cubic yard of sand (SANDAG, 2016b)
- 2001 Regional Beach Sand Program nourishment, North Beach sand volume (SANDAG, 2002)
- 2015 Regional Beach Sand Program nourishment, North Carlsbad sand volume (SANDAG, 2016c)
- 2001 Regional Beach Retention Strategy, subsequent nourishment with groins (SANDAG, 2001)

Carlsbad

For all Carlsbad action scenarios, we assumed beach nourishment would begin in 2050, with subsequent replenishments occurring once every ten years. For Scenario 1 beach nourishment (2050-2070), we assume nourishments subsequent to groin construction would be one half the volume of the initial nourishment. For Scenarios 2 and 3, we assumed all nourishments will be equal to the initial nourishment value.

Del Mar

For all Del Mar action scenarios, we assumed beach nourishment would begin in 2030, with subsequent replenishments occurring once every ten years. For Scenario 1a, we assume nourishments subsequent to groin construction would be one half of the initial nourishment. For Scenario 1b and 2, we assumed all nourishments will be equal to the initial nourishment value.

Revetment

The Del Mar Adaptation Plan states: “Raising and improving revetments provides an adaptation measure to offset the increase in flood risk with sea-level rise. This could be accomplished by adding a new section of rock to the top of the existing revetment; however, doing so may require significant modifications or a rebuilding of the wall.” A literature review revealed two options for valuing the cost of revetments: ongoing maintenance or full replacement. The former assumes annual maintenance (NOAA, 2005). The latter assumes a functional life of the revetment with consideration of whether or not there is beach in front of the structure.

Maintenance costs are estimated to range from 2 to 15 percent annually. As we did not have the data to support the selection of an annual maintenance value, we opted to select the functional life to value the revetment adaptation strategy. The functional life of a revetment is assumed to be 30 years with beach in front of it. The functional life of the revetment is assumed to last for 20 years after the beach is lost (Nature Conservancy, 2016). The repair cost after failure is assumed to equal the cost of new construction.

We did not obtain precise information for the amount of materials in the existing revetments. We assumed future revetments would be of similar size (NOAA, 2005). Length of existing revetments was calculated using Google Earth and imagery in ArcGIS.

Carlsbad

In the case of Carlsbad's Scenario 2, we assumed the first revetment replacement would occur in 2050 with subsequent replacement in 2080 and 2100. We then assumed revetment maintenance ever ten years following reconstruction of the revetment resulting in maintenance costs at 2060, 2070, and 2090.

Del Mar

In the case of Del Mar's Scenario 1b, we assumed the first replacement would occur in 2040 with subsequent replacement in 2070 and 2090. We then assumed revetment maintenance ever ten years following reconstruction of the revetment resulting in maintenance costs at 2050, 2060, 2080, and 2100.

Seawalls

Existing seawall lengths were calculated using Google Earth and aerial images in ArcGIS. The Del Mar Adaptation Plan states for seawalls: "Raising and improving walls provides an adaptation measure to offset the increase in flood risk with sea-level rise. This could be accomplished by adding a new section of sea wall to the top of the existing wall; however, doing so may require significant modifications or a rebuilding of the wall." Based on a conversation with coastal engineers and specialized construction firms, increasing the height of an existing seawall is far less common than rebuilding. Therefore, we opted to select rebuilding of walls as the adaptation measure. Following direction from previous studies and reports, we assumed that a seawall will last for approximately 30 years before needing replacement (NOAA, 2005; Seachange Consulting, 2011; Nature Conservancy, 2016).

Carlsbad

In the case of Carlsbad's Scenario 2, we assumed the first replacement would occur in 2050 with subsequent replacement in 2080.

Del Mar

In the case of Del Mar's Scenario 1b, we assumed the first replacement would occur in 2040 with subsequent replacement in 2070 and 2100.

Groins

For both Carlsbad and Del Mar, we assumed installation of two groins based on the SANDAG *Regional Beach Sand Retention Strategy* (2001). In addition, we assumed groin lengths of 400 feet consistent with existing groins in Carlsbad and another San Diego County city, Imperial Beach, as viewed through aerial images.

Generally, the most common type of material used for terminal groin structures is rock. Rock (or rubble mound) groins usually have a core of smaller, graded stone with an armor layer of larger stones overlying the core. We assumed a rock groin would be selected as the preferred choice for this adaptation strategy.

We assumed similar structure type as described in the SANDAG *Regional Beach Sand Retention Strategy* (2001) and therefore equivalent costs per linear foot scaled for two 400-foot groins. The cost per linear foot includes additional fees for contingency, design and engineering, and project management. In addition to installation, the groins will require beach sand pre-fill. To account for this volume, we assumed the required beach sand pre-fill for each groin is the same *volume per linear foot of the groin length* as defined by SANDAG (2001).

Raise Structures (Del Mar Only)

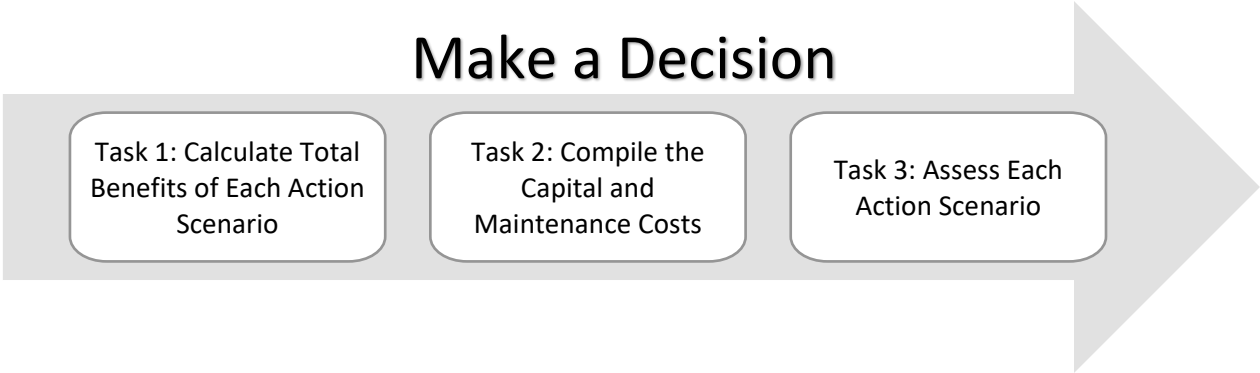
The Del Mar Adaptation Plan did not identify specific buildings to be raised, therefore, we assumed all buildings in significant or extreme coastal flooding areas would be affected. We also assumed the price per square foot to raise a structure applies only to the footprint of the structure. For example, at $25 per square foot to raise a structure, a 2,000 square foot single-story house would cost $50,000. However, at the same raising cost, a 2,000 square feet *two-story* structure with a 1,000 square feet ground floor would cost $25,000 reflecting only the structural footprint area.

We assumed an average cost to raise a structure at approximately $44 per square foot. This value represents the midpoint of estimated costs between raising foundations on pilings and raising slab structures (FEMA, 1998; Burrus, Dumas, & Graham, 2001).

Remove Structures (Del Mar Only)

As stated in the Del Mar Adaptation Plan, “With greater than around 3 feet of sea-level rise, the first seaward row of buildings and homes would likely need to be removed.” Therefore, we evaluated the cost of acquiring, demolishing and removing of the first seaward row of buildings. Acquisition costs were based on current market value using Zillow.com, and demolition costs were assumed per square foot of structure based on previous studies.

Make a Decision: Results



With the exception of Task 1, we followed the same methodology for both Carlsbad and Del Mar (Table 22). Therefore, this chapter reports on the application of the method for both cities together, with separate tables for each.

NOAA Methodology Adjustments

Table 22: Make a Decision: Adjustments to NOAA Methodology by Task and City

Make a Decision	Carlsbad Adaptations	Del Mar Adaptations
Task 1: Calculate total benefits of each action scenario	Created one table for no action scenario showing expected damages and annual expected losses. Did not create for each action scenario because the baseline model was the same for all. Did not have modeled (monetized) damages for all storm types. Interpolated average damages for each 5-yr. period and storm type from the benchmarked 100-yr. 2050 and 2100 average damages, rather than follow their formulas.	Created one table for no action scenario showing expected damages and annual expected losses. Did not create for each action scenario because the baseline model was the same for all. Only included current 10-year and 100-year storm events and increased probability of event (frequency) to represent an increase in damages over time, per city's vulnerability assessment.
Task 2: Calculate the capital and maintenance costs	None	None
Task 3: Assess each action scenario	None	None

Carlsbad and Del Mar

Applying the Method

Task 1: Calculate Total Benefits of Each Action Scenario

Task 1 calculates the total benefits of each action section by calculating baseline losses that are then considered damages prevented. Since we followed the risk assessment option throughout our analyses, we estimated these benefits or damages prevented by computing expected annual damages that incorporate the probability of storm events. We also included losses from bluff erosion (Carlsbad only) and chronic inundation as part of our damages prevented. Potential negative impacts of each action scenario were considered in this task as well.

For Carlsbad, we re-created NOAA's Table 4.2, which showed the annual estimated losses due to coastal flooding. We only calculated one table for the no action scenario, since it was the baseline that applied to all action scenarios as discussed in detail in the previous chapter. This table shows estimates of average damages due to the coastal flooding for each storm type (100-yr., 50-yr., 10-yr., 2-yr., and 1-yr.).

We estimated averages differently than NOAA's formulas (Equations 4.2 and 4.3) because we only had modeled damages for a 100-year storm at 2050 (0.5 meter) and 2100 (2.0) meter. Instead, we used the high water event table (Table 6 in "Baseline Risk" chapter) to interpolate average damages values for intermediate 5-year periods and all storm types. To interpolate, we multiplied the ratio of the difference between the relevant year's and the 2050 base year's high water level (numerator) AND the difference between the 2100 and 2050 high-water level (denominator) to the difference between our known expected 2100 and 2050 average damages. Then, we followed NOAA Equation 4.4 to estimate the expected damages. That is, we multiplied the average damages by the storm type probability. For example, the averages damage in Carlsbad for a 100-yr storm in 2080 is $6.56 million; we multiplied this value by 0.01 to get expected damages of $0.7 million. Table 23 shows the results of our estimation. Finally, again following NOAA, we assumed a linear change between the 5-year periods and interpolated annual data.

For Del Mar, we also calculated a table similar to NOAA Table 4.2 that estimated coastal flooding damages for today's extreme (100-year) and significant (10-year) storm events, and how those damages would increase over time due to the increased frequency of similar storms. In Table 24, we adapted NOAA's table by adding several columns to represent probability changes over time. Then, we multiplied those probabilities by average damages to get expected damages for each timeframe. We obtained those increased probabilities from the city's vulnerability assessment. Like Carlsbad, we only calculated one table for the no action scenario, since it was the baseline that applied to all action scenarios.

Next, we calculated the expected annual coastal flooding losses between 2030 and 2100. Again, following NOAA's methodology, we assumed a linear change between the select years (2030, 2050, 2070, and 2100) and interpolated the annual data.

Table 23: Annual Loss for Select Years, Coastal Flooding
Selected Study Area Planning Zone 1, Carlsbad, CA

		2050		2060		2070		2080		2090		2100	
Storm Type	**Annual Proba-bility**	**Ave. Damage ($million)**	**Expected Damage ($million)**	**Ave. Damage ($million)**	**Expected Damage ($million)**	**Ave. Damage ($million)**	**Expected Damage ($million)**	**Ave. Damage ($million)**	**Expected Damage ($million)**	**Ave. Damage ($million)**	**Expected Damage ($million)**	**Ave. Damage ($million)**	**Expected Damage ($million)**
100-year	0.01	$2.18	$0.02	$3.61	$0.04	$4.98	$0.05	$6.56	$0.07	$8.33	$0.08	$10.37	$0.10
50-year	0.02	$2.14	$0.04	$3.56	$0.07	$4.93	$0.10	$6.50	$0.13	$8.28	$0.17	$10.32	$0.21
10-year	0.1	$1.86	$0.19	$3.28	$0.33	$4.66	$0.47	$6.23	$0.62	$8.00	$0.80	$10.05	$1.01
2-year	0.5	$1.43	$0.71	$2.85	$1.42	$4.22	$2.11	$5.79	$2.90	$7.57	$3.78	$9.61	$4.81
1-year	1	$0.72	$0.72	$2.14	$2.14	$3.51	$3.51	$5.08	$5.08	$6.86	$6.86	$8.90	$8.90
Expected Annual Loss			$1.68		$4.00		$6.23		$8.80		$11.69		$15.03

Table 24: Annual Loss for Select Years, Coastal Flooding
North Beach, Del Mar, CA

	2030			2050			2070			2100		
Storm Type (current)	**Annual Probability in 2030**	**Ave. Damage ($million)**	**Expected Damage ($million)**	**Annual Probability in 2050**	**Ave. Damage ($million)**	**Expected Damage ($million)**	**Annual Probability in 2070**	**Ave. Damage ($million)**	**Expected Damage ($million)**	**Annual Probability in 2100**	**Ave. Damage ($million)**	**Expected Damage ($million)**
Extreme (Current 100-yr.)	0.05	$61.8	$3.1	0.15	$61.8	$9.3	0.5	$61.8	$30.9	1	$61.8	$61.8
Significant (Current 10-yr.)	0.5	$9.9	$4.9	1	$9.9	$9.9	1	$9.9	$9.9	1	$9.9	$9.9
Expected Annual Loss			$8.0			$19.1			$40.8			$71.6

For both cities, we then combined these annual loss estimates with the expected annual damages from chronic inundation and bluff erosion where applicable, and calculated the total annual benefits by action scenario. To do this, we followed NOAA's Equation 4.5 (Figure 14). We started with the baseline no action scenario damage at year *N*. We also incorporated our protection factor and assumed that each adaptation action scenario would prevent 100 percent of the potential damages in the no action scenario, meaning each action scenario received 100 percent of the total benefit. (We varied this assumption in sensitivity analysis.) Then, we subtracted the negative impacts for each action scenario (action scenario damages at year *N*). The negative impacts for each city are shown below. Because we did not have any additional positive impacts, we did not add positive action scenario benefits at year *N*. We discounted each year's benefits to get the present value. We applied a one percent discount rate as used in similar studies (Nature Conservancy, 2016). Finally, we summed all the years to get the Net Present Value (NPV) of the total benefits for each action scenario (Table 25 and Table 26).

Carlsbad Negative Impacts by Action Scenario:

- Scenario 1: None
- Scenario 2: Loss of beach tourism business revenue and city tax revenue for loss of beach starting in 2070
- Scenario 3: None

Del Mar Negative Impacts by Action Scenario:

- Scenario 1a: Loss of tax revenue for removed structures starting in 2100.
- Scenario 1b: Loss of beach tourism business revenue and city tax revenue for loss of beach starting in 2070; loss of tax revenue for removed structures starting in 2100.
- Scenario 2: Loss of tax revenue for removed structures starting in 2040.

What does it mean to discount future dollars?

In cost benefit studies, the monetary value of future costs and benefits are typically *discounted* to *present value*. This is because a future dollar is less valuable than a current dollar due. The ability to earn interest on current dollars, and inflation diminishing future buying power are just two reasons for future dollars being less valuable.

As demonstrated in the "Sensitivity Analysis" chapter, thoughtful consideration should be given to choosing a discount rate. The results could vary depending upon your assumption. Please see page 41 of *What Will Adaptation Cost? An Economic Framework for Coastal Community Infrastructure* (NOAA, 2013) for resources for choosing a discount rate.

Because this study began in early 2016, we used 2015 as our base year.

Figure 14: NOAA Total Benefits Equation (Adapted Equation 4.5)

$$Ben_{TN} = IC_{NA\text{-}N} - IC_{AN} + Ben_{AN}$$

Where:

Ben_{TN} = total benefits at year *N*

$IC_{NA\text{-}N}$ = baseline no action scenario damage at year *N*

IC_{AN} = action scenario negative impacts at year *N*

Ben_{AN} = action scenario positive impacts at year *N*

Carlsbad example (Scenario 2 at year 2080, $million):
$34.8 = $35.7-$0.9 + $0.0

Del Mar example (Scenario 1b at year 2080, $million):

$74.9 = $88.2 - $13.3 + $0.0

Source: Adapted Equation 4.5. *What Will Adaptation Cost? An Economic Framework for Coastal Community Infrastructure*, NOAA, 2013,

Table 25: Net Present Value of Total Benefits by Action Scenario
Selected Study Area Planning Zone 1, Carlsbad, CA

	NPV of Total Benefits ($million)
Scenario 1	$817.7
Scenario 2	$722.6
Scenario 3	$817.7

Table 26: Net Present Value of Total Benefits by Action Scenario
North Beach Del Mar, CA

	NPV of Total Benefits ($million)
Scenario 1a	$2,843.2
Scenario 1b	$2,601.2
Scenario 2	$2,805.2

Task 2: Compile the Capital and Maintenance Costs

Using each city's timeline for implementing their adaptation strategies, previously shown in

Figure 8 through Figure 13, we calculated the capital and maintenance cost for each action scenario.

Table 27 and Table 28 show the costs for implementing each action scenario. Similar to NOAA's Table 4.5, we combined the capital and maintenance costs to arrive at a total cost. Then, we calculated the present value (PV) of action scenario, using the same discount rate applied to our benefits (1% percent). Finally, we summed the present values for each decade to get the NPV for each action scenario.

Table 27: Net Present Value of Total Costs by Action Scenario
Selected Study Area Planning Zone 1, Carlsbad, CA

Action Scenario	Capital and Maintenance Costs Combined						
	Total ($million)	**2050 ($million)**	**2060 ($million)**	**2070 ($million)**	**2080 ($million)**	**2090 ($million)**	**2100 ($million)**
Scenario 1 - Total Costs	$17.0	$11.1	$2.1	$2.1	$0.8	$0.0	$0.8
PV of Total Costs	$11.2	$7.8	$1.4	$1.2	$0.4	$0.0	$0.4
NPV	**$11.2**						
Scenario 2 - Total Costs	$41.3	$18.4	$4.3	$4.3	$14.1	$0.0	$0.2
PV of Total Costs	$25.7	$13.0	$2.7	$2.5	$7.4	$0.0	$0.1
NPV	**$25.7**						
Scenario 3 - Total Costs	$25.7	$4.3	$4.3	$4.3	$4.3	$4.3	$4.3
PV of Total Costs	$14.4	$3.0	$2.7	$2.5	$2.2	$2.0	$1.8
NPV	**$14.4**						

Table 28: Net Present Value of Total Costs by Action Scenario
North Beach Del Mar, CA

Action Scenario	Capital and Maintenance Costs Combined								
	Total ($million)	**2030 ($million)**	**2040 ($million)**	**2050 ($million)**	**2060 ($million)**	**2070 ($million)**	**2080 ($million)**	**2090 ($million)**	**2100 ($million)**
Scenario 1a - Total Costs	$750.2	$19.8	$3.6	$10.4	$1.8	$1.8	$0.8	$0.0	$712.0
PV of Total Costs	$335.4	$17.0	$2.8	$7.3	$1.1	$1.0	$0.4	$0.0	$305.6
NPV	**$335.4**								
Scenario 1b - Total Costs	$797.4	$19.8	$20.9	$3.6	$3.6	$20.9	$0.0	$0.3	$728.3
PV of Total Costs	$363.0	$17.0	$16.3	$2.5	$2.3	$12.1	$0.0	$0.1	$312.6
NPV	**$363.0**								
Scenario 2 - Total Costs	$729.1	$3.6	$714.8	$3.6	$3.6	$3.6	$0.0	$0.0	$0.0
PV of Total Costs	$567.3	$3.1	$557.4	$2.5	$2.3	$2.1	$0.0	$0.0	$0.0
NPV	**$567.3**								

Task 3: Assess Each Action Scenario

Finally, we calculated the net benefits and benefit-cost ratios for action scenario. As shown in Table 29 and Table 30, the net benefits are the NPV of total benefits minus the NPV of total costs. The benefit-cost ratio is NPV of total benefits divided by NPV of total costs. The benefit-cost ratio is useful for comparing action scenarios and determining whether the benefits outweigh the cost. For each city, all of the ratios are higher than 1, meaning the benefits are greater than the costs.

Table 29: Net Benefits and Benefit-Cost Ratios
Selected Study Area Planning Zone 1, Carlsbad, CA

	NPV of Total Benefits ($million)	NPV of Total Costs ($million)	NPV Benefits ($million)	Benefit-to-Cost Ratio
Scenario 1	$817.7	$11.2	$806.5	72.88
Scenario 2	$722.6	$25.7	$696.9	28.12
Scenario 3	$817.7	$14.4	$803.3	56.97

Table 30: Net Benefits and Benefit-Cost Ratios
North Beach Del Mar, CA

	NPV of Total Benefits ($million)	NPV of Total Costs ($million)	NPV Benefits ($million)	Benefit-to-Cost Ratio
Scenario 1a	$2,843.2	$335.4	$2,507.8	8.48
Scenario 1b	$2,601.2	$363.0	$2,238.2	7.17
Scenario 2	$2,805.2	$567.3	$2,237.9	4.94

Results: Making a Decision

Finally, we compare the benefit-cost ratios.

For Carlsbad, Scenario 1 has the greatest return on investment. For every $1.00 spent, there is a return of $72.88. Scenario 2 has a return of $28.12 for every dollar spent, and Scenario 3's return is $56.97. These ratios assume that the three action scenarios are equally effective at preventing damages. This assumption is varied in the sensitivity analysis.

For Del Mar, Scenario 1a also has the greatest return on investment. For every $1.00 spent, there is a return of $8.48. Scenario 1b has a return of $7.17 for every dollar spent, and Scenario 2's return is $4.94. Again, these ratios assume that the three action scenarios are equally effective at preventing damages. The robustness of these results is tested in the sensitivity analysis.

While we did not incorporate qualitative considerations into our analyses, city planners and decision-makers would want to consider the implications of non-monetized benefits or costs. Additionally, per the NOAA framework, each city should also consider funding feasibility when deciding among action scenarios.

Sensitivity Analysis

We conducted sensitivity analysis to test the robustness of our results. That is, even if we modified some of our assumptions would Scenario 1 and Scenario 1a still have the most return on the investment? We did not test baseline model assumptions because each city's action scenarios started with the same baseline model and those same assumptions were applied equally. Although, baseline model assumptions could result different returns of investment for an action scenario, our project's scope was only to *compare* action scenarios, not estimate precise net benefits for each one. Thus, we only tested the key assumptions that could result in differences *between or among* the action scenarios.

We varied the following assumptions to test the robustness of our results.

Key parameters tested:

- Protection factor (effectiveness)
- Discount rate
- Loss of property tax revenue in Del Mar Scenario 2 (negative impact)
- Loss of beach tourism revenue and city tax revenue in Carlsbad Scenario 1 and Del Mar Scenario 1b (negative impact)

By entering different parameter values into the model, we calculated several benefit-cost ratios. The results of our analysis are found in this chapter.

Protection Factor

The protection factor was varied using 25 percent, 50 percent, and 75 percent effectiveness levels and compared to the results at a 100 percent effectiveness level. We found that for both cities, the initial results were not robust to assumptions about effectiveness. We assumed that each action scenario prevented damages equally by setting a protection factor of 100 percent, i.e., it prevents against all damages in the baseline model. However, as Figure 15 and Figure 16 show, if Carlsbad Scenario 1 and Del Mar Scenario 1a are not as effective as the other action scenarios, then they might not be the most cost-effective choice.

Figure 15 shows that while Carlsbad Scenario 1 (beach nourishment and groins) initially appears to be the best choice, that ranking depends upon its effectiveness. For example, if Scenario 1 is 75 percent effective at preventing baseline damages, and Scenario 3, (beach nourishment), is 100 percent effective, then Scenario 3 has the higher benefit-cost ratio (56.97 versus 54.66).

In Del Mar, we find a similar circumstance (Figure 16). Scenario 1a (beach nourishment and groins) has the highest benefit-cost ratio when all scenarios are assumed to have the same effectiveness. However, if Scenario 1a is 75 percent effective at preventing damages and Scenario 1b is 100 percent effective, then Scenario 1b is more cost-effective (7.17 versus 6.36).

Thus, for both cities, it would be prudent for city planners to consider whether one action scenario would be more effective than another. Potential effectiveness differences should be deliberated when considering what protection factor to apply when comparing ratios in sensitivity analysis.

Figure 15: Varied Effectiveness Assumption
Selected Study Area Planning Zone 1, Carlsbad, CA

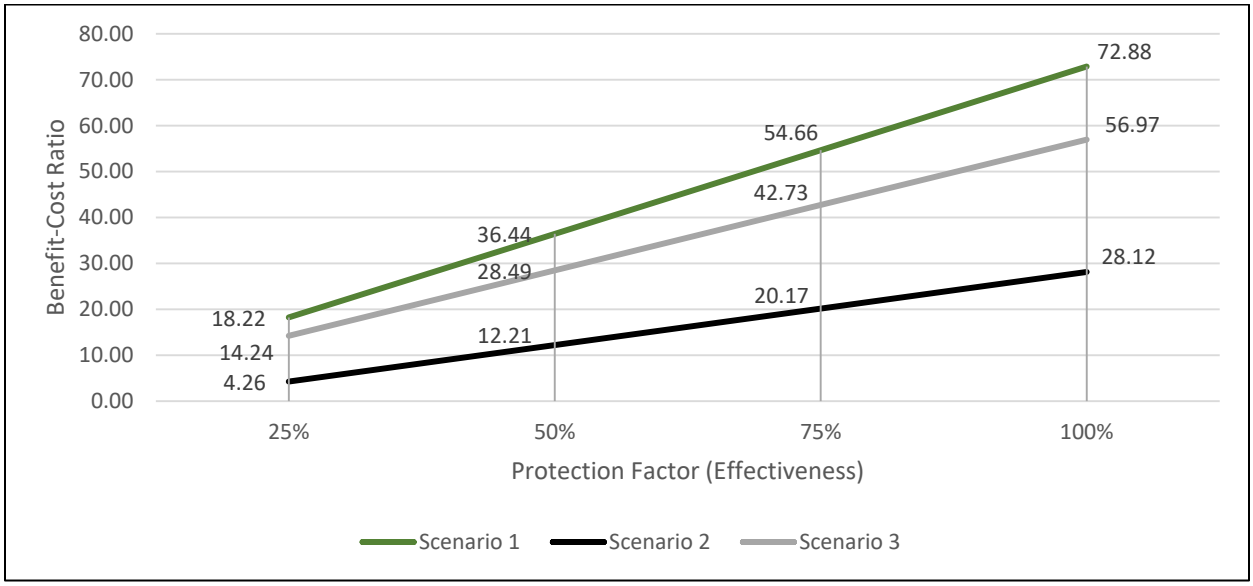
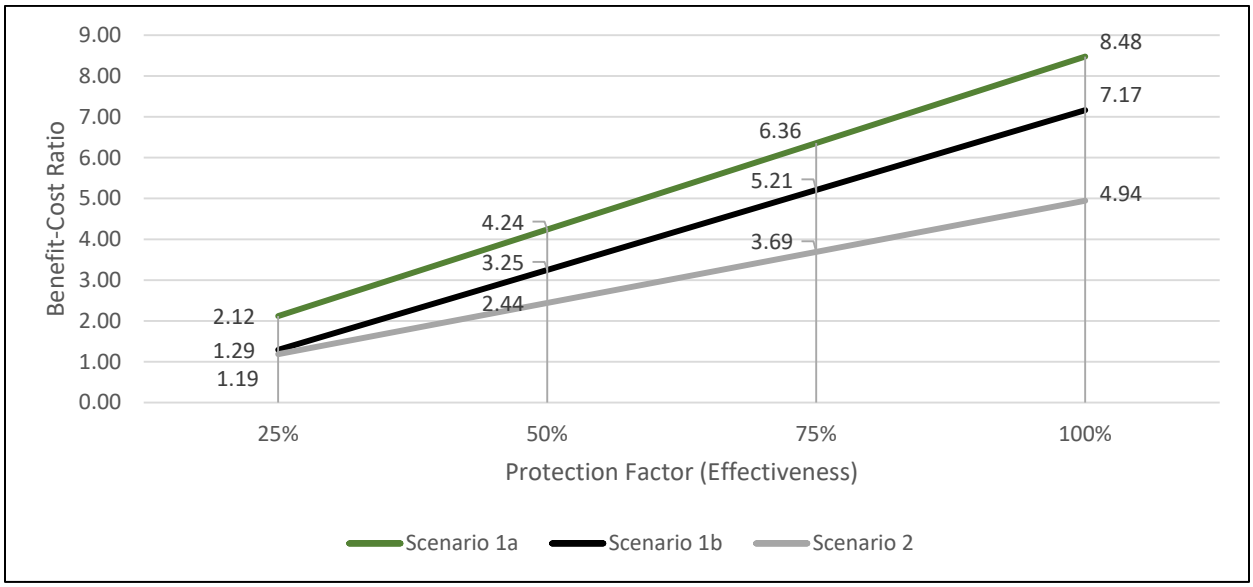


Figure 16: Varied Effectiveness Assumption
North Beach Del Mar, CA

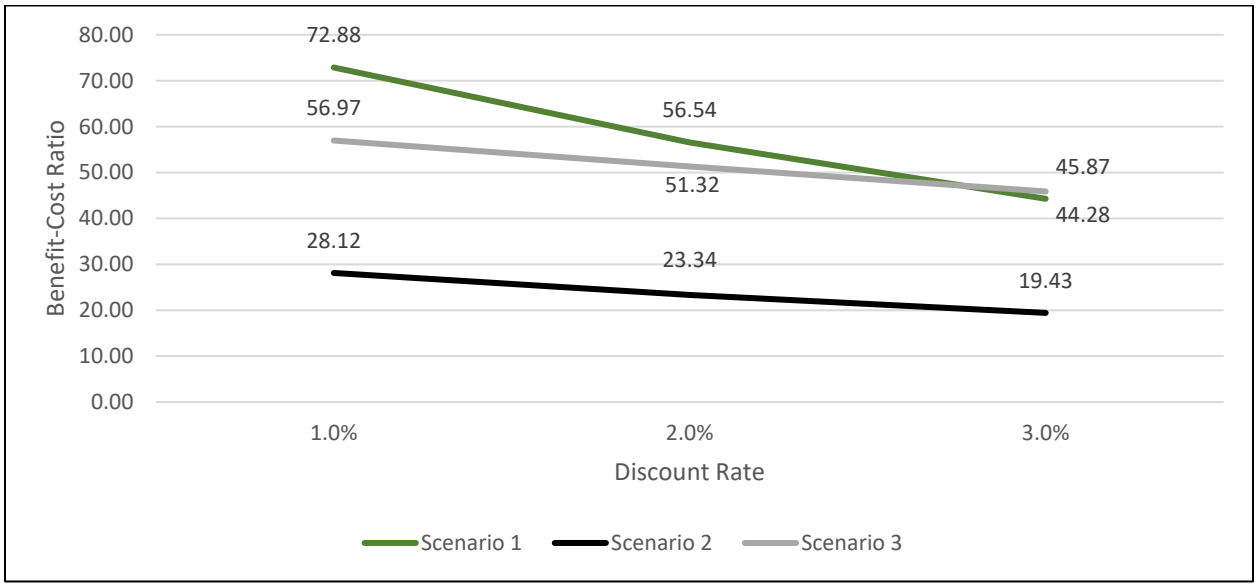


Discount Rate

As described earlier, it is important to discount future dollars because a dollar today is considered worth more than it will be in the future. To make fair comparisons, all dollars should be discounted to present value. Economists use different discount rates. In our case, we assumed one percent because it has been used in similar studies (Nature Conservancy, 2016). However, because the timeline of the adaptation strategies and negative benefits differed by action scenarios, it was pertinent to test our discount rate assumption. Costs that occur in the far future may be less than those that occur in the near future. Discount rates of two percent and three percent were compared to the results at a one percent discount rate.

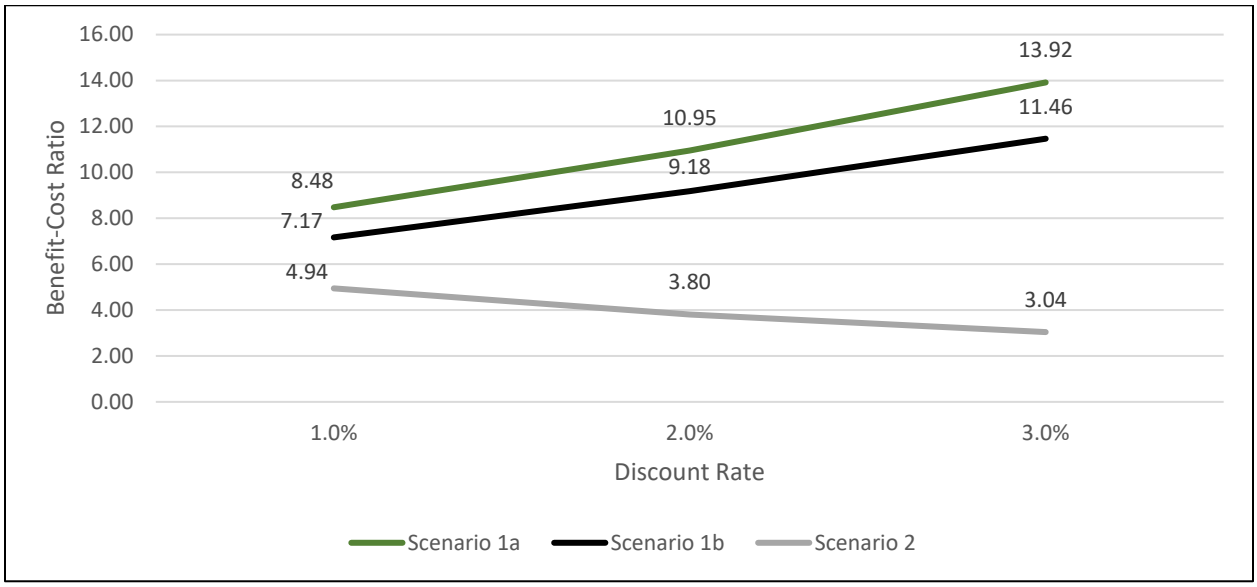
In Carlsbad, we found that are initial results were not robust to the discount rate assumption (Figure 17). While the Scenario 1 benefit-cost ratio (72.88) is the highest when assuming a one percent discount rate, Scenario 3's ratio (45.87) is higher than Scenario 1's ratio (44.28) when the discount rate is three percent. This ranking change is due to Scenario 1 having the higher implementation costs early on, while Scenario 3's costs are spread out more across decades.

Figure 17: Varied Discount Rates
Selected Study Area Planning Zone 1, Carlsbad, CA



Del Mar's initial results, on the other hand, are robust to the discount rate assumption. As shown in Figure 18, the sensitivity analysis of the discount rate does not change the ratio rankings. Scenario 1a has the highest benefit-cost ratio across all three discount rates.

Figure 18: Varied Discount Rates
North Beach Del Mar, CA



Loss of Property Tax Revenue (Del Mar Only)

Next, we considered the loss of property tax revenue in Scenario 2. This analysis only applies to Del Mar because structures were not removed in the Carlsbad action scenarios. In Del Mar, property taxes were assumed to be lost at 100 percent for the first row of beach homes removed in 2040. We continued to assume that it would be lost at 100 percent throughout the whole period, up to 2100. However, it is possible that those who lost homes could potentially build new homes within the city limits and some of the tax revenue would relocate within the city. We tested this assumption by computing ratios that assumed 25 percent, 50 percent, and 75 percent of the tax revenue was lost.

Table 31 shows that our initial results were robust to this assumption. Even if only 25 percent of the property tax revenue was lost for Scenario 2, Scenario 1a would still have a higher rate of return (8.48) than Scenario 2 (5.00). In fact, this assumption only slightly impacts Scenario 2's initial ratio (4.94).

Table 31: Varied Loss of Property Tax Revenue for Scenario 2
North Beach Del Mar, CA

Scenario 2 % of Tax Revenue Lost	Benefit-cost ratio
100%	4.94
75%	4.96
50%	4.98
25%	5.00

Loss of Beach Tourism Business Revenue and Tax Revenue

We next tested our assumptions regarding loss of beach business revenue and beach tax revenue because they affected the negative impacts of Scenario 2 in Carlsbad and Scenario 1b in Del Mar. We tested it two ways. Our results were robust to both tests.

First, we tested different rates for our day use value. The day use value is part of the area-based model that estimates the loss of beach tourism using an assumed amount of spending per day, per beach visitor. As mentioned previously, we assumed the same day use value of $54.24, adjusted to 2015 dollars, from a local Carlsbad study (King, 2005). Another recent study recommended a day use value of $39.49 ($40) to be used in southern California studies (Engel et al., 2015). Since we chose to use the Carlsbad-specific value instead, we tested the sensitivity of the relevant action scenarios' benefit-cost ratio using $40 along with three other values $30, $60, and $70.

As shown in Figure 19 and Figure 20, altered day use values did not affect our results for either city. While a lower day use value results in a smaller difference between Scenario 2's ratio and the other two action scenarios in Carlsbad, the ranking does not change for either city. Scenario 2 has the lowest return on investment across all day use value rates.

Finally, we tested what Carlsbad's Scenario 2 and Del Mar's Scenario 1b benefit-cost ratios would be if there were no beach loss negative impacts. That is, what if the sea walls did not ultimately result in the beaches being lost. While it is unlikely that there would be no loss, we sought to test the sensitivity of our results to the overall assumption of beach negative impacts. Setting negative impacts for both business revenue and tax revenue loss at $0, we calculated new ratios for both Carlsbad and Del Mar, 31.82 and 7.83 respectively. These new ratios did not change our results, or the benefit-cost ratio rankings.

Figure 19: Varied Day Use Values
Selected Study Area Planning Zone 1, Carlsbad, CA

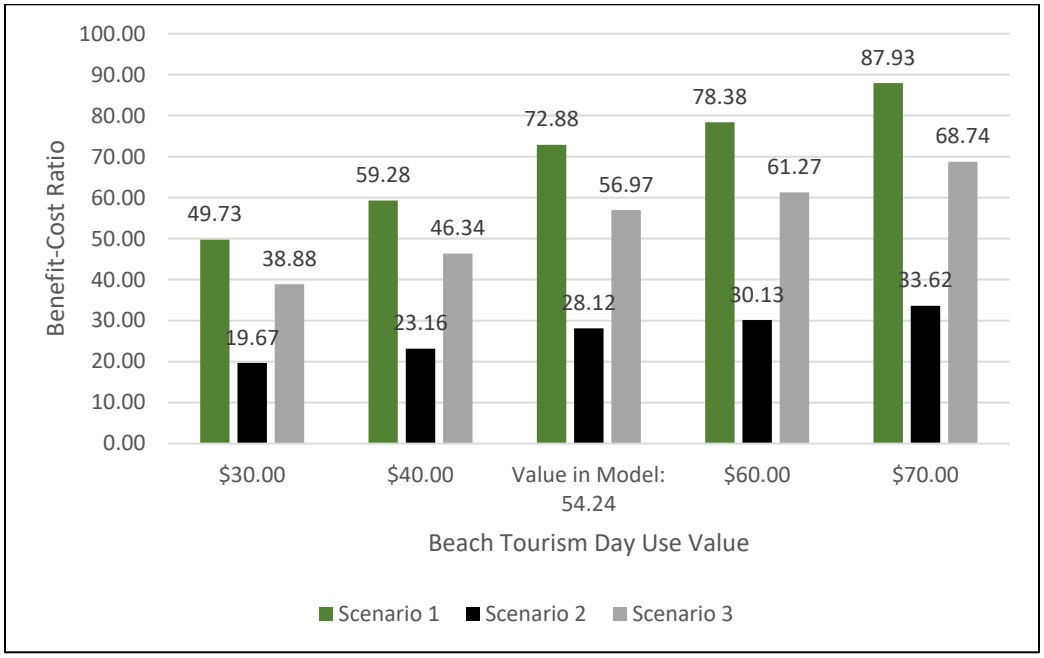
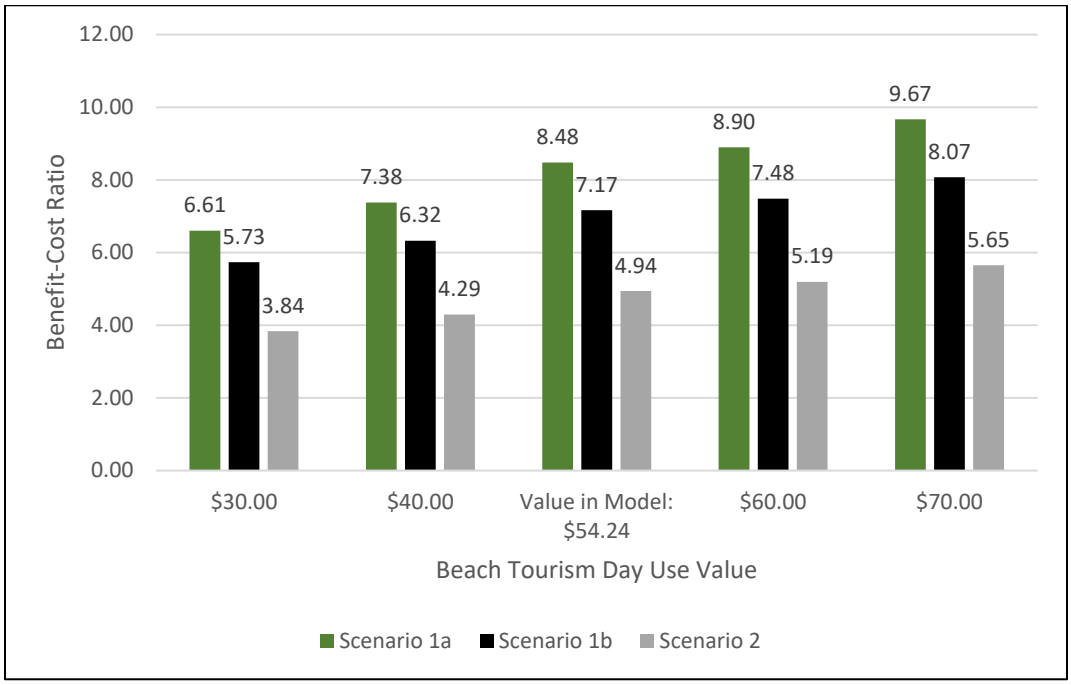


Figure 20: Varied Day Use Values
North Beach Del Mar, CA



Conclusion

The results of our sensitivity analysis suggest that assumptions of action scenario effectiveness and the discount rate do matter when conducting cost-benefit analysis of sea level rise adaptation strategies. Our results were not robust to the assumption of equal effectiveness of all action scenarios. For Carlsbad, if Scenario 3 is, in actuality, more effective at preventing damages than Scenario 1, it could be the more cost-effective strategy. In Del Mar, Scenario 1b could be the more cost-effective strategy if it is more effective than Scenario 1a. Finally, because action scenarios could incur costs on different timeframes, various discount rates could alter study results. When cities undertake similar analyses with adaption strategy implementation of distinct timelines that extend in the far future, they should carefully consider which discount rate to apply or conduct similar sensitivity analysis before making a decision.

Ultimately, each city needs to consider benefit-cost ratios for each of their action scenarios, and their own city's needs. In our examples, each city had two viable action scenarios. Carlsbad could choose Scenario 3 over Scenario 1 if there were concerns that a groin could impact their surfing community. Both options will have a strong return on investment. Del Mar could select to engineer groins, as in Scenario 1a, over raising or improving their seawalls, as in Scenario 1b, even though the results were not robust to effectiveness assumptions. For both cities, coastal resiliency choices should not only weigh short-term and long-term cost, but also reflect the communities' values and identity.

Lessons Learned

The intent of these "Lessons Learned" is to provide future practitioners with additional information and guidance that may help to focus and refine their own implementation of NOAA's framework for greater efficiency and effectiveness.

NOAA's framework offers different approaches to the benefit-cost analyses based on the goals of a study, technical knowledge and expertise, and data availability. While this study followed one general approach provided in NOAA's framework, we did take additional steps to modify the methodology or verify data accuracy when specific information was not available or directly applicable. The "Lessons Learned" attempts to capture our professional experience with implementation of NOAA's framework and the information revealed during application of the additional steps.

1. The NOAA Framework

We found the broad, flexible approach of the NOAA Framework adaptable to meet each of our city's needs, however, the trade-off was a lack of specificity. As such, it provides little direction regarding assumptions that are specific to a city's unique characteristics or needs. For example, post-flood clean-up costs may be additional costs to the city or incorporated into the existing budget. Practitioners attempting to apply the NOAA framework will need to make decisions about the most appropriate dollar values to apply, or the size and location of specific adaptation strategies (see #2 below).

Additionally, the NOAA framework is presented as a linear process, but in practice, performing the tasks is a nonlinear endeavor. Utilizing multiple team members, different tasks can be performed simultaneously as some tasks do not need to occur in the same order as presented in the framework. However, we recommend practitioners have the technical knowledge and expertise to adjust and revise the approach.

2. Project and site-specific information is necessary to provide more detailed cost estimates

Adaptation strategies are dependent on geographic and oceanic conditions specific to an area. As a result, options for adaptation strategies can vary widely depending on existing conditions and the goals of the adaptation strategy. Additionally, labor, materials and seasonal considerations will inevitably vary, nationally. We found historic city expenditures and quoted estimates from local resources and vendors to be better cost indicators than those obtained via out-of-region projects, other studies or generic software packages.

3. The value of GIS and parcel level information versus geographically aggregated approach

The NOAA framework provides different methods for evaluating impacts, ranging from broad, geographically aggregated approaches such as FEMA's Hazus MH Flooding or the COAST (Coastal Adaptation to Sea Level rise Tool) model. However, we found the use of more site-specific

information obtained via parcel level information (obtained using GIS or through primary data collection) provided more precise information regarding costs and potential impacts. We believe the additional time and cost to this approach is worthwhile.

4. The value of "ground-truthing" and on-the-ground site inspection

The vulnerability assessments rely upon CoSMoS flooding and inundation GIS layers overlain on city parcel maps and satellite imagery. Ground-truthing, the process whereby GIS layers and images are compared to what is on the ground in reality, is necessary to verify the contents of the image and, in this case, the output of the vulnerability assessments.

On-the-ground inspections resolved real and perceived conflicts in the data. In addition, site inspections revealed property features and changes not captured by the GIS analyses alone.

5. The value of collaboration with appropriate agencies

Adaptation planning and analyses, including benefit-cost analysis, is best performed as a collaborative, iterative process. Through open dialogue with local, state, and federal agencies, practitioners can collect and analyze the most relevant information. Periodic feedback from participating agencies contributes to an output with better defined parameters. We also found the collaboration necessary and vital to the project schedule, and setting (or resetting) project expectations.

Limitations of Study

The analysis does not include sea level rise impacts on public health, socio-economic issues, natural resources, including nearshore ecosystems or any critical habitat that supports threatened and endangered species, or environmental damage, e.g., oils spills and discharge of pollution. These potential impacts fell outside of the study scope of work.

Use Limitations

City planners and decision-makers should only use this study's benefit-cost ratios to *comparatively rank* which scenario has the greatest return on investment. Total net benefits, which can be used comparatively as well, should not be used as individual estimates of return on investment. Our analysis represents a high-level approximation for the study areas, with generic structure and infrastructure replacement or repair costs that may not reflect actual costs and specifications in the event of a real loss.

The action scenario cost estimates are intended to provide an approximation of total project costs and do not always include design, engineering or permitting costs. The actual project descriptions for adaptation strategies and construction costs may differ substantially from what are provided herein. It is recommended that financial feasibility not be assessed until any preliminary design is accomplished, based on a more thorough consideration of coastal processes, regulatory and environmental opportunities and constraints, and engineering.

The sources of information and basis of the estimates are stated herein. While we believe the sources of information are reliable, we do not express an opinion or any other form of assurance on the accuracy of such information.

The analyses contained herein are based on estimates and assumptions that are inherently subject to uncertainty and variation depending on evolving events. We cannot represent that the results presented here will definitely be achieved. Some assumptions inevitably will not materialize, and unanticipated events and circumstances may occur; therefore, the actual results achieved may vary from the projections.

Fiscal Impact Analysis

The fiscal impact analysis (FIA) contains an analysis of recurring revenues and costs to the jurisdiction from potential loss of property and services. The FIA is based on estimates, assumptions, and other information developed from our research, interviews, telephone discussions with the jurisdictions and County of San Diego staff, and information from our database, which were collected through fiscal impact analyses previously prepared by us and others.

The analysis of recurring revenues and cost impacts to the jurisdictions contained in the FIA is not considered to be a "financial forecast" or a "financial projection" as technically defined by the American Institute of Certified Public Accountants. The word "projection" used within this report relates to broad expectations of future events or market conditions.

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Appendices

Appendix A: Adaptation Strategy Descriptions

Appendix B: Baseline and Adaptation Strategy Unit Costs

Appendix C: NOAA Framework Report

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Appendix A: Adaptation Strategy Descriptions

Adaptation Strategies

Appendix A provides more detail about the individual adaptation strategies found within the action scenarios.

Beach Nourishment

Beach nourishment is a form of "soft" armoring that protects shorelines from erosion due to wave action and storm events by placing a replenishment of sand to increase a beach's seaward profile, length, height, and volume. The replenishment sand supply is sourced by either dredging and pumping from an offshore donor site, or by locating similar sediment at an upland site and transporting it to the nourishment location. Earth-moving equipment is used to strategically distribute the sand onto the beach in a way that supports native conditions, littoral functions, recreation, and aesthetics.

Raise/Improve Seawalls

Seawalls are a form of "hard" armoring designed to reflect wave energy away from the property behind them. Seawalls are generally constructed of sheet piling (interlocking panels of metal, concrete, or other materials), driven far below grade (30 feet is typical), with a lesser portion extending above grade. In this way, seawalls are like icebergs; they are much taller than what is visible. Freestanding seawalls located on back beaches also act as boundaries between public recreation areas and private property, sidewalks, parking lots, etc.

Seawalls that buttress coastal bluffs have the dual purpose of protecting against wave action, and supporting the bluff itself. Because bluff seawalls are designed to brace near-vertical slopes, they are taller than freestanding seawalls and require the addition of embedded horizontal tiebacks with anchors.

Raising the height of an existing freestanding seawall can be accomplished by drilling holes into the wall cap, inserting rebar extensions at specific intervals, and setting them in place with construction epoxy. New concrete is then poured into a form built around the rebar extensions, and leveled to the desired height. An engineering analysis would be needed to determine the maximum height a wall can be raised and still maintain its structural integrity.

Bluff seawalls rarely need to be made taller, but they are vulnerable to lower damage from "scouring" – accelerated erosion caused by waves plunging downward at the toe (base) of the wall. To slow such damage, hard reinforcement material such as large cobble can be placed at the front of the toe to dissipate scouring energy.

Raise/Improve Revetments

Revetments are engineered slopes placed parallel a waterline to attenuate wave energy and protect a shoreline. Large, angular rocks, concrete rubble, or gabions (large metal mesh containers filled with stone) are common revetment construction materials. The interlocking nature of the material's

geometry, coupled with their size and weight, make revetments a form of static hard armoring with a life expectancy of 30-50 years.

Raising or improving a revetment may become necessary when it no longer provides sufficient protection against increasing storm surges or wave action. In these cases, additional rock, cobble, or other materials may be added to the existing revetment to fill voids or increase its volume or length. Revetment design must maintain a certain degree of permeability, as they are known to speed erosion by impeding the natural migration of river deposits and other upland sediment sources from reaching the open beach.

Groins

Groins are linear hard structures that extend perpendicular from a beach into the open ocean, and form simple, physical barriers that interrupt littoral drift (naturally occurring longshore sediment movement.) As sediment accumulates on a groin's updrift side, the accretion increases the size of the beach there. However, the downdrift side of the groin can experience a loss of sediment due to this littoral interruption, especially if the groin is too high, too long, or lacks permeability.

Typically made of boulders, groins can also be constructed with manufactured sheet piles, concrete rubble, or large timbers. New groin construction should look at offshore geography, tide data, and local wave energy to determine the appropriate height, width, length, and void size to achieve the desired results. Permeability should be balanced between too little (unacceptable loss of beach on the downdrift side), and too much (not enough accretion on the updrift side to be effective.)

When used in conjunction with additional adaptation strategies such as beach nourishment, groins have proven to be successful in mitigating beach erosion. When placed adjacent to estuaries, bays and navigation channels, groins prevent sediment from accumulating in these waterways.

Raise Structures

Raising a structure is one of the most common retrofitting methods for flood adaptation. The goal of raising a structure is to elevate the lowest living area floor to be above known flood levels, allowing its continued occupation/use, while flood waters flow unimpeded beneath or around it.

To raise a structure, it is detached from its foundation, lifted by a crane, and set on temporary supports placed directly under it. An extended foundation, or new pilings (stilts) are constructed to the desired height. Once the now-elevated foundation is complete, the temporary supports are removed, and the structure is re-attached. The lowest level of the structure is now above flood levels.

The viability of elevating a structure is contingent on the size of the building, type of construction, number of floors, condition of the foundation, permits, over-size vehicle access, scheduling and other construction variables. Site preparations include permitting, engineering, accessibility considerations, disconnection from all utilities, and removing exterior steps, porches, decks, shrubbery, fencing, etc.

If raising the entire building is not economically or structurally feasible, a new floor can be built on top of the highest existing floor (after removing the roof), and the flood-prone, lowest floor is abandoned and modified into a floodproof system. The result maintains the structure's original square footage, raises its living area, and allows floodwaters to flow around it.

Remove Structures

Removing a structure from its location altogether is a component of a "managed retreat" strategy, which purposefully vacates a hazard area, and allows erosion to occur without intervention. Structures can be removed by demolition, or by relocating them to a new site.

Removal by demolition also requires disposal of all debris, and disconnecting-capping gas, power, water utilities. Earth-moving equipment is then used to backfill foundation or basement voids, and re-grade the parcel. Owners would likely purchase a new home or building elsewhere.

Removal can also achieved by keeping the structure, and relocating it to a new site. Costs for relocation include land acquisition, preparation for receiving the structure (foundation construction, utility work, driveway and landscaping considerations,) disconnection of the building from its existing foundation, transportation to the new location, and setting the structure on the new foundation. We did not assume relocation of structures for this report.

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Appendix B: Baseline and Adaptation Strategy Unit Costs

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Table B-1: Baseline Primary and Secondary Impact Unit Costs, Selected Study Area Planning Zone 1, Carlsbad, CA

Primary and Secondary Impacts:	**Estimate**	**Source**
Residential properties (flooding event)	Unique to each property	USACE Depth damage functions, RSMeans
Residential properties (chronic inundation or bluff erosion)	Unique to each property	Market value, Zillow and/or Redfin
Commercial/Industrial properties (flooding event)	Unique to each property	USACE Depth damage functions, RSMeans
City transportation infrastructure damages (bluff erosion)		
2050 Repair of Carlsbad Blvd. between Pine Ave. and Tamarack Ave.	$1,400 per linear foot ($2015)	Based on historical repair cost of Carlsbad Blvd. Carlsbad Dept. of Public Works
2100 Replacement of Carlsbad Blvd. between Pine Ave. and Tamarack Ave.	$6,774 per linear foot ($2015)	Cost to construct similar road from Carlsbad 2016-17 Capital Improvement Program (CIP)
2050 Replacement for beach path Pine Ave. to Cherry Ave.	$986 per linear foot ($2015)	Cost to originally build path, inflated to 2015 dollars. Carlsbad City Council Agenda report. Includes lighting, benches, garbage cans.
2100 Replacement for beach path Pine Ave. to Cherry Ave.	$986 per linear foot ($2015)	Cost to originally build path, inflated to 2015 dollars. Carlsbad City Council Agenda report. Includes lighting, benches, garbage cans.
2050 Replacement for beach path Cherry Ave. to Tamarack Ave.	$9.78 per square foot	Cost to build a sidewalk from local construction company. Increased by a factor of 1.27 to account for additional city costs. Factor determined from similar projects in the CIP Technical Appendix.
2100 Replacement for beach path Cherry Ave. to Tamarack Ave.	$9.78 per square foot	Cost to build a sidewalk from local construction company. Increased by a factor of 1.27 to account for additional city costs. Factor determined from similar projects in the CIP Technical Appendix.
2050 Repair beach access stairways between Pine Ave. to Hemlock Ave.	2 beach access stairways with viewing landings at $93,380 ($2015)	1988 bid for Cherry Ave. stairway repair inflated to 2015. City of Carlsbad Agenda Bill.

2100 Replacement beach access stairways between Pine Ave. to Hemlock Ave.	4 beach access stairways with viewing landings at $174,234 ($2015)	1988 bid for original Maple Ave. stairway construction inflated to 2015. City of Carlsbad Agenda Bill.
Beach access stairways at Tamarack Ave.	1 concrete stairs at $6,991 ($2015)	Cost to build a similar stairway from local construction company. Increased by a factor of 1.27 to account for additional city costs. Factor determined from similar projects in the CIP Technical Appendix.
Day use value in area-based beach attendance model (chronic inundation)	$54.24 per visitor per day ($2015)	King, 2005

Table B-2: Baseline Primary and Secondary Impact Unit Costs, North Beach Del Mar, CA

Primary and Secondary Impacts:	**Estimate**	**Source**
Residential properties (flooding event)	Unique to each property	USACE Depth damage functions, RSMeans
Residential properties (chronic inundation)	Unique to each property	Market value, Zillow and/or Redfin
Commercial/Industrial properties (flooding event)	Unique to each property	USACE Depth damage functions, RSMeans
City property and structure damages	Unique to each property	USACE Depth damage functions, RSMeans
City transportation infrastructure damages (flooding event)		
Road repair for extreme event	$1,208,030 ($2015)	Based on historical event repair costs of Camino Del Mar. Del Mar Dept. of Public Works
Day use value in area-based beach attendance model (chronic inundation)	$54.24 per visitor per day ($2015)	King, 2005
City road cleanup (flooding event)	$588 per storm event ($2015)	Del Mar Dept. of Public Works

Table B-3: Adaptation Strategy Unit Costs

Adaptation Strategy Unit:	**Estimate**	**Source**
Beach Sand Replenishment	$19.56 cubic yard ($2015)	SANDAG, 2012
Seawall	$4,200 linear foot ($2015)	TerraNova, 2017
Revetment	$326 linear foot ($2015)	California Coastal Commission, 2016; Port of San Diego
Groin	$5,140 linear foot ($2015)	SANDAG, 2001
Raise Structures	$44 square foot (first floor only) ($2015)	Burrus et al., 2000; Army Corps of Engineers, 1990
Remove Structures (Demolition and Removal)	$4 square foot ($2015)	Dependable Demolition 2016 (average of commercial and residential)

Appendix C: NOAA Framework Report

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Final Report

What Will Adaptation Cost? An Economic Framework for Coastal Community Infrastructure

June 2013

Eastern Research Group, Inc.

Written under contract for the
National Oceanic and Atmospheric Administration (NOAA)
Coastal Services Center

NOAA Coastal Services Center
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www.csc.noaa.gov

NOAA Coastal Services Center
LINKING PEOPLE, INFORMATION, AND TECHNOLOGY

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The Importance of Making Economically Informed Decisions

Global sea level has been rising over the past several decades and is expected to continue to rise in the decades to come. This shift poses a grave threat to coastal communities. Low-lying areas will experience more frequent inundation and shorelines will be more susceptible to increased erosion. Increased storm surges are already causing devastating floods. Sooner than most community leaders realize, some areas could be submerged so often or eroded so severely that people will be forced to abandon their homes and businesses. According to the National Ocean Economics Program, coastal communities account for nearly 60 percent of the nation's gross national product.[1] With so much of our nation's economy increasingly vulnerable to coastal hazards, communities need to consider future sea level rise in their decision-making.

Deciding on the best course of action, however, is not always easy. Issues are complex and there is a lot of uncertainty. Community leaders find themselves grappling with questions like:

- How will sea level rise and increased storm surge affect my community?
- What is the cost of doing nothing?
- What can we do to adapt?
- How can I determine the best adaptation strategy?
- How much will it cost to keep my community safe?

"Going forward, I think we do have to anticipate these extreme types of weather. And we have to start to think about how we redesign [infrastructure] so this doesn't happen again…I don't think anyone can sit back anymore and say 'Well, I'm shocked at that weather pattern.' There is no weather pattern that can shock me at this point. And I think that has to be our attitude, how do we redesign our system and our infrastructure assuming that?"

—New York Governor Andrew Cuomo responding to Hurricane Sandy

"As we get more high tides and tides seem to get higher, and we get more of these storms and they seem to come with a little more fury, we get more and more water in our city as the days go by. So we are taking it very seriously …and we are planning for it."

—Norfolk, Virginia, Mayor Paul Fraim

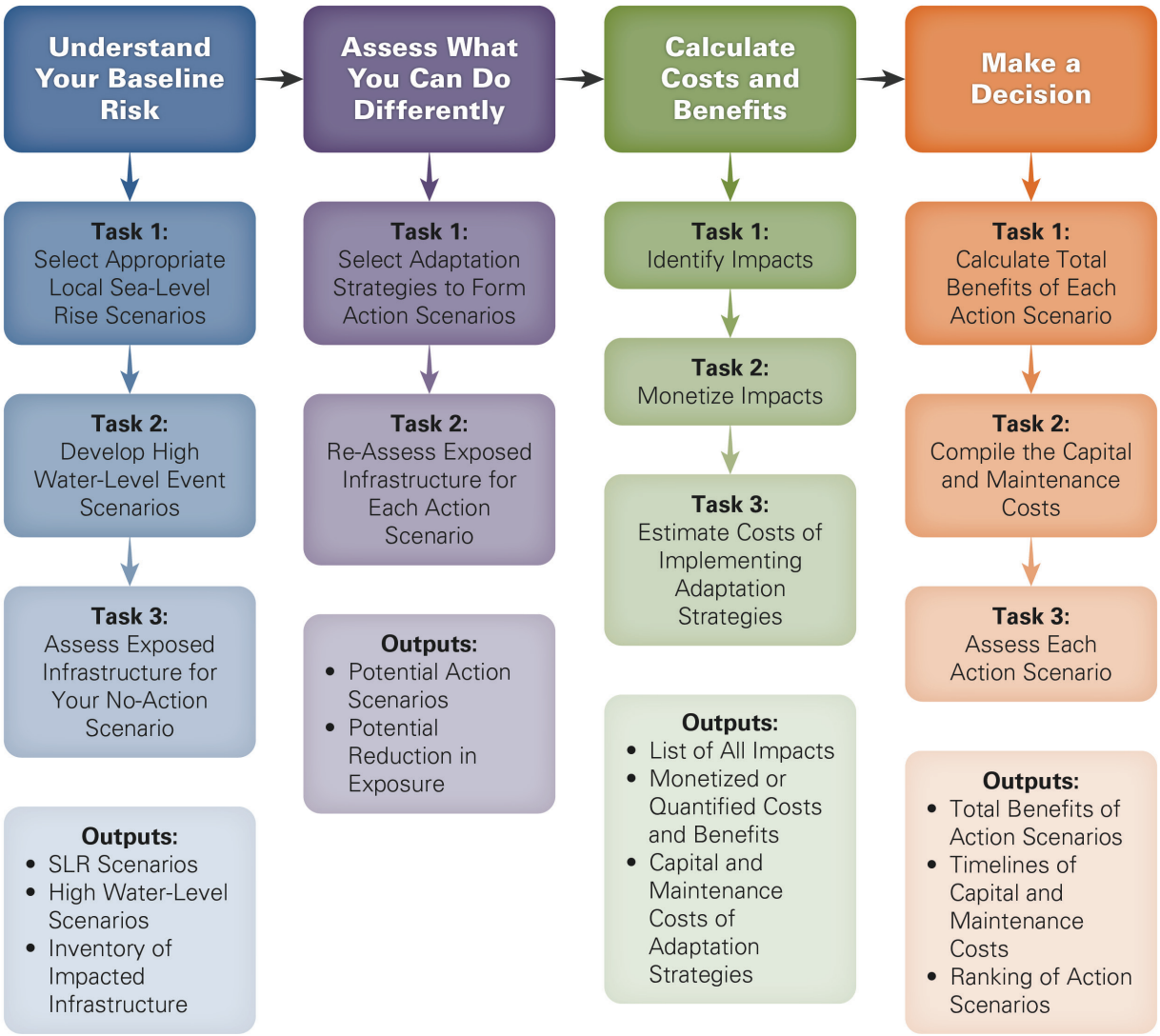
The purpose of this framework is to help communities begin to find answers to these difficult questions. By understanding the costs and benefits of different adaptation strategies, decision-makers can make more fully informed decisions that are fiscally responsible in the short and long terms. More importantly, economically informed decision-making will lead to safer, more responsible, economically sound communities. In the long run, the entire community benefits by investing in adaptation efforts: after a flood event, utilities will be restored quicker, stores and banks will be open sooner, children will return to school faster, and residents will be back at work with minimal disruption. Up-front investments can help ensure a successful future. By accounting for the full costs of inundation risks, leaders can make strategic choices about where, when, and how to make investments in adaptation responses to maximize benefits and minimize risk.

[1] *State of the U.S. Ocean and Coastal Economies—2009*.

How to Use This Framework

This framework guides communities on how to evaluate options for adapting infrastructure to make it more resilient, reducing the effects of sea level rise (SLR) and high-water-level events such as storm surge or astronomical high tides. As a step-by-step process, it leads communities through a scenario-based approach to understand the full range of costs and benefits. Figure 1 illustrates the framework that communities can use to develop and investigate their own unique scenarios.

Figure 1: Framework for Making Informed Decisions



This framework is highly adaptable and can help any community make decisions about infrastructure investment. Communities can use it to assess the impact of inundation on their entire infrastructure, which is referred to as the holistic approach. Alternatively, if a community wants to focus on select infrastructure, such as a hospital or wastewater treatment plant, the framework allows for this priority infrastructure approach.

A significant impetus for developing this framework was the growing demand from communities for guidance to help protect publicly-owned infrastructure, such as roads, schools, and sewer systems. However, the holistic approach includes assessing costs and benefits to homes and businesses as well as public assets, and the adaptation strategies discussed in Chapter 2 and Appendix A can be used to protect both private property and public infrastructure. In fact, some of the adaptation strategies are traditionally employed to protect private, but can be viable options to protect public property as well. You can choose to use this framework to perform a more focused analysis of public infrastructure, or to take a broader look at your entire community.

> *"As storms such as Hurricane Sandy have shown, it is vital that we commit our resources and expertise to create a ready and resilient Maryland, by taking the necessary steps to adapt to the rising sea and unpredictable weather. In studying and planning for storms and climate change, we can ensure that our land, infrastructure, and most importantly our citizens are safe and prepared."*
>
> **—Maryland Governor Martin O'Malley**

The framework can also help communities perform either an impact assessment or a risk assessment. An impact assessment involves assessing the impacts of just a few different water-level increase heights to develop a sense of the amount of damage to expect in certain scenarios compared to the financial cost of adaptation strategies. A risk assessment is a more resource-intensive analysis that multiplies the probability of each water-level increase by the value of the impact to generate an apples-to-apples comparison of the expected costs and the expected benefits of implementing adaptation strategies against coastal flooding. The details of each type of assessment are discussed in task 2 of the first chapter in this guide.

Finally, we encourage communities to assemble a team to effectively use this framework, as several of its steps require specialized expertise or training. Identifying qualified experts and engaging stakeholders is an important part of the process. Your team should include economists, planners, GIS experts, land use attorneys, civil engineers, and inundation modeling experts if available; it can also include utility supervisors and emergency managers. If you do not have the needed expertise in-house for all the tasks, seek support from outside resources such as local universities, nonprofit organizations, or consultants. We recommend that communities engage other stakeholders and residents to participate in the decision process. This guide can also be used to help you craft an effective request for proposals to get necessary consultant support.

Protecting Against Sea Level Rise: New York City

When hazard planning includes informed decisions, successes can follow. In 2007, New York City began working to prepare for the impacts of climate change as part of PlaNYC—a comprehensive planning effort to address every aspect of the city's physical infrastructure. The effort recognized that adapting to SLR must be a key part of city policy. Accordingly, New York took action to address the most pressing risks; areas of the city were rebuilt, rezoned, and refashioned to better weather those threats.

When Hurricane Sandy hit the city in October 2012, many of these changes helped prevent property damage. Governors Island experienced peak flooding of almost 13 feet above sea level and saw 5 feet of water come over the southern seawall, but a 30-acre park there came through the storm nearly untouched because its design accounted for hazards like Sandy. The new Brooklyn Bridge Park was also designed with the assumption that it would flood—and was open to the public just five days after the storm.

Chapter 1: Understand Your Baseline Risk

This chapter helps you understand your community's baseline risk for coastal flooding resulting from high-water-level events and SLR. You will explore the exposure of your infrastructure to a range of water-level increases resulting from high-water-level events such as storm surge and astronomical high tides combined with SLR. The flood maps that you create will serve as a valuable tool to illustrate what might happen to your community if no action is taken.

Task 1: Select Appropriate Local Sea-Level Rise Scenarios

Task 2: Develop High Water-Level Event Scenarios

Task 3: Assess Exposed Infrastructure for Your No-Action Scenario

Outputs:
- SLR Scenarios
- High Water-Level Scenarios
- Inventory of Impacted Infrastructure

Case Study: Boston, Massachusetts

In Boston, researchers used publicly available information from the U.S. Army Corps of Engineers and the Intergovernmental Panel on Climate Change to predict high-water-level event scenarios in 2050. They estimated that a 10-year storm in 2050 would bring the same height of water as a 100-year storm now, because of the compounded effects of SLR. In other words, the impacts of a storm that has a 1 percent chance of occurring now would equal those of a storm with a 10 percent chance of occurring in 2050.

Expertise required to complete Chapter 1:
- GIS analysts to help your team use spatial data in Task 3

Key resources referenced in Chapter 1 include:
- NOAA's *Global Sea Level Rise Scenarios for the United States National Climate Assessment*
- USACE Circular "Sea-level Change Considerations for Civil Works Programs"
- NOAA's Sea Levels Online
- NOAA's Extreme Water Levels map
- NOAA's Sea Level Rise and Coastal Flooding Impacts Viewer
- NOAA's Inundation Analysis Tool
- NOAA's *Mapping Coastal Inundation Primer*
- NOAA's Coastal LIDAR
- NOAA's Vertical Data Transformation
- USGS' National Elevation Dataset
- FEMA's Hazus-MH Flooding Model
- The New England Environmental Finance Center's Coastal Adaptation to Sea level Rise Tool

Task 1: Select Appropriate Local Sea Level Rise Scenarios

Objective: Use existing global and local projection data to select appropriate local SLR scenarios.

Process to complete this task:

Step 1: Identify a set of SLR curves that you will use for your analysis. It is possible that area researchers have developed localized SLR curves based on downscaled climate models, so you should check with area universities or the NOAA Regional Integrated Sciences and Assessments program closest to your community. For most locations, however, two recently published resources provide global SLR curves that can be used to develop your local SLR scenarios. This framework outlines how to use these two resources to generate local SLR scenarios. If you choose to use a different set of curves, you will need to apply quadratic equations for those curves to determine rates of SLR for different time periods.

Key considerations for this task:

- Are you considering a wide enough range of SLR scenarios? A low scenario based on historic SLR trends may make sense for short-term planning, but intermediate or high scenarios based on recent science showing that SLR is accelerating may be more appropriate to consider for longer-term planning (e.g. when planning for infrastructure meant to last multiple decades.)
- Did you project your local SLR scenarios far enough into the future? At this point, you have not looked at any adaptation strategies and their expected period of effectiveness. Consider projecting out to 2100 for now; you can shorten this horizon in a later task.

One available resource is U.S. Army Corps of Engineers (USACE) Sea-level Change Considerations for Civil Works Programs,[2] which presents three SLR curves: the low curve represents the historic or baseline rate, and the intermediate and high curves are based on science from the National Research Council and the Intergovernmental Panel on Climate Change. Option A in Step 3 explains how to use these curves to generate local SLR projections.

Another appropriate resource is NOAA's Global Sea Level Rise Scenarios for the United States National Climate Assessment. It is a multi-agency report of scientific literature on global SLR. Released in December of 2012, it presents four global SLR scenarios and notes the physical changes that would need to take place for each SLR scenario to be a reality (see Table 1.1). Options B and C in Step 3 of this chapter outline a simplified and more advanced methodology for using these curves to generate local SLR projections.

[2] This circular expires in September of 2013 but will likely be replaced by an updated version

Table 1.1: Global SLR Scenarios from *Global Sea Level Rise Scenarios for the United States National Climate Assessment*

SLR Scenario	Physical conditions scenario is based on	SLR by 2100 (ft)*
Lowest	Based on historical rates of observed sea level change	0.7
Intermediate-low	Based on projected ocean warming	1.6
Intermediate-high	Based on projected ocean warming and recent ice sheet loss	3.9
Highest	Based on ocean warming and the maximum plausible contribution of ice sheet loss and glacial melting	6.6

* Using mean sea level in 1992 as a starting point.

Step 2: Choose a few years along the planning horizon to evaluate local SLR. One approach would be every 30 years (2040, 2070, 2100), but there is no ideal planning horizon; timeframes of interest will be specific to your community, although you may want to consider performing this step out to 2100 to observe the effects of SLR over time. This will not limit you to a particular planning horizon in performing the cost-benefit analysis.

Step 3: Calculate local SLR increases for the years you chose, compared to the first year of your analysis. This involves incorporating local projection information into the global SLR curves, and using quadratic equations to determine the amount of rise for different years along the curves. Incorporating local information is necessary because different areas of the country have varying amounts of subsidence or uplift, and there are also differences due to ocean basin trends.

Option A: Use the three USACE curves to generate local SLR scenarios by year

Use the USACE on-line Sea Level Change Calculator to generate projections in five year increments. If you know the rate of subsidence or uplift for your area of coastline, you can enter this value into the calculator in millimeters. If you do not know this information, select the NOAA tide gauge closest to your location to generate an approximate subsidence rate. The calculator assumes a start date of 2010 for calculating values, but you may adjust this if desired. Use the results from the online calculator to fill out a table showing SLR rates for the time periods you selected in Step 2. Table 1.2 shows an example of what this table might look like, using St. Petersburg, Florida as an example. The values were generated using the online calculator by selecting the St. Petersburg tide gauge.

Table 1.2: St. Petersburg, Florida SLR Increase Scenarios by Year, Based on the USACE Curves.

SLR Scenario	Feet Above 1992* Sea Level		
	2040	2070	2100
High	0.93	1.97	5.25
Intermediate	0.67	1.21	2.93
Low	0.41	0.62	1.27

*The on-line Sea Level Change Calculator produces the amount of predicted sea level change from 1992 forward. 1992 corresponds to the midpoint of the current National Tidal Datum Epoch of 1983-2001.

Option B: Use the four curves in *Global Sea Level Rise Scenarios for the United States National Climate Assessment* to generate local SLR scenarios by year – Simplified methodology

A relatively simple way to adjust the global SLR curves to produce local scenarios is to factor in the difference between the global mean sea level trend and the trend in your location, which may be greater or lesser than the global rate depending on local vertical land movement (subsidence or uplift) and regional ocean basin trends. Use the following steps to generate values for the four scenarios (lowest, intermediate-low, intermediate-high, and high.) Again, St. Petersburg, Florida is used as an example, and Table 1.4 illustrates the final output.

1. Determine the lowest rate (in/year) of SLR increase using the NOAA Sea Levels Online mean sea level trend from the water level gauge closest to your community. Assume this to be a constant increase, and use 1992 as the starting point for your calculations; use it to calculate your "lowest" projection for the years you chose in the previous step of this process. For St. Petersburg, Florida, the mean sea level trend is 2.36 mm/year, which converts to 0.093 in/year. The rise for 2040 will be 4.46 in (0.093 in/year x [2040-1992]), for 2070 will be 7.25 in (0.93 in/year x [2070-1992]), and for 2100 will be 10.04 in [0.093 in/year x [2100-1992]). Insert these values in the row for the "lowest" scenario in Table 1.4. (Note that Table 1.4 is in feet so these values have been converted from inches to feet.)

2. Use the quadratic equations in Section 4.3 of the *Global Sea Level Rise Scenarios for the United States National Climate Assessment* report (shown in Equation 1.1 below) to calculate global SLR associated with the "intermediate-low," "intermediate-high," and "highest" SLR scenario for the years you have chosen to analyze. An example of calculating these equations is provided below, and Table 1.3 provides an example of the values (in feet) for the three time periods of 2040, 2070, and 2100.

Future global mean SLR is represented by the following quadratic equation:

$$E(t) = 0.0017t + bt^2 \qquad \textbf{(Equation 1.1)}$$

Where:
t *= years, starting in 1992*
b *= constant value of 1.56E-04 for the Highest Scenario, 8.71E-05 for the Intermediate-High Scenario, and 2.71E-05 for the Intermediate-Low Scenario*[3]*.*
E(t) *= eustatic SLR, in meters, as a function of t.*

Using the highest scenario in the year 2070 as an example, t equals 78 (i.e. 2070 – 1992), and the equation would be:

$$E(t) = (0.0017 \times 78) + [(1.56 \times 10^{-4}) \times (78^2)]$$

This yields a result of 1.08 meters, which converts to 3.54 feet.

Table 1.3: Global SLR Increase Scenarios by Year Based on the Global Sea Level Rise Scenarios for the United States National Climate Assessment Curves

Global SLR Scenario	Feet Above 1992 Sea Level		
	2040	2070	2100
Highest	1.4	3.5	6.6
Intermediate-high	0.9	2.2	3.9
Intermediate-low	0.5	1.0	1.6

3. Adjust the global "intermediate-low," "intermediate-high," and "highest" values calculated in the previous step to account for the difference between your local mean sea level trend and the global mean SLR average (0.067 in/year.) For example, St. Petersburg's local SLR rate of 0.093 in/year is 0.026 in/year above the global average. So for the year 2040, 1.25 inches need to be added to each of the three scenarios (0.026 in/year x [2040-1992]). For the year 2070, 2.03 inches need to be added (0.026 in/year x [2070-1992]), and for the year 2100, 2.81 inches need to be added (0.026 in/year x [2100-1992]). Insert the adjusted numbers into the "highest," "intermediate-high," and "intermediate-low" rows of table 1.4.

Table 1.4: Example Local SLR Increase Scenarios by Year Based on the St. Petersburg, Florida tide gauge and the *Global Sea Level Rise Scenarios for the United States National Climate Assessment* Curves

Local SLR Scenario (St. Petersburg, FL)	Feet Above 1992 Sea Level		
	2040	2070	2100
Highest	1.5	3.7	6.8
Intermediate-high	1.0	2.4	4.1
Intermediate-low	0.6	1.2	1.8
Lowest	0.37	0.60	0.84

[3] *Global Sea Level Rise Scenarios for the United States National Climate Assessment (2012)*

Option C: Use the four curves in *Global Sea Level Rise Scenarios for the United States National Climate Assessment* to generate local SLR scenarios by year – Advanced methodology

For the greatest accuracy, follow the detailed guidance in sections four and five of *Global Sea Level Rise Scenarios for the United States National Climate Assessment* to calculate local SLR estimates.

1. Use Table 1.5 below as a template to help you generate your estimates for the year 2100. As the table footnotes indicate, *Global Sea Level Rise Scenarios for the United States National Climate Assessment* provides more information about developing values for Table 1.5.

Table 1.5: Template for Calculating Local SLR for 2100

Contributing Variables	SLR Scenarios			
	Lowest Scenario	Intermediate Low Scenario	Intermediate High Scenario	Highest Scenario
Global mean SLR from 1992 to 2100 (ft)*	0.7	1.6	3.9	6.6
Vertical land movement (subsidence or uplift) (ft)**				
Ocean basin trend (from tide gauges and satellites) (ft)***				
Total Relative Sea Level Change (ft)				

* Equations from Section 4.3 of *Global Sea Level Rise Scenarios for the United States National Climate Assessment* can be used to calculate scenarios of sea level change over desired period and to populate the global mean SLR term in the first row.

** This row can be populated using, in part, the information found in Sections 5.1 of *Global Sea Level Rise Scenarios for the United States National Climate Assessment*.

*** This row can be populated using, in part, the information found in Sections 3.1, 3.2, 3.3 and 5.3 of *Global Sea Level Rise Scenarios for the United States National Climate Assessment*

2. Once you have generated values for 2100, create additional tables for your selected years between now and 2100. Use the quadratic equations in Section 4.3 of the *Global Sea Level Rise Scenarios for the United States National Climate Assessment* to complete the top row of each table. (There are equations for the "intermediate-low," "intermediate-high," and "highest" scenarios; for the "lowest" scenario, multiply the global mean SLR average (0.067 in/year) times the number of years since 1992.)

3. Once you have calculated local SLR for each of your selected time periods, create one final table with the total relative sea level change for each time period and each of the four SLR scenarios. This final table would follow the format of Table 1.4 shown above.

Task 2: Develop High-Water-Level Event Scenarios

Objective: Review historical data to select a range of high-water-level events. Integrate these data with SLR scenarios to select several water-level height increases that you will use for the basis of your risk or impact assessment.

Process to complete this task:

Step 1: Using the NOAA Extreme Water Levels map, find the "Exceedence Probability Curves" for the available city closest to your community. Use the bolded curve on the graph to determine the water-level increase relative to the mean higher high water (MHHW) level for any storm intensity from the 1-year storm to the 200-year storm. Consider selecting at least the 1-year, 2-year, 10-year, 30-year, 100-year, and 200-year storm in developing this initial table. (Note that "10-year storm" refers to a storm that is projected to occur once every 10 years. That is, such a storm has a 10 percent chance of occurring in any given year—it could happen more than once.) See the first two columns of Table 1.6, which show the storm-type and present water-level increases, for a sample of how this table might look. This table presents two SLR scenarios; however, your community may choose to examine more or fewer scenarios in your analysis.

Key considerations for this task:

- Did you consider extreme water-level increases? Considering that future climate change could exacerbate the strength and frequency of storms and global mean sea level is projected to increase at an accelerated pace, it is very important that a community develop informed adaptation strategies while considering the possibility of catastrophic water-level increases.
- Do you have the resources to perform a risk assessment? A risk assessment provides an apples-to-apples comparison of your costs and benefits; however, it requires assessing the impacts of significantly more water-level increases than an impact assessment.

What is a 100-year storm?

A 100-year storm has a 1-in-100—or 1 percent—chance of occurring in a given year. This does not guarantee that it will occur exactly once every 100 years, nor does it preclude it from happening twice in a year. Here are some example storm types and their associated annual probability of occurring:

- 200-year storm: 0.005 percent
- 100-year storm: 1 percent
- 30-year storm: 3.3 percent
- 10-year storm: 10 percent
- 2-year storm: 50 percent

Table 1.6: Sample Table of Water-Level Increases by Year (feet)

Scenario/Year	Present*	2040	2070	2100
Intermediate-Low SLR Scenario (3-Foot Rise by 2100)				
200-year storm	12	13	14	15
100-year storm	10	11	12	13
30-year storm	8	9	10	11
10-year storm	5	6	7	8
2-year storm	4	5	6	7
1-year storm	3	4	5	6
Highest SLR Scenario (6-Foot Rise by 2100)				
200-year storm	12	14	16	18
100-year storm	10	12	14	16
30-year storm	8	10	12	14
10-year storm	5	7	9	11
2-year storm	4	6	8	10
1-year storm	3	5	7	9

* These data are for illustrative purposes only and do not represent any particular exceedance probability curve.

Step 2: Expand your table to include your SLR scenarios from Chapter 1, Task 1. Add all the scenarios you developed for your chosen years. Table 1.6 shows what this might look like. The integrated water-level increase is the sum (it should be adequate to round to the nearest foot) of the water-level increase associated with a certain storm type and the water-level increase in your SLR scenario for that given year.

Step 3: Decide whether to perform an impact assessment or a risk assessment. The steps in either case are similar, but vary according to your decision—be sure to pay attention when specific steps for your assessment type are called out in each task. Risk assessment is significantly more resource intensive, but gives you a much more informative comparison of your costs and benefits.

When performing an impact assessment, you will assess three or four water-level increases as they relate to infrastructure. However, you could assess over 10 water-level

What is the difference between a risk assessment and an impact assessment?

An **impact assessment** calculates the dollar value of flooding damage for your selected water-level increases. A **risk assessment** takes the analysis one step further by multiplying the probability of each water-level increase occurring by the value of the impact to yield a direct comparison of expected costs and expected benefits.

increases to adequately perform a risk assessment. An impact assessment could give you enough information to assess what combination of events could justify the costs of implementing your adaptation strategies. A risk assessment factors in the probability of the storm and will allow you to directly compare your expected total costs and benefits, giving you a clearer answer as to whether your adaptation strategies are worthwhile. The risk assessment does not factor in the probability of an SLR scenario; there are no probabilities associated with each SLR scenario. That is, your community will select an SLR scenario as a given assumption, and perform a risk assessment for each SLR scenario you choose to assess. If you do choose an impact assessment and (on reaching the last chapter of this framework) find that you need more detailed cost and benefit data to make your decision, you can always go back and replicate many of these tasks for more water-level increases to perform a risk assessment.

Step 4: Select the water-level increases you will assess for either your impact or risk assessment. The specific process you will undertake for each assessment type is outlined below.

Option A: impact assessment

Select three or four water-level increases that represent a range of the values in your table. Consider choosing a low, medium, high, and perhaps catastrophic water-level increase. A low water-level increase may be, for example, an astronomical high tide, a 1-year storm, or SLR only. A catastrophic water-level increase may be, for example, the 200-year storm in 2100 under the "highest" SLR scenario or the water-level increase associated with the highest surge that has ever been experienced in your region of the country—Sandy, Katrina, etc. Create a table showing the selected water-level increases (see Table 1.7 for an example) and the associated storm type and SLR scenario combinations represented by those increases.

Table 1.7: Sample Table of Selected Water-Level Increases for the Impact Assessment

Water Height*	What Does This Height Represent?
3 feet	Present 1-year storm, intermediate-low SLR-only in 2100, high SLR only around 2055.
8 feet	30-year storm in present, 10 year-storm in 2100 under intermediate-low SLR scenario or 2055 under highest SLR scenario, 2-year storm in 2070 under highest SLR scenario, 1-year storm in 2085 under high SLR scenario.
12 feet	200-year storm in present, 100-year storm in 2070 under intermediate-low SLR scenario or 2040 under highest SLR scenario, 30-year storm in 2070 under highest SLR scenario.
18 feet	200-year storm in 2100 under highest SLR scenario.

* These data are for illustrative purposes only and do not represent any particular exceedance probability curve.

Option B: risk assessment

Choose one or more SLR scenarios for which you will assess every water-level increase in the table. For example, for the sample water-level increases in Table 1.6, you will assess water-level increases of 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, and 15 feet if you choose to assess only the intermediate-low scenario. If you choose to assess the highest scenario as well, you will also need to select water-level increases of 16

feet and 18 feet. In many cases, including this sample case, there is only a small increase in the number of water-level increases that you will need to assess as you consider more SLR scenarios.

Task 3: Assess Exposed Infrastructure for Your No-Action Scenario

Objective: Identify at-risk infrastructure and land area for each water-level increase.

Key considerations for this task:

- Are you interested in assessing the impacts to all infrastructure in your community (holistic approach), or will you be choosing one or two priority infrastructure elements to assess (priority infrastructure approach)?
- What is the complexity of your flooding map, and what are its limitations? Some are simplifications that just consider elevation and would show an area flooding even with a mountain shielding it from storm surge. Others account for this by evaluating how the connectivity of adjacent land parcels affect the flood waters (e.g., hills that prevent the tide from coming further inland. Does your modeling account for wave action?
- What is the resolution digital elevation map data? This will impact the uncertainty of your flood modeling.

Experts required for this task:

- GIS analysts to help your team use spatial data in Step 3.
- Inundation modeling expert, if available, to assist with all three steps.

Process to complete this task:

Step 1: Use water-level increases developed in the previous task and the NOAA Sea Level Rise and Coastal Flooding Impacts Viewer (where available) to make a reconnaissance-level assessment of the exposed land and infrastructure in your local community. Note that this step is not necessary to the analysis; when available, though, it can provide a useful visual of flooding in your community for 1- to 6-foot water-level increases.

Step 2: Determine whether you are interested in assessing the impacts to specific elements of your infrastructure such as a wastewater treatment plant, utility, or hospital (the priority infrastructure approach), or assessing the impacts to your community as a whole (the holistic approach). Generally, the tasks will be the same for either approach; however, certain tools and methodologies in this framework are more tailored toward a specific approach. Although the steps in each task will typically be the same either way, be sure to note cases in which a task calls out specific steps for your approach type.

Step 3: Determine the exposure, including the depth of flooding relative to the bottom of your infrastructure, for the infrastructure you will be considering in your analysis. While it is not critical to performing this step, it is helpful to understand how much of the water-level increase is due to permanent inundation from sea-level rise as that will impact your community differently from temporary flood from a high-water-level event such as storm surge or astronomical high tides. For both the holistic and priority-infrastructure approach, you might find that flooding levels are relative to one point of reference, typically MHHW, and the elevation data sets are relative to another point of reference, typically North American Vertical Datum. Use NOAA's Vertical Data Transformation

tool or another method to convert your data to a common reference point if this is the case. This step varies for the holistic and priority infrastructure approach.

Option A: holistic approach

This step of the process involves creating inundation (flooding) maps and will require GIS or inundation mapping experience. See the NOAA *Mapping Coastal Inundation Primer* for more information about different approaches to developing these models, data needs for each approach, and data resources. State and local GIS staff members can be a great resource to help you get elevation data and mapping tools; also useful are NOAA's Coastal LIDAR, NOAA's Digital Elevation Model Discovery Portal, USGS' National Elevation Dataset, USGS' Center for Lidar Information Coordination and Knowledge (CLICK), and the Open Topography portal—among others. Alternatively, consider using comprehensive tools such as the FEMA Hazus MH flooding tool and COAST. These tools also require expertise, but they are also programmed to monetize (or assign a dollar value to) the damage costs associated with water-level increase inputs. You can read more about them in **Appendix B.**

Option B: priority infrastructure approach

You can typically complete this step by determining the elevation of the bottom of your infrastructure relative to MHHW using elevation data such as a digital elevation map, and determining the depth of flooding associated with each water-level increase relative to MHHW selected in the previous task. For example, if your coastal infrastructure is 6 feet above MHHW, and your selected water-level increase is 14 feet above MHHW, you would assume approximately 8 feet of flooding relative to the base of your infrastructure.

Chapter 2: Assess What You Can Do Differently

Once your community understands the severity of your baseline risks from coastal flooding, the next step is to explore how to adapt to these risks. In this chapter, you will develop action scenarios, which will be composed of one or more adaptation strategies to make your community more resilient to coastal flooding. You can assess each action scenario to determine how it alters the severity of flooding in your community compared to your baseline case. This chapter will set the stage for you to apply dollar values to the damage of your no-action and action scenarios in order to arm your community with the information it needs to make fiscally and socially responsible decisions about implementing adaptation strategies.

Task 1:
Select Adaptation Strategies to Form Action Scenarios

↓

Task 2:
Re-Assess Exposed Infrastructure for Each Action Scenario

Case Study: Hampton Roads, Virginia

Outputs:
- Potential Action Scenarios
- Potential Reduction in Exposure

In Hampton Roads, the nation's 35th largest metropolitan area, the cities of Norfolk and Virginia Beach face starkly different decisions in selecting resilient infrastructure and adaptation strategies in response to higher anticipated sea level rises than any other Atlantic Coast metropolitan area. Norfolk is the financial, medical, and cultural center of the region, with a downtown waterfront of about 7 miles. Hard infrastructure projects, such as seawalls and levees, protect its major downtown assets and will likely be an important component of future adaptation. Virginia Beach, however, relies primarily on its tourism industry made possible by its miles of white sand beaches. Investments in beach nourishment have countered erosion while maintaining the natural aesthetic qualities of the beach.

Expertise required to complete Chapter 2:
- GIS analysts to help your team use spatial data in Task 2
- Land use attorney and planners to help select adaptation strategies in Task 1
- Civil engineers to help evaluate adaptation strategies in Task 2

Key resources referenced in Chapter 2 include:
- Adaptation strategy fact pages in **Appendix A** of this framework
- NOAA's *Adapting to Climate Change: A Planning Guide for State Coastal Managers*
- EPA's *Synthesis of Adaptation Options for Coastal Areas*
- UNEP's *Technologies for Climate Change Adaptation*
- UNESCO's Hazards Awareness and Mitigation in Integrated Coastal Area Management
- Climate Tech Wiki

Task 1: Select Adaptation Strategies

Objective: Develop action scenarios for flooding adaptation strategies. An adaptation strategy is an individual measure, such as elevating development, that reduces the impacts of flooding. An action scenario is a compilation of one or more of these strategies.

Key considerations for this task:

- Do your adaptation strategies directly respond to your risks?
- Do your action scenarios range in cost and effectiveness? A wide range of scenarios can establish the foundation for constructive discussions.
- What is the period of effectiveness of your adaptation strategies? Many solutions are only temporary and need to be combined with plans for managed retreat in the future.
- Can a combination of smaller adaptation strategies produce results at least as good as a more expensive adaptation strategy goal?

Experts required for this task:

- Land use attorney and planners to help select adaptation strategies in Steps 1 and 2.

Process to complete this task:

Step 1: Review Table 2.1 to identify possible adaptation strategies that could help reduce the exposure of infrastructure to coastal flooding in your community. Use **Appendix A,** which includes a fact sheet about each of the adaptation strategies in Table 2.1, to learn more about the cost, effectiveness, implementation obstacles, and other considerations about each measure. Investigate other measures not listed in the table that other communities have considered or implemented, like moving expensive equipment to higher ground in a hospital or other priority infrastructure. While Table 2.1 and Appendix A provide some general, introductory information, there are other factors to consider as you select adaptation strategies that include:

- The costs of strategies can vary significantly depending on the unique characteristics of your community.
- Non-economic factors such as legal challenges or public outreach needs can increase the resources needed to implement a strategy.
- The lifespan and effectiveness of any project will depend on the severity of future events.

Keep in mind that some of these adaptation strategies may be more geared to an entire community and others are more applicable to protecting priority infrastructure.

Step 2: Based on your list of possible adaptation strategies, develop one or more action scenarios. Each action scenario should consist of at least one adaptation strategy; you may want to combine strategies to enhance the effectiveness of the action scenario.

Table 2.1: How Adaptation Strategies Reduce the Impacts of Coastal Flooding

Adaptation Strategy	How This Adaptation Strategy Changes the Impacts of Coastal Flooding
Managed Retreat Policies	
Transfer of development rights (TDR)	Encourages future development to be located out of harm's way.
Purchase of development rights (PDR)	Encourages future development to be located out of harm's way.
Rolling easements	May discourage future development from being located in harm's way. Can lead to removal of existing development from harm's way as shorelines move inland.
Fee-simple acquisition (buyout)	Prevents new development from being located in harm's way and/or removes development currently in harm's way.
Infrastructure relocation	Relocates the infrastructure out of harm's way.
Tidal Management	
Storm-surge barriers	Prevents higher water from traveling through inlets or into estuaries up to a certain water-level increase.
Engineered Barriers	
Levees and dikes	Prevents flooding up to a certain water-level increase.
Sea walls	Prevents flooding up to a certain water-level increase.
Beach nourishment	Prevents flooding up to a certain water-level increase.
Sandbagging	Prevents flooding up to a certain water-level increase.
Infrastructure Modification/Design	
Elevated development	Reduces the damage caused by flooding by raising the infrastructure above ground level.
Flood-proofing infrastructure	Reduces the damage caused by flooding.
Floating development	Prevents flooding to structure as the development rises with the water.
Floodable development	Prevents structural damage up to a certain height. May contain some water which can prevent flooding of other assets.
Movable buildings	Allows for relocating the infrastructure out of harm's way.
Drainage systems	Manages flood water to reduce damage.
Land Use Policy	
Preservation of open space	Prevents future development from being located in harm's way. Preserved open space may also absorb flood water and/or serve as a buffer during inundation events.
Zoning in vulnerable areas	Minimizes or prevents future development from being in harm's way or requires future development to be more resilient to flooding.

Table 2.1: How Adaptation Strategies Reduce the Impacts of Coastal Flooding

Adaptation Strategy	How This Adaptation Strategy Changes the Impacts of Coastal Flooding
Development fees in vulnerable areas	Can be used to pay for flood mitigation measures and may encourage future development to be located out of harm's way.
Green Infrastructure	
Wetlands	Absorb water to reduce the overall water-level increase, and dissipate wave and storm surge energy.
Mangroves	Reduce the wave power, typically resulting in a smaller storm surge and a slightly lower water-level increase.
Oyster and coral reefs	Reduce the wave power, typically resulting in a smaller storm surge and a slightly lower water-level increase.
Living dunes	Prevent flooding up to a certain water-level increase.
Barrier island restoration	Reduces the wave power, typically resulting in a smaller storm surge and a slightly lower water-level increase.

Task 2: Re-Assess Your Exposed Infrastructure for Your Action Scenarios

Objective: Identify your infrastructure and land area at risk for each action scenario.

Key considerations for this task:

- Does your action scenario move infrastructure out of harm's way, reduce the level of flooding for a given water-level increase, or completely prevent flooding up to a certain water-level increase? The key to re-assessing the change in exposure, and ultimately the change in impacts, is to understand and make assumptions about how your action scenarios change coastal flooding and the resulting impacts compared to the no-action scenario.

Experts required for this task:

- GIS analysts to help your team use spatial data in Step 2.
- Civil engineers to help assess the effectiveness of your action scenario against coastal flooding. In Step 1.

Process to complete this task:

Step 1: Identify how each action scenario changes the coastal flooding impacts for each water-level increase identified in Chapter 1. Determine the impact of each action scenario. For example, does it move your infrastructure out of harm's way to completely prevent flood damage, reduce the frequency of inundation, prevent flooding up to certain water-levels, make the building more resilient against flooding, or combine some of these possibilities? See Table 2.1 and **Appendix A** for more information about how each flooding adaptation strategy reduces the impact of coastal flooding.

Step 2: Re-assess the exposure of your infrastructure for each action scenario. This step's complexity will depend on how your action scenario changes the level or impacts of flooding.

<u>If your action scenario prevents flooding up to a certain water-level increase:</u>

You will eliminate impacts of flooding for water-level increases up to a certain point; however, once that point is exceeded, the flooding impacts will be similar to those in a no-action scenario. For example, beach nourishment may prevent flooding completely up to a 5-foot water-level increase; for a 10-foot increase, though, the flooding might be the same as in the no-action scenario. This will not require GIS modeling beyond what you did in Task 3 of Chapter 1. Rather, you will just need to note the water-level increases for which impacts are prevented and those for which impacts will be similar to the no-action scenario.

<u>If your action scenario reduces the severity of flooding for a given water-level increase:</u>

You will need to determine by how much the level of flooding changes. For example, if a wetland restoration project or series of projects reduce a 10-foot water level by 1 foot, create a new GIS flood map for 1 foot less of flooding or note that you have 1 foot less of flooding for any priority infrastructure.

If your action scenario moves your infrastructure out of harm's way:

You will not need to create any new flood maps, since the level of flooding associated with a given water-level increase does not change. When you assign dollar values to the impacts in the next step, the difference in damage between your no-action and action scenarios will be the avoided damage to this relocated infrastructure.

If your action scenario increases the resilience of your infrastructure:

You will not need to create a new flood layer. For example, if you flood-proof or elevate your infrastructure, the amount of damage to your infrastructure will be reduced for a given level of flooding. Though this will not require a new flood map, it will reduce the monetized value of damage to that infrastructure for a given level of flooding, so you will have to track which infrastructure elements are involved and change the depth-damage curve in Chapter 3. By isolating the changes in damage to these particular buildings, you can estimate the avoided costs.

Chapter 3: Calculate Costs and Benefits

After determining the exposure of your infrastructure in both no-action and action scenarios, you can identify and then monetize—or assign a dollar value to—the impacts of coastal flooding on your infrastructure or your community. These include direct impacts from coastal flooding as well as impacts, both positive and negative, from implementing your adaptation strategies. In practice, it will be too resource intensive to monetize or quantify all impacts, so you will need to consider some impacts qualitatively to avoid underestimating the value of impacts.

Task 1: Identify Impacts

Task 2: Monetize Impacts

Task 3: Estimate Costs of Implementing Adaptation Strategies

Outputs:
- List of All Impacts
- Monetized or Quantified Costs and Benefits
- Capital and Maintenance Costs of Adaptation Strategies

Case Study: Lower Fox River Basin, Wisconsin

In the Lower Fox River Basin, Resources for the Future estimated flood damage with Hazus-MH Flooding Model, a GIS-based model developed for the Federal Emergency Management Agency (FEMA) to help local officials and emergency planners estimate losses from floods, earthquakes, and hurricanes. They modeled baseline flood damage estimates for 10-year, 50-year, 100-year, and 500-year flood events in terms of total building, content, and inventory loss; business interruption loss; the number of moderately damaged buildings; truckloads of debris generated; the number of displaced households; and agricultural losses—all based on the current land-use patterns. The predicted total losses ranged from $47.5 million for a 10-year flood event to almost $109 million for a 500-year flood.

Expertise required to complete Chapter 3:

- Experienced economists to help you identify and monetize the costs and benefits in Tasks 1 and 2
- GIS analysts to help your team use spatial data in comprehensive monetization tools in Task 2
- Engineers to help you estimate the costs of adaptation strategies in Task 3

Key resources referenced in Chapter 3 include:

- Monetization approaches in **Appendix B** of this framework
- Comprehensive tools including FEMA's Hazus-MH Flooding Model and the New England Environmental Finance Center's Coastal Adaptation to Sea Level Rise Tool (COAST)
- The U.S. Army Corps of Engineers' depth-damage functions
- Parametric software including RS Means, the RS Means Quick Cost Estimator, the U.S. Cost Success Estimator, and the Parametric Cost Engineering System

Task 1: Identify Impacts

Objective: Recognize and categorize the potential impacts of coastal flooding on your infrastructure and community and the impacts from implementing resilient infrastructure options.

Key considerations for this task:

- Are there additional impacts not included in the "Comprehensive Listing of Impacts" tables below that are specific to your community?
- Do you have internal team members with basic economic understanding to generate a list of impacts or will you need an economist to review your list?

Experts required for this task:

- Experienced economists to help you identify impacts in Steps 1-3.

Process to complete this task:

Step 1: Create a list of primary, secondary, and environmental impacts from flooding using Table 3.1 for input. Keep in mind that impacts will depend on the severity of flooding for certain action scenarios, and some impacts might not exist at all under certain action scenarios or water-level increases. However, for the purpose of this task, develop a single comprehensive list of all impacts that your community might face under any flooding scenario. If you are only assessing the impacts on priority infrastructure, create a similar list identifying the direct impacts to your infrastructure and resulting secondary impacts. You may want to provide a higher level of detail about the impacts such an inventory of specific content in the infrastructure damaged or components of the infrastructure that would be affected.

Step 2: List potential impacts of implementation, both positive and negative, for each adaptation strategy identified in your action scenario. See Table 3.2 for input. Make a separate list of impacts for each action scenario identified in Chapter 2. This step will be similar for both the priority infrastructure and holistic approach.

Step 3: Brainstorm whether your community needs to consider any other impacts, not listed in Tables 3.1 or 3.2. Add these to the two lists you developed. This step will be similar for both the priority infrastructure and holistic approach.

Table 3.1: List of Impacts from Flooding

Impact	*Tool or Measurement Methodology*						
	FEMA Hazus MH Flooding	COAST	Overlay Infrastructure-Level Economic Data on Flood-Depth Data	Use General Economic and Flood Data to Estimate Primary Damage	Non-Market Valuation Methodologies	Monetize Business Interruption Loss	Benefits Transfer
Primary Impacts							
Residential building damage*	●	●	●	●			●
Commercial building damage*	●	●	●	●			●
Damage to special facilities such as hazardous waste, wastewater treatment plants, landfills, and energy utilities*	●	●	●	●			●
Damage to essential facilities such as hospitals, fire stations, and schools*	●	●	●	●			●
Vehicle damage	●		●				●
Building content loss*	●	●	●				●
Road damage					●		●
Bridge damage	●						●
Railway damage							●
Crop loss	●						●
Loss of human life							●
Animal and livestock loss							●
Secondary Impacts							
Business interruption costs*	●					●	●
Debris cleanup	●						●
Emergency response	●						●
Evacuation costs	●						●
School hours loss					●		●
Rental income loss	●						●
Relocation costs	●				●		●
Displaced families	●				●		●
Roadway congestion					●		●

Table 3.1: List of Impacts from Flooding

Impact	*Tool or Measurement Methodology*						
	FEMA Hazus MH Flooding	COAST	Overlay Infrastructure-Level Economic Data on Flood-Depth Data	Use General Economic and Flood Data to Estimate Primary Damage	Non-Market Valuation Methodologies	Monetize Business Interruption Loss	Benefits Transfer
Anxiety and discomfort					●		●
Environmental Impacts							
Salinization of freshwater supply					●		●
Parks, campgrounds, and beaches destroyed					●		●
Wastewater intrusion					●		●
Erosion					●		●
Wetlands, mangroves, marshes, and estuaries destroyed					●		●
Other ecosystem service related costs					●		●

* Most substantial impacts for a typical community.

Table 3.2: List of Impacts from Implementing Adaptation Strategies

Impact	*Tool or Measurement Methodology*	
	Non-Market Valuation Methodologies	Benefits Transfer
Benefits		
Recreation with enhanced water quality	●	●
Property value increase in a protected community	●	●
Enhanced ability to attract new business	●	●
Quality of life (decreased anxiety, increased safety)	●	●
Enhanced aesthetics	●	●
Other ecosystem service related benefits	●	●
Other Costs		
Decreased aesthetics	●	●
Decreased access to a beach or harbor	●	●
Environmental damage from constructing or implementing the resilient infrastructure	●	●
Other ecosystem service related costs	●	●

Task 2: Monetize Impacts

Objective: Select tools and approaches to monetize costs and benefits of the impacts identified in Task 1 of this chapter based on available resources.

Process to complete this task:

Step 1: Determine which tools and approaches you will use to monetize your list of impacts. Review Tables 3.1 and 3.2 from the previous task to see the type of impacts each tool or approach can monetize. Review **Appendix B,** which includes more detailed information about all of the tools and approaches, to learn more about the approach, including a description, general process for performing it, level of effort needed, expertise needed, and important resources. Keep in mind that Appendix B does not list all possible monetization approaches—consult your economic expert for more suggestions. As for many of the comprehensive tools and monetization approaches, you can monetize many primary impacts by answering three questions.

- How high is the water for each flooding scenario?
- How badly will the water damage your priority assets?
- How much is the asset worth?

While comprehensive tools often rely on more generic data, they can be quite useful when performing the holistic approach and monetizing damage on a large number of infrastructure. However, when you are monetizing damage for priority infrastructure, you should use as much site-specific information as possible.

Key considerations for this task:

- Will you be able to monetize the most significant impacts? These typically include damage to priority infrastructure, buildings, and building contents, and sometimes business or utility interruption.
- Does it make sense for your community to use a comprehensive monetization tool —such as COAST or FEMA Hazus-MH Flooding—when performing this task? These are resource intensive but are sometimes your best option when performing the holistic approach.
- Can you monetize the impacts on your priority infrastructure without using comprehensive tools? Priority infrastructure can be unique, and you will generate more accurate damage estimates by leveraging site-specific data than relying on comprehensive monetization tools that may rely on more generic data.
- Is it possible to quantify any of the impacts that you cannot monetize? Doing so will provide more insight than just considering qualitatively.

Experts required for this task:

- Experienced economists to help you monetize the costs and benefits in Steps 1, 2, 3, 4, and 6.
- GIS analysts to help your team use spatial data in comprehensive monetization tools in Step 4.

Step 2: List the tool or approach you will use to monetize or quantify each impact you listed in Task 1 of the chapter. Otherwise, note that you will only consider that impact qualitatively.

Step 3: From the list of primary, secondary, and environmental impacts you plan to monetize or quantify, create tables that show which impacts are applicable at each water-level increase for your no-action scenario as well as each action scenario. This will help you focus on the impacts you need to monetize or quantify at each water-level increase. The contents of these tables will depend somewhat on whether you are performing the impact or risk assessment. The impact assessment approach involves creating one table with a column for each action scenario, whereas the risk assessment approach involves creating a separate table for each action scenario, including the no action scenario for each SLR scenario selected, so that you can assess costs for the different storm types and years selected in Chapter 1. If you performed an impact assessment as part of Chapter 1 Task 2, continue to use Option A. If you elected to perform a risk assessment, continue to follow Option B of this task.

Option A: impact assessment

Create a table listing the impacts due to coastal flooding that you plan to quantify or monetize. List the primary, secondary, and environmental impacts that are applicable at each water-level increase for the no-action and each action scenario. Table 3.3 shows how this table can look, however you will input monetized cost data in the next step. Keep in mind that many impacts may only be applicable for higher water-level increases or in a no-action scenario. For example, an action scenario that implements engineered barriers may eliminate impacts at certain water-level increases. If you are following the priority infrastructure approach, you may want to provide more detailed site-specific information than is shown in Table 3.3 such as the specific content in the infrastructure damaged or components of the infrastructure that would be affected at each water-level increase.

Table 3.3: Sample Table of Monetized Damage for the Impact Assessment

Water-Level Increase	No-Action Scenario Damage ($million)*	Action Scenario 1 Damage ($million)	Action Scenario 2 Damage ($million)
3 feet	**PRIMARY DAMAGE** Residential: $50 Commercial: $30 Public Infrastructure: $15 **SECONDARY DAMAGE** Business interruption: $5	**PRIMARY DAMAGE** Residential: None Commercial: None Public Infrastructure: None **SECONDARY DAMAGE** Business interruption: None	**PRIMARY DAMAGE** Residential: $25 Commercial: $15 Public Infrastructure: $7 **SECONDARY DAMAGE** Business interruption: $3
8 feet	**PRIMARY DAMAGE** Residential: $500 Commercial: $300 Public Infrastructure: $150 **SECONDARY DAMAGE** Business interruption: $50	**PRIMARY DAMAGE** Residential: None Commercial: None Public Infrastructure: None **SECONDARY DAMAGE** Business interruption: None	**PRIMARY DAMAGE** Residential: $250 Commercial: $150 Public Infrastructure: $75 **SECONDARY DAMAGE** Business interruption: $25
12 feet	**PRIMARY DAMAGE** Residential: $2,000 Commercial: $1,200	**PRIMARY DAMAGE** Residential: None Commercial: None	**PRIMARY DAMAGE** Residential: $1,000 Commercial: $600

Table 3.3: Sample Table of Monetized Damage for the Impact Assessment

Water-Level Increase	No-Action Scenario Damage ($million)*	Action Scenario 1 Damage ($million)	Action Scenario 2 Damage ($million)
	Public Infrastructure: $600 **SECONDARY DAMAGE** Business interruption: $200	Public Infrastructure: None **SECONDARY DAMAGE** Business interruption: None	Public Infrastructure: $300 **SECONDARY DAMAGE** Business interruption: $100
18 feet	**PRIMARY DAMAGE** Residential: $8,000 Commercial: $4,800 Public Infrastructure: $2,400 **SECONDARY DAMAGE** Business interruption: $800	**PRIMARY DAMAGE** Residential: $8,000 Commercial: $4,800 Public Infrastructure: $2,400 **SECONDARY DAMAGE** Business interruption: $800	**PRIMARY DAMAGE** Residential: $4,000 Commercial: $2,400 Public Infrastructure: $1,200 **SECONDARY DAMAGE** Business interruption: $400

*This is a simplified table for illustrative purposes and does not include all impacts such as environmental impacts. It is recommended to monetize as many impacts in your table as possible from Tables 3.1 and 3.2.

Option B: risk assessment

Create tables, one for the no-action scenario and one for each action scenario for each SLR scenario selected, for the impacts due to coastal flooding that you plan to quantify or monetize. List the primary, secondary, and environmental impacts that are applicable to each storm type and year you selected in Task 2 of Chapter 1. At this point, you may want to modify the years if you choose to change the timeframe of your analysis. You will need a separate set of tables for each SLR scenario you selected. Table 3.4 shows how one table might look for a sample no-action scenario (though at this step you would not yet have included monetized cost data, which is added in the next steps). Keep in mind that many impacts may only be applicable at higher levels of inundation or in a no-action scenario. For example, an action scenario that implements engineered barriers may eliminate impacts at certain water-level increases. If you are following the priority infrastructure approach, you can provide more detailed site-specific information than is shown in Table 3.3. For example, consider including the specific content of the infrastructure damaged or components of the infrastructure that would be affected at each water-level increase.

Table 3.4: Sample Table of Monetized Damage for the Risk Assessment

Storm Type	2010 Damage ($million)*	2040 Damage ($million)	2070 Damage ($million)	2100 Damage ($million)
1-year	**PRIMARY DAMAGE** Residential: $75 Public Infrastructure: $20 **SECONDARY DAMAGE** Business interruption: $5	**PRIMARY DAMAGE** Residential: $90 Public Infrastructure: $25 **SECONDARY DAMAGE** Business interruption: $5	**PRIMARY DAMAGE** Residential: $120 Public Infrastructure: $22 **SECONDARY DAMAGE** Business interruption: $8	**PRIMARY DAMAGE** Residential: $150 Public Infrastructure: $40 **SECONDARY DAMAGE** Business interruption: $10

Table 3.4: Sample Table of Monetized Damage for the Risk Assessment

Storm Type	2010 Damage ($million)*	2040 Damage ($million)	2070 Damage ($million)	2100 Damage ($million)
2-year	**PRIMARY DAMAGE** Residential: $150 Public Infrastructure: $40 **SECONDARY DAMAGE** Business interruption: $10	**PRIMARY DAMAGE** Residential: $200 Public Infrastructure: $135 **SECONDARY DAMAGE** Business interruption: $15	**PRIMARY DAMAGE** Residential: $350 Public Infrastructure: $200 **SECONDARY DAMAGE** Business interruption: $50	**PRIMARY DAMAGE** Residential: $750 Public Infrastructure: $200 **SECONDARY DAMAGE** Business interruption: $50
10-year	**PRIMARY DAMAGE** Residential: $750 Public Infrastructure: $200 **SECONDARY DAMAGE** Business interruption: $50	**PRIMARY DAMAGE** Residential: $950 Public Infrastructure: $300 **SECONDARY DAMAGE** Business interruption: $50	**PRIMARY DAMAGE** Residential: $1,200 Public Infrastructure: $400 **SECONDARY DAMAGE** Business interruption: $100	**PRIMARY DAMAGE** Residential: $1,875 Public Infrastructure: $500 **SECONDARY DAMAGE** Business interruption: $125
30-year	**PRIMARY DAMAGE** Residential: $1,875 Public Infrastructure: $500 **SECONDARY DAMAGE** Business interruption: $125	**PRIMARY DAMAGE** Residential: $2,200 Public Infrastructure: $1,100 **SECONDARY DAMAGE** Business interruption: $200	**PRIMARY DAMAGE** Residential: $3,200 Public Infrastructure: $1,500 **SECONDARY DAMAGE** Business interruption: $300	**PRIMARY DAMAGE** Residential: $7,500 Public Infrastructure: $2,000 **SECONDARY DAMAGE** Business interruption: $500
100-year	**PRIMARY DAMAGE** Residential: $7,500 Public Infrastructure: $2,000 **SECONDARY DAMAGE** Business interruption: $500	**PRIMARY DAMAGE** Residential: $15,000 Public Infrastructure: $4,000 **SECONDARY DAMAGE** Business interruption: $1,000	**PRIMARY DAMAGE** Residential: $22,000 Public Infrastructure: $11,000 **SECONDARY DAMAGE** Business interruption: $2,000	**PRIMARY DAMAGE** Residential: $38,000 Public Infrastructure: $18,000 **SECONDARY DAMAGE** Business interruption: $4,000
200-year	**PRIMARY DAMAGE** Residential: $32,000 Public Infrastructure: $15,000 **SECONDARY DAMAGE** Business interruption: $3,000	**PRIMARY DAMAGE** Residential: $48,000 Public Infrastructure: $22,000 **SECONDARY DAMAGE** Business interruption: $6,000	**PRIMARY DAMAGE** Residential: $70,000 Public Infrastructure: $35,000 **SECONDARY DAMAGE** Business interruption: $10,000	**PRIMARY DAMAGE** Residential: $100,000 Public Infrastructure: $60,000 **SECONDARY DAMAGE** Business interruption: $12,000

*This is a simplified table for illustrative purposes and does not include all damage such as damage from environmental impacts. It is recommended to monetize as many impacts in your table as possible from Tables 3.1 and 3.2.

Step 4: Perform the monetization or quantification, and list the monetized or quantified value next to the impacts in the table(s) you created in the previous step of this process.

Step 5: Create a table similar to Table 3.5 or 3.6 that compiles the total of all your monetized impacts. This table's contents will depend on whether you are performing the impact or risk assessment.

Option A: impact assessment

Sum the total of all monetized damage for each water-level increase for the no-action scenario and each action scenario. Table 3.5 provides an example, showing how costs from Table 3.3 were compiled.

Table 3.5: Sample Table of Compiled Monetized Damage for the Impact Assessment

Water-Level Increase	No-Action Scenario Damage ($million)	Action Scenario 1 Damage ($million)	Action Scenario 2 Damage ($million)
3 feet	$100	$0	$50
8 feet	$1,000	$0	$500
12 feet	$4,000	$0	$2,000
18 feet	$16,000	$16,000	$8,000

Option B: risk assessment

Sum the total of all monetized damage for each storm type at each year. Create one table for each table developed in the previous step of this process; include a column for the annual probability of each storm type. For example, the 2-year storm occurs on average once every 2 years, so its annual probability is 0.5. Table 3.6 provides an example, showing how costs from Table 3.4 were compiled for a sample no-action scenario.

Table 3.6: Sample Table of Compiled Monetized Damage for the Risk Assessment

Storm Type	Annual Probability	2010 Damage ($million)	2040 Damage ($million)	2070 Damage ($million)	2100 Damage ($million)
1-year	1	$100	$120	$150	$200
2-year	0.5	$200	$350	$600	$1,000
10-year	0.1	$1,000	$1,300	$1,750	$2,500
30-year	0.033	$2,500	$3,500	$5,500	$10,000
100-year	0.01	$10,000	$20,000	$35,000	$60,000
200-year	0.005	$50,000	$76,000	$115,000	$172,000

Step 6: Monetize or quantify all of the benefits and other costs that you can from the list you created in Task 1, Step 2 of this chapter. These are typically independent of the water-level increase. You will probably just need to do this once for each benefit or other cost within each action scenario.

Task 3: Estimate Costs of Implementing Adaptation Strategies

Objective: Identify and estimate all capital and maintenance costs of implementing the adaptation strategies in your action scenario.

Key considerations for this task:

- Can you find cost data from other similar adaptation projects? This can be an easy way to do a preliminary analysis of your best action scenarios. If you decide that an action scenario is a top candidate to implement, consider getting a more precise estimate from an architecture or engineering firm.

Experts required for this task:

- Engineers to help you estimate the costs of adaptation strategies in Step 2.

Process to complete this task:

Step 1: Get existing cost data about similar projects in your community or other communities. You may be able to find this information by reviewing **Appendix A** for your adaptation strategy, performing Internet searches for case studies, or asking other community leaders about their projects.

Step 2: Develop estimates for the capital costs, maintenance costs, and timing of each maintenance cost for each adaptation strategy within each action scenario using existing data and parametric software, or by consulting an architectural or engineering firm. Keep in mind that some capital costs will be incurred in the near future and others will not be incurred until later in the planning horizon. Try to get specification details and information about the useful life of each measure. Do not overlook planning costs in the initial capital costs or administrative costs in the maintenance costs.

Table 3.7: Parametric Software

Software	Overview
RS Means	Used for high-level "assembly" costs, as well as more detailed estimates for individual building systems and components. ***Level of technical expertise needed:*** An engineering background and training with this software. ***Availability:*** Check with your local planning public works engineering offices.* ***Cost:*** $100 to $1,000.
RS Means Quick Cost Estimator	Online database providing planning-level costs based on building type, square footage, and location; however, it may only apply to limited building-related adaptation strategies. ***Level of technical expertise needed:*** It is a basic online system that requires simple entry of building type, square footage, and location. ***Availability:*** Online. ***Cost:*** Free.

Table 3.7: Parametric Software

Software	Overview
U.S. Cost Success Estimator	Performs detailed bottom-up analyses. Provides the ability to integrate with commonly used design tools and draw from multiple cost databases. ***Level of technical expertise needed:*** An engineering background and training with this software. ***Availability:*** Check with your local planning or public works engineering offices. ***Cost:*** $4,295.
Parametric Cost Engineering System	Prepares parametric cost estimates for new facility construction, renovation, and life cycle cost analysis using pre-engineered model parameters and construction criteria. ***Level of technical expertise needed:*** An engineering background and training with this software. ***Availability:*** Check with your local planning or public works engineering offices. ***Cost:*** $850 for federal government users; $3,000 all other users.

* If your local community does not have a public works engineering office or another local planning office with someone trained to use one of these parametric software programs, it can be quite resource intensive to invest in training, and it may be worthwhile to consult an engineering firm.

Chapter 4: Make a Decision

Now you will compile the monetized, quantitative, and qualitative data you developed in the previous chapter and decide whether your action scenario makes financial sense—whether the benefits outweigh the costs. If you prepared multiple action scenarios, more than one of them might make financial sense; in that case, you will want to find the best option for your community based on the cost-benefit results, financial feasibility, and other relevant considerations.

Task 1: Calculate Total Benefits of Each Action Scenario

Task 2: Compile the Capital and Maintenance Costs

Task 3: Assess Each Action Scenario

Outputs:
- Total Benefits of Action Scenarios
- Timelines of Capital and Maintenance Costs
- Ranking of Action Scenarios

Case Study: Old Orchard Beach, Maine

Old Orchard Beach, a popular summer beach destination in southern Maine, assessed three action scenarios for dealing with increased coastal flooding due to SLR: taking no action, nourishing the beach within the 100-year floodplain, and nourishing the beach within the 50-year floodplain. The city reviewed each scenario under high, low, and no SLR conditions, concluding that the robust decision was to nourish the beach within the 100-year floodplain. With no SLR, the city predicted that this action would have only slightly higher costs than the 50-year nourishment strategy; with low or high SLR, they predicted lower damage and costs. They also found that taking no action would result in higher costs under all SLR conditions.

Expertise required to complete Chapter 4:

- Experienced **economists** to help you determine a discount rate in Task 2 and interpret your results in Task 3

Key resources referenced in Chapter 4 include:

- Discount rate guidance: Office of Management and Budget's Circular A-4, "Regulatory Analysis"
- Discount rate guidance: EPA's *Guidelines for Preparing Economic Analyses*, Chapter 6

Task 1: Calculate Total Benefits of Each Action Scenario

Objective: Calculate the total benefits of each action scenario for each high-water-level event using damage and other costs and benefits monetized in Chapter 3.

Process to complete this task:

The steps in this process are different for the impact and risk assessment. If you performed an impact assessment as part of Chapter 1 Task 2, continue to use Option A. If you performed a risk assessment, continue to follow Option B of this task.

Key considerations for this task:

- What discount rate will you choose if you are performing the risk assessment?
- Would it be helpful to your discussion to choose multiple discount rates?

Option A: impact assessment

Step 1: Create a table that lists total benefits by water-level increase for each action scenario, similar to the example shown in Table 4.1, which shows the total benefits of just one action scenario. The rows for this table will correspond to the water-level increases you chose to assess in Chapter 1. Steps 2 to 4 below explain more about where to gather data and how to make the calculations for this table.

Table 4.1: Example Table of Total Benefits for the Impact Assessment

Water-Level Increase	No-Action Scenario Damage ($million)	Action Scenario 1 Damage ($million)	Action Scenario 1 Other Monetized Benefits ($million)	Action Scenario 1 Other Costs ($million)	Action Scenario 1 Total Monetized Benefits ($million)
3 feet	$100	$50	$25	$5	$70
8 feet	$1,000	$500	$25	$5	$520
12 feet	$4,000	$2,000	$25	$5	$2,020
18 feet	$16,000	$8,000	$25	$5	$8,020

Step 2: Add monetized damage of inundation for no-action and action scenario(s) from Step 5 of Task 2 in Chapter 3 to this table.

Step 3: Add other costs and benefits data for each action scenario from Step 6 of Task 2 in Chapter 3 to this table. These other costs and benefits are typically the same across water-level increases. As discussed in Chapter 3, they can often be quite difficult to assign a dollar value to—you may need to just consider them qualitatively, in which case you would put $0 into the appropriate fields of this table but footnote the qualitative costs and benefits.

Step 4: Calculate the total benefits for each water-level increase using Equation 4.1 and add to your table:

$$Ben_T = IC_{NA} - IC_A + Ben_A - OC_A \qquad \textit{(Equation 4.1)}$$

$$\$8{,}020 \text{ (million)} = \$16{,}000 - \$8{,}000 + \$25 - \$5$$

(sample data from Table 4.1 at an 18-foot water-level increase)

Where:

Ben_T = total benefits
IC_{NA} = no-action scenario damage
IC_A = action scenario damage
Ben_A = action scenario benefits
OC_A = other monetized action scenario other costs

In many cases, your benefits and other costs may just be qualitative or quantitative, and your monetized total benefits will simply be calculated from avoided costs: the difference in the losses from flooding associated with no-action and those associated with your action scenario. Non-monetized benefits should be described and, to whatever extent possible, quantified. These benefits should be considered in the final plan selection, as shown in Table 4.7 below.

Qualitative and Quantitative Benefits

Qualitative benefits are simply a description of the benefit. These should always be considered in decision making as they can be substantial, but it can often be difficult to weigh them against **Monetized** costs, which have been assigned dollar value. **Quantitative** benefits provide additional information by assigning a non-monetary value to the benefit such as number of fishing days enhanced by improved water quality. When it is not possible to monetize benefits, you should at least try to quantify them as it provides further information beyond a qualitative description for making informed cost-benefit decisions.

Option B: risk assessment

Step 1: Create tables of the average and expected damage for select years, similar to the example shown in Table 4.2, which shows damage for the sample no-action scenario. The equations in subsequent steps show how to calculate the values for the tables. Average damage provides an average across storms of varying severity, and expected damages factors in the probability of those different storms occurring. Create one table under each SLR scenario for the no-action scenario and each action scenario. Calculations for this table are shown in Steps 2 to 4 below.

Table 4.2: Sample Table of Annual Loss for Select Years for the Risk Assessment

	Year	2010		2040		2070		2100	
Storm Type	**Annual Probability**	**Average Damage ($billion)**	**Expected Damage ($billion)**	**Average Damage ($billion)**	**Expected Damage ($billion)**	**Average Damage ($billion)**	**Expected Damage ($billion)**	**Average Damage ($billion)**	**Expected Damage ($billion)**
1- to 2-year	0.5	0.15	0.08	0.24	0.12	0.38	0.19	0.60	0.30
2- to 10-year	0.4	0.60	0.24	0.83	0.33	1.18	0.47	1.75	0.70
10- to 30-year	0.067	1.75	0.12	2.40	0.16	3.63	0.24	6.25	0.42
30- to 100-year	0.023	6.25	0.15	11.75	0.27	20.25	0.47	35.00	0.82
100- to 200-year	0.005	35.00	0.15	48.00	0.24	75.00	0.38	116.00	0.58
Beyond 200-year	0.005	50.00	0.25	76.00	0.38	115.00	0.58	172.00	0.86
Expected Annual Loss ($billion)			0.98		1.50		2.32		3.67

Step 2: Calculate the annual probability of consecutive storm types for each year in your table using Equation 4.2, and add these data to your table. For the biggest storm type, the annual probability is just the probability of that storm type. This is the second column of Table 4.2.

$$AP_{XY} = AP_X - AP_Y \qquad \textit{(Equation 4.2)}$$

$$0.4 = 0.5 - 0.1$$

(sample data from Table 4.2 for the annual probability of a 2- to 10-year storm)

Where:

X and ***Y***	=	different storm types, for example, a 1-year and 2-year storm
AP_{XY}	=	annual probability of storm type *X* to storm type *Y*
AP_X	=	annual probability of storm type *X*
AP_Y	=	annual probability of storm type *Y*

Step 3: Calculate the average damage of consecutive storm types for each year in your table using Equation 4.3, and add these data to your table. For the biggest storm type, the average damage is just the monetized damage for that storm type from Step 5 of Task 2 in Chapter 3. These data are calculated for four different years in Table 4.2.

$$AD_{XYN} = (MD_{XN} + MD_{YN}) \div 2 \qquad \textit{(Equation 4.3)}$$

$0.83 (billion) = ($0.35 + $1.30) ÷ 2
(sample data from Table 3.6 for 2- to 10-year storm in 2040)

Where:

AD_{XYN}	=	average damage of storm type *X* to storm type *Y* at year *N*
N	=	year
MD_{XN}	=	monetized damage of storm type *X* at year *N*
MD_{YN}	=	monetized damage of storm type *Y* at year *N*

Step 4: Calculate the expected damage of consecutive storm types for each year in your table using Equation 4.4, and add these data to your table. These data are calculated for four different years in Table 4.2.

$$ED_{XYN} = AD_{XYN} \times AP_{XY} \qquad \textit{(Equation 4.4)}$$

$0.33 (billion) = $0.83 x 0.4
(sample data from Table 4.2 for 2- to 10-year storm in 2040)

Where:

ED_{XYN}	=	expected damage of storm type *X* to storm type *Y* at year *N*
AP_{XY}	=	annual probability of storm type *X* to storm type *Y*
AD_{XYN}	=	average damage of storm type *X* to storm type *Y* at year *N*

Step 5: Calculate the expected annual loss across all storm types for each year by summing the expected damage for all storm types in your table for that given year. This is shown in the bottom row of Table 4.2.

Step 6: Create timelines showing the expected annual loss for each year, as shown in Table 4.3, which shows a timeline for the sample no-action scenario. Create one timeline for each table developed in Step 2 of this process. Create columns at annual increments, beginning with the first year for which you calculated losses and ending at the last year of your assessment. Steps 7 and 8 explain more about completing this timeline.

Table 4.3: Sample Timeline of Annual Loss for the Risk Assessment

Year	2010	2011		2039	2040		2069	2070		2099	2100
Expected Annual Loss ($billion)	0.98	0.99		1.48	1.50		2.29	2.32		3.63	3.67

Note: The years in this table should continue uninterrupted from the first year of the analysis until the final year.

Step 7: Input the expected annual losses from Step 5 directly into your timeline. In the example provided in Table 4.2, this includes data from 2010, 2040, 2070, and 2100.

Step 8: Calculate the values for each year between the selected years from Step 6. Assume that the losses increase or decrease linearly between select years. For example, in Table 4.3 the damage is $1.50 billion in 2040 and $2.32 billion in 2070, and the average annual increase over that 30-year window is $0.027 billion. Thus, the annual loss is assumed to increase by $0.027 billion starting in 2040 until 2070.

Step 9: If the benefits or other costs are monetized and differ from select year to select year, in the absence of a methodology that better estimates the monetized values for the years between your estimates, repeat Steps 7 and 8 above to create timelines for the value of benefits or other costs.

Step 10: Compile data from your timelines in the preceding steps to create a comprehensive timeline (as illustrated in Table 4.4 for one action scenario) showing annual total benefits, present value of annual total benefits, and net present value (NPV) of total benefits. Create one timeline for each action scenario under each SLR scenario. You can choose to include one or multiple discount rates. Steps 11 to 13 provide more information about where to get data and how to make calculations for this table.

Table 4.4: Sample Timeline of the Present Value of Total Benefits for the Risk Assessment

Year	2010	2011		2039	2040		2069	2070		2099	2100	
Expected Annual Loss (No Action) ($billion)	0.98	0.99		1.48	1.50		2.29	2.32		3.63	3.67	
Expected Annual Loss (Action Scenario 1) ($billion)	0.33	0.33		0.49	0.50		0.76	0.77		1.21	1.22	
Action Scenario Annual Benefits ($billion)	0.05	0.05		0.05	0.05		0.05	0.05		0.05	0.05	
Action Scenario Other Costs ($billion)	0.02	0.02		0.02	0.02		0.02	0.02		0.02	0.02	
Annual Total Benefits ($billion)	0.68	0.69		1.02	1.03		1.56	1.58		2.45	2.48	**NPV**
Present Value of Total Benefits (3 Percent Discount Rate) ($billion)	0.68	0.67		0.43	0.42		0.27	0.27		0.18	0.17	33.95
Present Value of Total Benefits (No Discounting) ($billion)	0.68	0.69		1.02	1.03		1.56	1.58		2.45	2.48	127.26

Note: The years in this table should continue uninterrupted from the first year of the analysis until the final year.

Step 11: Pull expected annual loss data for both your no-action and action scenario created in Steps 6 through 8, as well as annual benefits and other cost data created in Step 9, into your comprehensive timeline. Refer to the first four rows of Table 4.4.

Step 12: Calculate annual total benefits for each year using Equation 4.5, and add these data to your table. In Table 4.4, these data correspond to the fifth row below the header.

$$Ben_{TN} = IC_{NA\text{-}N} - IC_{AN} + Ben_{AN} - OC_{AN} \qquad \textbf{(Equation 4.5)}$$

$$\$0.69\ (billion) = \$0.99 - \$0.33 + \$0.05 - \$0.02$$

(sample data from Table 4.4 ***for 2011*** total benefits)

Where:

Ben_{TN}	=	total benefits at year *N*
$IC_{NA\text{-}N}$	=	no-action scenario damage at year *N*
IC_{AN}	=	action scenario damage at year *N*
Ben_{AN}	=	action scenario benefits at year *N*
OC_{AN}	=	action scenario other costs at year *N*

Step 13: Calculate the present value of total benefits for each year using Equation 4.6, and add these data to your table. You can make this calculation for one or more discount rates. In Table 4.4, these data correspond to the bottom two rows.

$$Ben_{PVND} = Ben_{TN} / (1 + D)^{(N\text{-}Y0)} \qquad \textbf{(Equation 4.6)}$$

$$\$0.27\ (billion) = \$1.58 / (1 + 0.03)^{(2070\text{-}2010)}$$

(sample data from Table 4.4 ***for 2070*** net present value of total benefits)

Where:

Ben_{PVND}	=	present value of benefits at year *N* for discount rate *D*
Ben_{TN}	=	total benefits at year *N*
D	=	discount rate
N	=	year you are assessing in the table
$Y0$	=	current year

Discounting Future Dollars—The "Discount Rate"

- Dollar values associated with future costs and benefits are typically discounted, because a dollar received today is considered more valuable than one received in the future. This allows dollar values associated with long-term costs and benefits to be compared equally against the values of short-term costs and benefits.
- The discount rate is the rate at which society as a whole is willing to trade present for future benefits, and it helps to account for inflation and other factors. However, determining the discount rate can be a source of controversy, and as shown in Table 4.4, it can significantly affect the analysis. Therefore, it would be helpful to consult an economic expert before selecting a discount rate.

Step 14: Calculate NPV of total benefits at each discount rate chosen. See Table 4.6 for resources about choosing a discount rate. The NPV is simply the sum of the present value of benefits for a given discount rate across all years. In Table 4.4, these data correspond to the bottom two rows in the last column.

Task 2: Calculate the Capital and Maintenance Costs

Objective: Determine the NPV of total costs for each action scenario using cost data from Task 3 of Chapter 3.

Key considerations for this task:

- What discount rate will you choose if you are performing the risk assessment?
- Would it be helpful to your discussion to choose multiple discount rates?

Experts required for this task:

- Economists to help you determine a discount rate in Step 4.

Process to complete this task:

Step 1: Create a timeline outlining the capital and maintenance costs using data outputs from Task 3 in Chapter 3 for each adaptation strategy within each of your action scenarios. Table 4.5 shows what this timeline might look like for a given action scenario. Create one table for each action scenario. Add a row for each adaptation strategy within an action scenario, as well as rows for total costs, present value of total costs, and NPV of total costs. The column headers will include capital costs and maintenance costs for any year in which you expect maintenance to be performed for any adaptation strategy. Steps 2 to 6 provide further information about where to get data and how to make calculations for this table.

Table 4.5: Sample Timeline of Capital and Maintenance Costs and NPV

Cost Type	**Capital ($million)**	**Maintenance ($million)**	**Maintenance ($million)**	**Maintenance ($million)**	**Maintenance ($million)**	**Maintenance ($million)**
Year	2010	2020	2030	2040	2050	2060
Adaptation Strategy 1	$180	$175	$175	$175	$175	$175
Adaptation Strategy 2	$3,000	$17	$17	$17	$17	$17
Adaptation Strategy 3	$7,000	$0	$0	$0	$0	$0
Total cost for Action Scenario 1	$10,180	$192	$192	$192	$192	$192
Present value of total costs*	$10,180	$143	$106	$79	$59	$44
NPV of Total Costs ($million)	**$10,611**					

* Assumes a 3 percent discount rate.

Step 2: Add capital and maintenance cost information to this table from your outputs in Task 3 in Chapter 3.

Step 3: Calculate the total capital and maintenance cost for each year in your table by summing these costs across all adaptation strategies within a given year.

Step 4: Choose a discount rate or multiple discount rates in order to calculate the present value of these costs. Consult your economic expert and Table 4.6 below.

Table 4.6: Resources for Choosing a Discount Rate

Resource	Key Information
State agencies	Some states have guidance on using discount rates and may have adopted rates to use for performing cost-benefit analyses.
Office of Management and Budget's Circular A-4, "Regulatory Analysis"	Provides information on using discount rates in cost-benefit analyses, including rationale for using discount rates, considerations about intergenerational discounting, and a recommendation to at least consider 3 percent and 7 percent discount rates.
EPA's *Guidelines for Preparing Economic Analyses,* Chapter 6	Provides information on using discount rates in cost-benefit analyses, including an overview of discounting, information about NPV, issues in applying discount rates, and recommended approaches.

Step 5: Calculate the present value of capital and maintenance costs at each year using Equation 4.7, and add these data to your table. This equation applies to both future maintenance and future capital costs. You can perform this calculation for one or more discount rates. In Table 4.4, these data correspond to the bottom two rows.

$$Cost_{PVND} = Cost_{TN} / (1 + D)^{(N-Y0)} \qquad \textit{(Equation 4.7)}$$

$$\$106\ (million) = (\$175 + \$17 + \$0) / (1 + 0.03)^{(2030-2010)}$$

(sample data from Table 4.5 for maintenance costs in 2030)

Where:

$COST_{PVND}$	=	present value of costs at year *N* for discount rate *D*
$Cost_{TN}$	=	total costs at year *N* (from step 3)
D	=	discount rate
N	=	year you are assessing in the table
Y0	=	current year

Step 6: Calculate NPV of total capital and maintenance costs at each discount rate selected. This is simply the sum of the present value of costs for a given discount rate across all years. In Table 4.5, this value is in the bottom row.

Task 3: Assess Each Action Scenario

Objective: Identify the action scenarios, if any, whose total benefits exceed total costs—both monetized and qualitative. Rank these based on the cost-benefit results, financial feasibility, and any other considerations you might have.

Key considerations for this task:

- Did you factor qualitative and quantitative impacts and benefits into your monetized results? These can help you choose the best action scenario or decide whether an action scenario is worthwhile, especially when the monetized results are less conclusive.
- Did you assess the feasibility of paying both capital and maintenance costs in each action scenario? Communities often neglect to plan how to finance maintenance and administrative costs.

Experts required for this task:

- Economists to help you interpret your results in Steps 1 and 2.

Process to complete this task:

Step 1: Assess the monetized cost-benefit results of each action scenario. This step differs slightly for the risk and impact assessments.

Option A: impact assessment

Compare the NPV of total costs calculated in Task 2 of this chapter to the total benefits of each action scenario calculated in Task 1. In determining whether an action scenario makes financial sense, consider what types of coastal flooding events must occur for total benefits to outweigh costs. One or two frequent, low-water-level increase scenarios might justify an action, perhaps indicating a worthwhile scenario. Alternatively, it might require 10 huge high-water-level events for total benefits to exceed NPV of total costs, perhaps indicating a bad financial decision.

Option B: risk assessment

Calculate the net benefits—the difference in NPV of total benefits calculated in Task 1 of this chapter and NPV of total costs calculated in Task 2 of this chapter. Calculate the benefit-to-cost ratio—NPV of total benefits divided by NPV of total costs. Make these calculations for each action scenario under each SLR scenario. Table 4.7 provides an example.

Table 4.7: Sample Net Benefit and Benefit to Cost Calculations for a Risk Assessment

	NPV of Total Benefits*	NPV of Total Costs	Net Benefits	Benefit-to-Cost Ratio	Non-Monetized Benefits
Action Scenario 1	$33.95 billion	$10.61 billion	$23.34 billion	3.2:1	Medium
Action Scenario 2	$1.5 billion	$0.5 billion	$1 billion	3:1	High
Action Scenario 3	$25 million	$5 million	$20 million	5:1	Low

* The NPV of Total Benefits and NPV of Total Costs for Action Scenario 1 are pulled from Tables 4.4 and 4.5, respectively, and assume a 3 percent discount rate. Values for Action Scenario 2 and 3 were not derived from another table in this framework but are included for illustrative purposes.

Step 2: For each action scenario, decide whether the benefits outweigh the costs. As well as the monetized costs and benefits you have just tabulated, consider qualitative and quantitative impacts and benefits. When the monetized results are less conclusive, these considerations may make the difference. (When the monetized results are overwhelming in one direction, on the other hand, they may not affect the outcome.) Also consider the implications of non-monetized co-benefits described in Task 1 of this Chapter. These non-monetized benefits can tip the balance in favor of scenarios with a lower monetized benefit-to-cost ratio, indicating that they may warrant a higher ranking than would be indicated by monetized values alone.

Step 3: Assess the feasibility of funding each action scenario that you found to be potentially worthwhile. Determine the feasibility of funding the capital and maintenance costs for each action scenario.

Step 4: Rank your action scenarios from best to worst based on the first three steps of this process and any other factors you want to bring into the discussion.[4] Remember to factor in the outcome of the monetized cost-benefit analysis, qualitative and quantitative impacts, and funding feasibility. In the sample data in Table 4.7, for example, action scenario 1 could have the highest net benefits and the second highest benefit-to-cost ratio; however, for many communities, the inability to finance such a measure could make it an inferior option.

[4] The FEMA "STAPLEE" method is one process for considering a range of factors. This method is designed to help planning teams consider in a systematic way the Social, Technical, Administrative, Political, Legal, Economic, and Environmental (STAPLEE) opportunities and constraints of implementing a hazard mitigation action. This method is detailed in a FEMA guide entitled Developing the Mitigation Plan: Identifying Mitigation Actions and Implementation Strategies, which is available online at http://www.fema.gov/library/viewRecord.do?id=1886.

Conclusion: Economics is Only One Piece of Informed Decision-making

Understanding short and long-term costs and benefits of different adaptation strategies, as well as the costs of not taking action, is critical to making resilience-minded decisions that are fiscally and socially responsible. But community decisions are not based solely on economics. Other factors will need to be considered prior to implementing an action scenario—including social feasibility, community culture, and administrative and legal aspects. While economics are a very important criterion to consider, the unique conditions, history, and desired vision of each community will influence decisions about how to plan for and adapt to inundation threats from sea level rise and storms. As mentioned at the beginning of this guide, we recommend community leaders engage area stakeholders and residents in the decision process to develop a complete picture of community interests. Applying this framework can produce economic information that will be an important part of a community discussion.

Appendix A: Adaptation Strategies

The fact sheets in this appendix provide general, introductory information about a variety of adaptation strategies that communities may consider. Many of these strategies could be used to protect either private property or public infrastructure. Some of the strategies are traditionally employed to protect private property but could also be viable options to protect public property as well. This appendix is not intended to be a comprehensive inventory, but rather to introduce a range of strategies that help illustrate varying approaches: managed retreat policies, tidal management, engineered barriers, infrastructure modification/design, land use policy, and green infrastructure.

The fact sheets provide an overview of costs, effectiveness, and barriers to implementation. When reviewing these strategies for use in your own community, keep in mind that:

- Costs can vary significantly depending on the unique characteristics of your community and the exact nature of a project or policy,
- Non-economic factors such as legal challenges or public outreach needs can increase the resources needed to implement a strategy,
- The lifespan and effectiveness of any project will depend on the severity of future events.

Some fact sheets include special considerations for certain adaptation strategies, but when investigating any potential strategy a community will need to consider a number of factors such as social feasibility, environmental impacts, and administrative and legal aspects.

The current state of knowledge pertaining to adaptation strategies is growing rapidly as more and more communities seek and test out solutions to current and future inundation hazards. Communities should seek out additional sources of information to learn more about the strategies contained in this appendix and to identify additional strategies. The resources listed in the "Key References" text box in Chapter 2 of this framework as well as those that follow are a few potential sources of additional information:

- The Federal Emergency Management Agency (FEMA) has a variety of publications related to flood hazard mitigation measures, including guidance documents as well as case studies. FEMA recently released Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards, which includes actions to mitigation risks from storm surge, flood, and sea level rise.
- The U.S. Army Corps of Engineers (USACE) has resources related to both structural and non-structural flood mitigation measures. Visit the Flood Risk Management for State and Local Partners section of the USACE Flood Risk Management Program website for more information.
- The Georgetown Climate Center has a searchable Adaptation Clearinghouse that provides more detailed information on a wide range of adaptation measures.
- NOAA's Adapting to Climate Change: A Planning Guide for State Coastal Managers includes a chapter on adaptation strategies, many of which are related to inundation hazards.

Fact Sheet A-1: Transfer of Development Rights

A transfer of development rights (TDR) ordinance provides a way for property owners to transfer development rights from one area to another. In the context of coastal flooding, this can be used as a measure to move future development from vulnerable areas to those that are completely out of harm's way. Additionally, TDR programs can be used to preserve open space, thereby facilitating the implementation of other mitigation measures, such as wetlands development or other green infrastructure to further increase a community's resilience to coastal flooding. TDRs are usually administered through a local government zoning ordinance, with specific districts zoned as either sending or receiving parcels. It is the local government's responsibility to determine the specific number and type of development rights (usually in terms of dwelling units or floor area per acre) that will be transferred. Once the transaction is complete, development rights are legally separated from the first "sending" parcel of land and attached to the second "receiving" parcel for use by the owner for development.[1]

Cost

TDR is a low-cost option for local governments because they are typically only responsible for the costs of developing and implementing the program through its planning and zoning functions, while the owners and sellers typically pay the costs for the development rights. Sometimes, local governments include transaction fees with the cost of the development rights when they are sold to help offset the costs of administering the program.

Effectiveness

TDR can be a highly effective and long-term solution to mitigate impacts of coastal flooding, as long as the development parcels are moved out of harm's way—to higher, further inland, and more protected areas.

Barriers to Implementation

TDR can be legally complex to implement and is generally not quickly implemented. For a program to be effective, TDR requires purchaser demand for the development rights as well as willing sellers.

Special Considerations

In some cases, a buyer, such as the local government or a nonprofit organization, may purchase the development rights to hold or sell them at a later date. In this case, the buyer could choose to permanently retire the development rights for conservation purposes

[1] American Planning Association (2006). *Planning and Urban Design Standards*.

Fact Sheet A-2: Purchase of Development Rights

Purchase of development rights (PDR) involves a local government or nonprofit purchasing development rights while the land remains privately owned. This restricts the future use of a property from certain types of development and is often used to preserve open space or farmland. In the context of coastal flooding, this can be used as a measure to prevent future development from occurring in vulnerable areas. PDRs are usually administered through a local government and often performed in collaboration with a nonprofit or trust that manages preservation activities.

Cost

PDR is a mid-price option with a higher cost than TDR but lower cost than a fee-simple acquisition—or outright buyout of the land. Costs for local government include those for developing and implementing the program as well as for purchasing the development rights. Purchase price for the development rights is estimated based on the most valuable use for the land allowed by zoning. For example, if the land is currently used for farming but could be developed for commercial uses based on current zoning laws, then the purchase price is generally based on the commercial value of the land.[2]

Effectiveness

Much like TDR, PDR is an effective and long-term solution; however, because participation in a PDR program is voluntary for the land owner, the programs can take a long time to implement over a large area. The PDR programs that would be most effective for limiting damage from coastal flooding are those that create large and contiguous areas with permanently preserved open space to serve as a buffer between flooding and development.

Barriers to Implementation

Because PDR programs rely on the voluntary participation of land owners, they generally are not quickly implemented. In addition, despite costing less than fee-simple acquisition, development rights can be prohibitively expensive for some local governments and are often tax-funded, which subjects PDR programs to political and economic risk.

Special Considerations

PDR usually only limits future development of housing, commercial, and similar functions; it does not remove existing development on a piece of land and does not prevent all future use of that land. The agreements generally allow the current land owner to stay on the land and, unless explicitly stated, do not prevent other activities, such as mining and farming.

[2] http://ohioline.osu.edu/cd-fact/1263.html

Fact Sheet A-3: Rolling Easements

Rolling easements are enforceable legal agreements that prohibit engineered barriers or other types of coastal armoring and that require removal of structures seaward of a migrating shoreline.[3] Rolling easements ensure that the shoreline will move naturally, and the shoreline is specifically defined (e.g. mean high water, vegetation line, or the upper boundary of tidal wetlands.) As the shoreline erodes or is inundated by sea level rise, existing development that ends up seaward of the defined line must be removed from harm's way. The easements may also potentially discourage future development in these areas. As the shoreline continues to recede, the easement "rolls" farther inland. The intent of rolling easements is to allow natural erosion to take place, which preserves natural sediment transport systems, wetlands, and other tidal habitats.[4] Easements can be purchased by a local government, donated by the land owner, or carried out through zoning.

Cost

Rolling easements are typically cheaper than protecting the land. In less developed areas, land owners are more likely to donate easements or sell them for a low price. Rolling easements for more densely developed areas have a higher cost because the land is more valuable and structures will have to be moved or abandoned as the shoreline moves in.

Effectiveness

When rolling easements lead to the removal of existing structures, they can prevent future flood damages in structure no longer subject to repeated or sustained inundation, but the value of the structure is also lost. Rolling easements are, however, a long-term strategy for potentially discouraging new housing developments along shorelines because they create the expectation that shoreline development will not be protected from flooding and erosion with engineered barriers or other types of coastal armoring. Thus, rolling easements have the potential long-term effect of mitigating future flood-related damage. Rolling easements can be most effective when implemented along undeveloped stretches of shoreline.

Barriers to Implementation

One method for implementing rolling easements is by obtaining voluntary participation of land owners; this can make the easements difficult to quickly implement, however, because property values are negatively impacted and existing structures cannot be protected with coastal armoring. Additionally, regulatory approaches toward implementation can often be legally complex.

Special Considerations

Rolling easements have sometimes been relaxed or removed in future years if the public starts becoming more sympathetic with regard to the destruction of waterfront housing.

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[3] http://water.epa.gov/type/oceb/cre/upload/rollingeasementsprimer.pdf
[4] http://coastalmanagement.noaa.gov/initiatives/shoreline_ppr_easements.html

Fact Sheet A-4: Fee-Simple Acquisition

Fee-simple acquisition involves the outright purchase of property and all associated development rights. Fee-simple acquisition is often used when local governments purchase waterfront properties that are vulnerable to erosion and flooding.[5] In the context of coastal flooding, the purpose of the acquisition is to remove or prevent future development in vulnerable areas and to reduce future damage from coastal flooding. Fee-simple acquisitions can be used in conjunction with other managed retreat policies to preserve open space, which in turn can be used to implement other mitigation measures, such as wetlands development or green infrastructure, to further increase a community's resilience to coastal flooding.

Cost

Fee-simple acquisition is a high-cost option. The costs include purchasing the property and structures at fair value from a private owner. These costs are generally paid by local governments and financed by bonds (which can be difficult to implement) or federal or state grants (e.g., FEMA's Hazard Mitigation Grant Program.) Grants are sometimes available to help counties acquire important coastal lands. Fee-simple acquisition could also reduce property tax generation that had been collected from the purchased structures and/or land.

Effectiveness

Fee simple acquisition is highly effective because the public owns all rights to the land and can restrict development for as long as it maintains ownership.

Barriers to Implementation

The mechanisms for executing and financing fee-simple acquisition can be challenging. If property owners are unwilling to sell, the local government must exercise eminent domain in order to execute the purchase. Additionally, large-scale purchases can be prohibitively expensive for local governments to finance, although grants are sometimes available to help counties acquire important coastal lands.

Special Considerations

If local governments choose to pursue this through a forced buyout—or eminent domain—the process, cost, and ability of local governments can vary significantly depending on location.

[5] http://nationalshorelinemanagement.us/docs/Econ_Workshop_IWR04-NSMS-2.pdf

Fact Sheet A-5: Infrastructure Relocation

Infrastructure relocation involves moving vulnerable infrastructure to areas less susceptible to coastal flooding. Relocation can be a viable option for many types of infrastructure, including roads, bridges, buildings, utilities, and wastewater treatment plants. Moving infrastructure may involve physically relocating the existing infrastructure, constructing new replacement infrastructure, or otherwise shifting the function of the infrastructure to a different location. One way to shift the function to a less vulnerable area is through regionalization (e.g., expanding capacity at an existing waste water treatment plant in a less vulnerable area to eventually replace another wastewater treatment plant in a vulnerable area).

Cost

Cost varies depending on the infrastructure being relocated and can include the cost for new construction, moving lines, or physical relocation, as well as the cost of the land to which the infrastructure is being moved. Large and expensive infrastructure, such as power plants, sewer systems, and water treatment plants, can be very expensive to relocate, while roads and simple buildings are more financially feasible. Regionalization offers a lower cost alternative by having large infrastructure from a neighboring community replace the at-risk infrastructure in your community. With this approach, existing equipment is moved into the new facility, potentially increasing the capacity of the neighboring infrastructure. This could be a more cost-effective strategy for a wastewater treatment plant compared to relocating it because the land and supporting infrastructure (e.g., feeder lines) are already in place.

Effectiveness

Relocation is effective if the infrastructure is moved out of the vulnerable area. If the infrastructure is not moved completely outside the vulnerable area, the overall effectiveness depends on the exposure and resilience of the infrastructure to coastal flooding.

Barriers to Implementation

Some types of infrastructure (e.g., power, water, and communication lines) are relatively easy to move, while larger structures, such as power plants, large highways, and water treatment facilities, are not. These larger structures also require relocating supporting infrastructure, such as feeder pipes, substations, and distribution lines that connect them to the existing infrastructure. In addition, new utility facilities can require large areas of land and the establishment of new utility lines, which sometimes must be routed through private property.

Special Considerations

Regionalization can be an effective way to move critical infrastructure away from flood-prone areas; however, this approach can also increase the overall level of vulnerability, because if the infrastructure is damaged, the impact will be felt over a larger area. Additionally, relocating critical infrastructure components could limit the accessibility for some vulnerable populations.

Fact Sheet A-6: Storm Surge Barriers

A surge barrier is a hard-engineered structure at a river mouth or estuary designed to prevent flooding. It can be either a fixed structure (e.g., closure dam) that is permanently closed or consist of moveable gates or barriers that can be closed when high water levels are forecast.

Cost

Surge barriers tend to have high capital and maintenance costs, although the cost can vary significantly depending on local conditions. In general, movable barriers are more expensive than fixed barriers. Due to the cost, only a handful of movable barriers exist, including the Thames Barrier in London, the Maeslantkering Barrier in Rotterdam, the St. Petersburg Flood Protection Barrier, and the MOSE project in Venice. The costs of these projects varied from $100 million to several billion dollars. Generally, surge barrier construction costs range between $0.7 and $3.5 million per meter, and annual maintenance costs can be about 5 to 10 percent of the capital cost.[6] By preventing the inflow of water to an estuary, closure dams can significantly impact the environment by altering water salinity, temperature, suspended matter, and nutrients, all of which have the potential to affect the local ecosystem. Closure dams also may interfere with the use of the waterways for transportation. Using movable barriers mitigates both these impacts.

Effectiveness

Surge barriers prevent storm surges from entering interior areas for water-level increases up to what they are built to withstand. The technology effectively reduces the height of extreme water levels in the area behind the barrier. For movable barriers, a storm surge monitoring and forecasting system must be used to ensure that the barrier is moved into position before a storm surge arrives.

Barriers to Implementation

Significant environmental costs as well as impacts on waterway transportation can be substantial barriers to implementation.

Special Considerations

Many closure dams are outfitted with turbines to produce electricity from tidal energy. One concern is that closing barriers might cause additional flooding behind the closure during heavy rainfall because the water would not be able to escape the protected area.

[6] http://www.unep.org/pdf/TNAhandbook_CoastalErosionFlooding.pdf

Fact Sheet A-7: Beach Nourishment

As beaches erode, coastlines move inland, closer to people and property along the shore, and storm surges are more likely to flood coastal areas. Narrower beaches also expose dunes to wave action and erosion, which negates the protection they offer to coastal infrastructure.[7] Beach nourishment, also known as beach replenishment or renourishment, is a common strategy used to combat such erosion and flooding along sandy coastlines. It involves dumping or pumping high-quality sand from an outside source to replace sand lost to erosion. Nourishment typically uses dredges, trucks, or conveyor belts to move sand from one location to the other. By replacing sand lost to erosion, beach nourishment creates a wider beach, which can help mitigate potential damage to coastal property, It can also cause waves to begin to break farther from the shoreline, weakening their strength before they reach the beach.

Cost

Beach nourishment is a fairly expensive mitigation measure, generally costing between $300 and $1,000 per linear foot, including material, transportation, and construction costs. [8] In addition, the maintenance costs of beach nourishment are substantial, as it must be repeated every few years. Negative environmental impacts are a concern, primarily ecosystem impacts from dredging and burying organisms with the new sand in the area where the nourishment occurs.

Effectiveness

Beach nourishment is a short-term solution that protects people and property by decreasing the energy of waves and limiting how far inland storm surges travel. Beaches must be supplemented with additional quantities of sand every few years, however, for this measure to continue to be effective. Beach nourishment is very effective against water-level increases up to the beach height; for larger events that greatly exceed the beach height, however, beach nourishment will have a minimal effect on mitigating coastal flooding, and the flooding levels will be similar to what they would be without the measure.

Barriers to Implementation

Initial cost and frequent maintenance typically are the largest barriers to implementation. Finding adequate and suitable sand may be a challenge in some areas. Additionally, the question of who pays and who benefits may lead to some outcries about fairness in terms of spending money to protect and potentially increase the value of a small number of beachfront properties. The permitting process could also be slow, given the potential for negative environmental impacts.

Special Considerations

Beach nourishment expands the size of beaches, which could lead to increases in beach-related recreation and associated tourism revenues. Nourishment can have an unintended effect of creating a "false sense of security" for existing or new property owners who underestimate the vulnerability of areas landward of the beach.

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[7] http://www.iwr.usace.army.mil/docs/projects/HowBeachNourishmentWorksPrimer.pdf
[8] Dean, Robert G. (2002). *Beach nourishment: theory and practice*. Vol. 18. World Scientific Publishing Company.

Fact Sheet A-8: Seawalls

Seawalls are vertical or near-vertical structures built along the coast and designed to prevent erosion and coastal flooding. Seawalls form a protective wall in front of coastal structures and may be constructed from a variety of materials, including concrete, steel, wood, and boulders.

Cost

Seawall construction costs range from $150 to $4,000 per linear foot, depending on engineering and construction specifications and local site conditions.[9] In general, the taller and wider the seawall, the more expensive it is to construct. Seawalls also require significant maintenance over the life of the structure. Seawalls can decrease tourism and accompanying revenue, however, if the associated beach is lost.

Effectiveness

To the degree that a seawall is tall enough and strong enough, it can prevent coastal flooding from sea-level rise and storm-surge. If the water-level increase exceeds the height of the seawall, however, substantial coastal flooding will occur, and the seawall might only reduce wave power and water velocity, not flood height.

With proper construction and maintenance, seawalls last for 30 years, on average, depending on type of construction and the frequency of extreme weather events.[10]

Barriers to Implementation

Seawalls require a high capital cost. Additionally, seawalls often elicit a mixed response from local communities because they can actually increase erosion of fronting beaches and adjacent properties and often generate controversy over their aesthetic impacts. Some areas, by regulation, strictly limit or forbid the use of seawalls.

Special Considerations

Seawalls can cause increased erosion (called “flanking erosion”) in adjacent areas. At either end of a seawall, waves tend to reflect sideways along the shore, causing those areas to erode faster.

[9] Yohe, Gary, et al. (1996). “The economic cost of greenhouse-induced sea-level rise for developed property in the United States.” *Climatic Change* 32(4): 387–410.
[10] Seachange Consulting (2011). *Weighing Your Options: How to Protect Your Property from Shoreline Erosion: A Handbook for Estuarine Property Owners in North Carolina.* North Carolina Division of Coastal Management, National Oceanic and Atmospheric Administration, and Nicholas Institute for Environmental Policy Solutions.

Fact Sheet A-9: Levees and Dikes

Levees, also known as dikes, are constructed embankments designed to reduce the risk of flooding to the areas behind them. Levees are typically built parallel to the course of a river or along coastlines in order to contain, control, or divert the flow of water. Levees are constructed from compacted soil or artificial materials such as concrete or steel. To protect against erosion and scouring, earthen levees can be covered with grass and gravel or a hard surface like stone, asphalt, or concrete.

Cost

When land acquisition costs are low, levees are often the cheapest form of hard defense relative to how much protection they can offer. In general, construction can cost between $100[11] and $1,500 per linear foot depending on the height and slope[12] Maintenance costs are also an ongoing requirement to ensure the structure continues to provide appropriate levels of protection.

Effectiveness

Levees can provide a high degree of protection against flooding in low-lying coastal areas. Effective levees are built with a high volume of material to resist water pressure, sloping sides to reduce wave energy, and crest heights sufficient to prevent overtopping by flood waters. Levees prevent flooding until they are overtopped with water or are breached (i.e., broken or eroded away), at which point flood waters will rise about as high as they would without a levee.

Barriers to Implementation

The high volume and sloping shape of levees necessitates a large building footprint. This factor will be especially important in areas with high property values.

[11] FEMA 2007. Selecting Appropriate Mitigation Measures for Floodprone Structures. Table 5.2
[12] Moore. 2009. The Impacts of Sea-Level Rise on the California Coast. Sacramento: California Climate Change Center.

Fact Sheet A-10: Sandbagging

Sandbagging is a simple and common way to prevent or reduce flood damage. A sandbag is a sack made of burlap, polypropylene, or other material that is filled with sand or soil. Sandbags are stacked to build temporary barriers to hold back flood waters. The bags can be brought in empty and filled with local sand or soil.

Cost

Sandbagging is generally one of the cheapest methods for flood protection since the bags cost about 25 cents each and are typically filled by volunteers. The U.S. Army Corps of Engineers estimates that constructing a 100-ft long, 3-ft high sandbag barrier would cost about $3,100.[13] Depending on the situation, additional costs may be incurred for the fill material and removal. Sandbagging can be time-consuming, however, and requires a significant amount of labor.

Effectiveness

Sandbags are usually effective at temporarily mitigating flood damage. They are most effective when used to build barriers that are less than 4 feet tall.[14] Taller or poorly constructed barriers can be prone to sliding and overturning. Sandbags are also susceptible to water seeping through or beneath the bags. Sandbags should be used to provide a basic level of protection, but they are unlikely to hold back flood waters entirely.

Barriers to Implementation

Sandbagging requires a significant amount of labor that must be mobilized quickly before a storm.

Special Considerations

Disposing of sandbags after a flood can be problematic. Sandbags that have been exposed to water cannot easily be reused. Wet sandbags tend to start deteriorating after a few weeks and may be contaminated by unsafe materials in the flood water. Disposing of the bags requires a considerable effort and generates a significant amount of solid waste.

[13] http://publications.gc.ca/collections/Collection/D82-46-1999E.pdf
[14] http://www.slate.com/articles/news_and_politics/explainer/2008/06/the_25cent_flood_protection_device.html

Fact Sheet A-11: Elevated Development

Elevated development involves physically raising infrastructure (e.g., on stilts/pilings or raised land) so that water can temporarily flow underneath and/or around without harming the main structure.[15] Elevated development can be included in the original design or added as a retrofit. Traditionally, only buildings are elevated, while the surrounding infrastructure (e.g., roads, walkways) is not; thus, while a building may be protected from flood damage, access to it may be limited during a coastal flood. It is possible to raise surrounding infrastructure, including roads, bridges, walkways, and utility lines. One common example of elevated development is beach homes that are built on stilts, often with the first floor at a height of 10 feet or more above ground level. Elevating structures is a relatively easy feature to incorporate into the design of a facility or infrastructure during initial construction, but it is more challenging to incorporate as a retrofit. Physically raising a structure that is already elevated slightly (e.g. with a crawlspace) is more feasible than elevating "slab-on-grade" construction.

Cost

Incorporating elevated development into the design of a new house adds $2,000 to $30,000 to the cost of the house depending on its size and foundation type, while raising an existing building can easily be well over double this cost. The total costs for raising a building increase with building size and weight but are not directly related to building size.[16,17] Raising an area of land and/or raising surrounding infrastructure is much more expensive. The cost will vary depending on the amount and type of infrastructure being raised. Raising entire areas of land is very expensive because large amounts of dirt and fill must be transported to the raised site.

Effectiveness

Elevated development is effective in protecting buildings and infrastructure from floods at water levels lower than the base of the first floor of the raised facility and is generally effective for the expected life expectancy of the structure, which might range from 25 to 50 years.

Barriers to Implementation

There are rarely major barriers to implementing elevated development into new construction. Cost to implement, particularly for larger and older buildings, as well as the potential for structural damage, are major barriers to raising an existing building. Creating sufficient access for the handicapped and elderly is also a potential concern. Potential legal liability can hinder being able to raise roads in existing developed areas, because the government entity raising the road is then responsible if drainage patterns are altered and increased flooding results.

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[15] http://www.usace.army.mil/Missions/CivilWorks/ProjectPlanning/nfpc.aspx
[16] http://www.nytimes.com/2005/12/12/national/nationalspecial/12flood.html
[17] Deschapelles, Natalie (2012). Dissertation: *An Evaluation of, and Suggestions for, Charlotte County Coastal Management, with Regards to Sea Level Rise Vulnerability*.

Special Considerations

Unless the surrounding infrastructure is also raised, flooding will still impact the accessibility of the raised structures and disrupt the economic activities they support.

Fact Sheet A-12: Floating Development

Floating development builds structures on foundations that, when flooded, rise vertically on top of flood waters instead of being inundated. The structures are prevented from moving horizontally by pilings or similar anchors that keep them in the same location and prevents them from floating away. Typically, only individual buildings are constructed on floating foundations, not the surrounding infrastructure. Although there are few common and widely used examples of floating buildings, architects have developed designs that add minimal cost to new construction. Retrofitting an existing facility with a floating foundation would prove challenging, and success would depend on the structure size, age, and type of foundation. Floating development becomes more difficult for buildings with larger weight-to-foundation-size ratios and taller buildings due to the potential instability of a floating foundation.[18]

Cost

Although not a widely used technology, floating development is expected to cost about the same as elevated development. Retrofitting a large and/or old building is often cost prohibitive compared to demolishing and rebuilding, unless the building has historic significance or some other intangible value.[19]

Effectiveness

Floating development is an unproven technology for modern and dense development. Theoretically, it is effective for protecting buildings from floods at water levels lower than the maximum height to which the building is designed to float. Floating development is designed to be effective for the life cycle of the building.

Barriers to Implementation

Theoretically, there are few barriers to incorporating floating development into new construction. The main technological constraints are related to building size. Retrofitting an existing building with a floating foundation can be challenging. The process of setting a building on a new and potentially unstable foundation can result in structural damage.[20]

Special Considerations

Floating development is susceptible to damage from wind, waves, and currents from storms. Therefore, it is only effective in relatively protected areas, not in open water along the coastline, which is susceptible to high-energy waves.

[18] http://green.blogs.nytimes.com/2009/10/27/as-sea-levels-rise-dutch-see-floating-cities/
[19] http://www.pbs.org/newshour/rundown/2012/05/preparing-for-a-life-on-water-with-floating-architecture.html
[20] http://www.spur.org/publications/library/report/strategiesformanagingsealevelrise_110109

Fact Sheet A-13: Floodable Development

Buildings can be designed to allow water to flood the lower floor(s) while causing minimal structural damage to the walls, floors, and foundation. On a larger scale, floodable development can also include structures and green infrastructure designed to capture, retain, and gradually release water when the flood recedes. This helps guide flood water away from more sensitive infrastructure. Examples include large underground storage systems such as parking garages designed to hold flood waters, as well as low-lying fields, ponds, or lakes designed to hold water drained from surrounding areas.

Cost

Floodable development can be integrated into facilities at little to no cost for new construction. Costs for neighborhood-level infrastructure to support floodable buildings (for example, a parking garage designed to hold flood water) vary greatly depending on the type and size.

Effectiveness

Floodable buildings are designed to be effective at preventing structural damage from floods up to a specific height. Supporting floodable infrastructure, such as a water-holding parking garage or pond, can hold a specific amount of water, making it easy to calculate how well the structure will mitigate flooding.

Barriers to Implementation

Design-related challenges are associated with floodable buildings because structures must be engineered to withstand regular flooding. Depending on the size of larger scale retention structures, coordination with multiple public and private land owners as well as other stakeholders may be required to work through large-scale planning or land-use issues.

Special Considerations

Floodable development can be hazardous to health, particularly in seaward areas, because floodwater often contains high concentrations of organic chemicals, heavy metals, bacteria, and sediment and could leave behind contamination after the waters subside.[21]

[21] http://www.spur.org/publications/library/report/strategiesformanagingsealevelrise_110109

Fact Sheet A-14: Movable Buildings

Movable buildings are designed to be easily relocated in advance of flooding or storm events. The most common movable buildings are trailers and modular buildings, which are moved by truck or train. These buildings are usually left on trailers or set on a concrete slab foundation. Movable buildings are usually limited to small structures because of the logistics and cost involved in relocating them.

Cost

Prefabricated movable buildings, such as modular homes, are inexpensive to build and relocate relative to the cost of replacement. Costs for both construction and relocation increase significantly with size. Large buildings are generally not designed to be movable because the high cost and complicated logistics involved in regularly moving large buildings makes them cost prohibitive—especially when including the costs for multiple moves. In addition, retrofitting buildings to be movable can be expensive compared to demolishing and rebuilding when you add in the cost of relocation.

Effectiveness

The ability to physically move buildings outside of an at-risk area eliminates damage to buildings from flooding. The logistics of moving a large number of buildings are complex, however, because of the time involved. Being able to move buildings requires advance flood warnings as well as sufficient transportation infrastructure to support the movement of both people and buildings.

Barriers to Implementation

There must be designated receiving areas where the buildings will be relocated. These areas must be out of the flood zone but close enough to allow the buildings to be quickly relocated. In addition, planners will want to consider whether utilities and infrastructure are in place to support the buildings for both temporary and permanent relocation.

Special Considerations

Advance planning and early warning are needed to mobilize and coordinate building relocation in advance of a storm or flood.

Fact Sheet A-15: Drainage Systems

Drainage systems can be designed to mitigate flooding on a building, local, or regional level. Like floodable development, buildings and infrastructure can be designed with drains, pumps, and other systems to transport flood water into existing sewer systems, waterways, or other designated floodable areas. Regional drainage systems can include natural or manmade waterways that quickly remove water from a flooded area. Drainage systems are often integrated into stormwater and wastewater infrastructure at the local and regional level; thus, simply diverting large amounts of water into these systems risks overwhelming them, increasing erosion rates, and amplifying the severity of downstream floods.

Cost

Costs for drainage systems vary according to the area over which they are deployed and the size of flood they are designed to mitigate. Large-scale structural drainage systems, typically composed of concrete and steel, have a high cost that increases relative to the amount of area they are supposed to drain and have a cost on par with other heavily engineered structures. Localized drainage systems that simply drain water from a building or parcel into existing waterways are less expensive to install. In addition, manmade drainage systems require regular maintenance to inspect, repair, and clean the systems after large floods.

Effectiveness

While building, parcel-sized, and more localized drainage systems can be designed to accommodate specific-size flood events, large and more regional systems are hard to design, integrate, and maintain. As such, the overall effectiveness of these systems is not very predictable.

Barriers to Implementation

Drainage systems are straightforward to incorporate into development on a local and neighborhood level. Designing effective regional drainage systems can be complex, especially for densely populated areas.

Special Considerations

Trends for stormwater management increasingly focus on managing flooding and stormwater in place through infiltration and evaporation instead of draining into heavily constructed stormwater infrastructure that quickly moves the water off site. In addition, it is important to consider the downstream impacts of draining off large amounts of water and ensure that draining one area does not lead to damaging floods and erosion downstream.

Fact Sheet A-16: Floodproofing Infrastructure

Floodproofing infrastructure uses a combination of methods, including many described in this report, to mitigate or eliminate the potential for flood damage at a given level of flooding, thus lowering the depth-damage curve for a given building. Floodproofing can allow water to flood a building or area (wet flood-proofing) or prevent water from entering a building or area (typically referred to as dry flood-proofing). Building-level examples of floodproofing include sump pumps, spray-on cement, waterproofing membrane, wood or metal shielding, and locating utilities and key equipment at higher levels.

Cost

Floodproofing a building is relatively inexpensive compared to other mitigation measures and usually increases the cost of new construction by 0 to 25 percent, depending on the desired level of protection.

Effectiveness

Usually floodproofing is designed to reduce but not completely eliminate the amount of damage for a given level of flooding. Floodproofing involves the recognition and acceptance of certain amounts of damage for specific flood levels and is only effective up to these predetermined levels. Dry floodproofing is effective up to a certain water-level increase, after which the force of the water acting on the structure can cause it to collapse.

Barriers to Implementation

Cost is typically the largest barrier to implementing floodproofing infrastructure.

Special Considerations

While floodproofing typically protects against certain water-level increases, these measures do not always account for a high velocity of water rushing in from the ocean, which can destroy structures.

Fact Sheet A-17: Preservation of Open Space

Preserving open space involves setting aside land for limited or no development. This can be accomplished in a variety of ways, including by purchasing the land or through a conservation easement. A conservation easement is a voluntary agreement that limits development on a property while maintaining private ownership of the land. In the context of coastal flood mitigation, open space preservation is used to prevent development in vulnerable areas and mitigate the severity of flooding. Preservation of open space is commonly used in conjunction with other green-infrastructure-based flood mitigation measures.[22]

Cost

Costs vary depending on land value and the method of preservation. The cost of preserving land in a locality through fee-simple acquisition—or direct purchase—is equal to the assessed property value. Easements average 60 percent of the cost of fee-simple acquisition; a more accurate cost can be determined by calculating the present worth of the highest value land use that would be given up with the easement.[23] There are also maintenance costs and the potential loss of property taxes versus what could be generated if the land were to be developed.

Effectiveness

For as long as the open space is preserved, designating vulnerable areas as undevelopable is highly effective at preventing flood-related damage in those areas by reducing the amount of infrastructure that could be exposed. Effectiveness is most often evaluated by modeling the impacts of flooding under different open-space and development scenarios.

Barriers to Implementation

The costs to purchase and manage open space present the most significant challenges to implementation because localities often lack the resources to fund effective open-space preservation programs. In addition, property owners can be unwilling to give up development rights or to sell land in prime waterfront areas.

Special Considerations

Preserving open space can also provides valuable social and environmental benefits based on the use of the open space, which may equal or exceed the flood mitigation benefits.

[22] American Planning Association (2006). *Planning and Urban Design Standards*.
[23] http://www.rff.org/RFF/Documents/RFF-Rpt-Kousky%20etal%20GreatLakes%20(2).pdf

Fact Sheet A-18: Zoning in Vulnerable Areas

Zoning ordinances restrict allowable land uses for a defined area or district. Zoning may regulate land use; intensity; density; building height, placement, and bulk; and other development features. In the context of flood planning, zoning can prevent or limit development in exposed areas, ensure that new development does not increase the severity of flooding, and require that new and renovated structures incorporate flood-resilient features. Local ordinances must, at a minimum, comply with federal requirements for developing within floodplains, and many zoning ordinances already include measures related to flood-hazard areas.

Cost

Zoning is a low-cost option. Zoning to mitigate flood-related impacts can be incorporated into a municipality's existing zoning code. The local government bears the cost of developing zoning codes, reviewing development applications for consistency with the code, and enforcing the zoning code. These costs vary by the complexity of the zoning code, the volume of development application, and the area and level of enforcement.

Effectiveness

The effectiveness is directly related to the regulations that the zoning implements and the associated enforcement. For example, preventing any development is highly effective, while requiring raised and flood-proofed structures is moderately effective at preventing future damage.

Barriers to Implementation

Processes for changing zoning ordinances vary by state and locality. Often, proposed zoning amendments must go through a lengthy review process that includes public involvement as well as approval by a local board or city council. Zoning that restricts development is sometimes a controversial and unpopular strategy, and may lead to legal challenges.

Special Considerations

Changes to zoning amendments generally must be consistent with a local comprehensive or master plan, which describes the long-term land use goals for an area. Changes to the zoning code that are inconsistent with the plan could be subject to legal challenge.[24]

[24] American Planning Association (2006). *Planning and Urban Design Standards*.

Fact Sheet A-19: Development Fees in Vulnerable Areas

Development fees are one-time charges imposed by local governments on new development projects and are designed to cover costs for infrastructure to support the new development. The purpose of a development fee is to have new development pay for the impact to infrastructure instead of having it all paid for by taxpayers. Development fees are used to pay for infrastructure outside the developed area. In the context of flood prevention, development fees could be used to pay for flood-prevention infrastructure or adaptation strategies to prevent flooding in the developed area, or to mitigate the flood-related impacts on other areas that might be caused by the new development.

Cost

Development fees are a low-cost option for local governments. The local governments pay for developing and implementing the ordinances and administering the system. Developers pay the fees to pay for infrastructure associated with new development. Development fees typically only cover construction costs, while maintenance or operating expenses are usually funded through taxes.

Effectiveness

Development fees are an effective way for local governments to pay for new infrastructure to mitigate potential future impacts of coastal flooding brought about by new development. Thus, the effectiveness of the development fees depends on the success of the chosen infrastructure at mitigating flooding damage.

Barriers to Implementation

Not all local governments can enact development-fees because laws and enabling legislation for these fees vary by state.[25]

Special Considerations

If development fees make the overall cost of development in a particular place higher than in neighboring areas, developers may choose to build in another area or decide not to build at all, which can further increase the effectiveness of the measure in terms of minimizing development in vulnerable areas.

[25] American Planning Association (2006). *Planning and Urban Design Standards*.

Fact Sheet A-20: Wetlands

Wetlands are ecosystems that may be saturated with water during all or part of the year and are often found at the boundary between land and water. By absorbing flood waters, wetlands protect inland areas from flooding. Coastal wetlands in the United States have been estimated to provide up to $23.2 billion annually in storm protection services.[26]

Communities can take steps to conserve, enhance, restore, or create wetlands in their area. Restoration—returning a degraded or former wetland to its original condition—is typically easier and cheaper to implement than wetland creation, which involves converting either dry land or open water to a wetland.

Cost

Communities can engage in a variety of activities to conserve, create, enhance, or restore wetlands, and specific costs will vary depending on the scope of the project and local conditions. Land acquisition can be a significant upfront cost. Wetland restoration can cost between $3,500 and $80,000 per acre, excluding land costs, and wetland construction typically costs between $35,000 and $150,000 per acre, excluding land costs.[27] Communities usually face additional costs for planning, long-term management, and monitoring, but maintenance costs are typically very low.

Effectiveness

Wetlands reduce the risk of property damage and loss of life from flooding through a number of mechanisms. Wetlands act as natural reservoirs, storing flood waters and then slowly releasing them, delaying and attenuating peak flood flows. Wetlands also dissipate wave, wind, and storm surge energy through resistance provided by the wetland vegetation. Studies have found that a loss of one hectare (about 2.5 acres) of wetland corresponds to an average increase of $33,000 in storm damage from hurricanes.[26] However, wetlands are less likely to be effective in mitigating the effects of very large flood events, particularly regional floods of long duration.

Barriers to Implementation

Construction of new wetlands may not be well-suited for highly developed areas, where there is often no land available or the land can be costly.

Special Considerations

Wetlands provide a number of other valuable services, including improving water quality, providing fish and wildlife habitats, and maintaining water supplies during drought periods.

[26] Anderson, Sharolyn J. and Kenneth Mulder (2008). "The value of coastal wetlands for hurricane protection." *Ambio* 37(4): 241.
[27] http://www.bnl.gov/erd/peconic/factsheet/wetlands.pdf

Fact Sheet A-21: Mangroves

Mangroves are medium-sized trees and shrubs found in tropical and subtropical regions that grow in salt water environments. In the United States, mangroves are primarily found in Florida but also exist in other locations around the Gulf of Mexico. Florida's southwest coast supports one of the largest mangrove forests in the world. By acting as a buffer zone against waves and wind, mangrove forests can save lives and reduce storm-surge-related damage.

Cost

The cost of mangroves can vary widely depending on specific conditions. Land acquisition may be necessary to protect existing mangrove forests. If restoration is needed to maintain mangrove forests, the price of labor and the extent of necessary earth work will dramatically affect costs. In general, mangrove restoration has been estimated to cost between $2,150 and $81,000 per acre, excluding land costs.[28]

Effectiveness

Mangroves can reduce storm surge levels by slowing the flow of water and reducing surface waves. Experts estimate that each kilometer of mangrove forest provides a 5- to 50-cm water level reduction. In addition, surface wind waves are expected to be reduced by more than 75 percent over 1 kilometer of mangroves.[29,30] However, some models indicate that mangrove forests may provide less protection against intense, slow-moving hurricanes.

Barriers to Implementation

Mangroves have a limited geographic range due to climate. The temperate climate found in most of the United States is not suitable for mangrove growth.

Special Considerations

Mangroves offer the additional benefits of nutrient retention and wastewater treatment; they support fisheries by serving as a breeding ground and serve as a home to a variety of other wildlife.

[28] http://el.erdc.usace.army.mil/elpubs/pdf/vnrs3-2.pdf
[29] http://coastalresilience.org/sites/default/files/resources/storm-surge-reduction-by-mangroves-report.pdf
[30] http://conserveonline.org/workspaces/naturalcoastalprotection/documents/reports/view.html

Fact Sheet A-22: Oyster and Coral Reefs

Reefs—underwater structures made by living creatures—can protect shoreline property from erosion and storm surges. Reefs absorb wave energy, acting as a natural breakwater, and stabilize bottom sediments. Reef restoration—expanding the size and number of reefs—can help communities protect shoreline property and infrastructure.

In the United States, both coral and oyster reefs have been used to protect coastal areas. However, most coral reefs are found in tropical waters and have limited suitability along the coast of the United States. Oyster reefs, on the other hand, are common along much of the eastern seaboard. Reefs are built by adding material such as small bags of oyster shells, loose oyster or clam shells, riprap, or other suitable substances to the water. The material attracts live oyster larvae, which settle and create a live reef.

Restoring coral reefs generally works in the same way; material is provided for corals to settle on. Limestone and concrete are commonly used as these substrate materials are appropriate for coral recruitment. .

Cost

Depending on size, constructing an oyster reef can cost between a few thousand and several million dollars. On average, oyster reef restoration costs about $100 to $150 per linear foot.[31] Oyster reefs have very low maintenance costs. Oyster reefs are extremely durable and may last for 50 years or longer.

Effectiveness

Reefs function as natural breakwaters that reduce the height and energy of waves hitting the shore. According to the Nature Conservancy, in Louisiana, two oyster reef restoration projects, with a total length of 3.6 miles, are expected to reduce wave height by 51 to 90 percent and wave energy by 76 to 99 percent.[32] This reduces both shoreline erosion and storm surge flooding. Reefs are particularly effective against smaller events but may provide limited protection against erosion and coastal flooding during major storms.[33]

Barriers to Implementation

Reef restoration has been known to cause environmental problems. If done irresponsibly, restoration may introduce invasive species to the ecosystem, placing native species at risk. When constructing a reef it is important to take local conditions into account. Seafood safety concerns mean that oyster restoration is not allowed in some locations.

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[31] Seachange Consulting (2011). *Weighing Your Options: How to Protect Your Property from Shoreline Erosion: A Handbook for Estuarine Property Owners in North Carolina.* North Carolina Division of Coastal Management, National Oceanic and Atmospheric Administration, and Nicholas Institute for Environmental Policy Solutions.
[32] http://www.nature.org/ourinitiatives/regions/northamerica/oyster-restoration-study-kroeger.pdf
[33] http://water.epa.gov/type/oceb/cre/upload/CRE_Synthesis_1-09.pdf

Special Considerations

Reef restoration offers a number of additional benefits beyond coastal protection. For example, reefs can improve water quality and help maintain a healthy coastal ecosystem, promoting commercial and recreational fishing, recreational boating, and tourism.

Fact Sheet A-23: Living Dunes

Coastal dunes are sand deposits located on the land side of a beach. Dunes protect beaches from erosion and protect shoreline property from storm surges. Dunes are extremely fragile. If they are disturbed by human activity, such as trampling, vehicular traffic, and construction, they become unstable and susceptible to erosion. One of the most common and effective methods of stabilizing coastal dunes is to plant vegetation to create living dunes. Some communities also install fencing and/or use discarded Christmas trees to trap sand that ultimately creates new dunes. Building dune walkovers or designating footpaths can also limit damage from human traffic.

Cost

Creating living dunes is a relatively economical option and can be undertaken at the community level using widely available tools. Locally-appropriate vegetation can be obtained from nursery stocks or from nearby intact dune systems. The most commonly used species in dune transplantation are American beach grass, European beach grass, sea oats, and bitter panic grass. American beach grass is sold in 100-stem bundles for approximately $35 to $55 per bundle.[34] The stems are planted two or three to a hole at 1- to 3-foot intervals, resulting in a cost of under $0.50 per square foot of dune.[35] Plantings can be done by hand or with a mechanical planter.[36] New plantings require periodic watering for the first few months and fertilization for up to two years. Decreased access to the beach due to planting vegetation can result in additional costs such as offsetting the loss in access by enhancing or maintaining other beach access points.

Effectiveness

Dune vegetation, which acts to stabilize loose sand, is the most reliable way to protect dunes from wind and waves. Dune plants are especially effective at trapping and holding windborne sand, promoting dune growth over time. Dune vegetation also decreases the wind velocity near the ground, reducing wind erosion at the sand surface. [37] Dune vegetation root networks can also help to stabilize the dune. Ultimately, the vegetation helps preserve dunes and enhances their ability to protect the coast from erosion and coastal flooding. Dunes are effective in preventing flooding up until the water-level increase exceeds the height of the dune, or until sufficient erosion occurs to cause the dune to collapse

Barriers to Implementation

Dunes can sometimes block views of the beach and projects to create new dunes often require landowners to cede some property rights for dune development.

Special Considerations

Special care must be taken in the selection of plant species to avoid introducing invasive species into the ecosystem.

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[34] http://www.town.orleans.ma.us/pages/orleansma_parks/whgreport.pdf
[35] http://www.whoi.edu/fileserver.do?id=87224&pt=2&p=88900
[36] http://140.194.76.129/publications/eng-manuals/EM_1110-2-1100_vol/PartV/Part-V-Chap_7.pdf
[37] http://conservancy.umn.edu/bitstream/58856/1/2.5.Olafson.pdf

Fact Sheet A-24: Barrier Island Restoration

Barrier islands are naturally occurring, narrow strips of land that run parallel to the coast. Barrier islands protect inland areas during severe weather events by reducing wind and wave energy and by mitigating storm surges. In many areas, however, barrier islands are eroding at extreme rates. In some places, barrier island shorelines are shrinking by up to 100 feet per year.[38]

Barrier island restoration projects are designed to protect and restore barrier island chains. Restoration projects may incorporate a variety of techniques, including using dredged material to increase island height and width, building hard structures to protect the island from erosion, and using sand-trapping fences to build and stabilize sand dunes.

Cost

Barrier island restoration is a large-scale undertaking and can cost tens or hundreds of millions of dollars. For example, restoring East Grand Terre Island in Louisiana, which included restoring 2.8 miles and 620 acres of barrier shoreline and 450 acres of marsh by dredging 3.3 million cubic yards of offshore material, cost $31 million.[39] In addition, barrier island restoration projects require periodic maintenance to ensure resiliency.

Effectiveness

Barrier islands protect coastal communities from damage caused by waves and storm surge. Studies have indicated that the loss of barrier islands can increase wave height by as much as 700 percent during fair-weather forecasts.[40] Recent observations following hurricanes have shown that areas behind restored barrier islands weather storms much better than nearby areas.[41]

Barriers to Implementation

Cost is typically the largest barrier to restoring barrier islands.

Special Considerations

In many cases, barrier islands help shelter wetlands, so restoring barrier islands can indirectly preserve many of the benefits of coastal wetlands.

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[38] http://pubs.usgs.gov/fs/barrier-islands/
[39] http://www.nola.com/environment/index.ssf/2012/01/louisiana_releases_50-year_blu.html
[40] Stone, Gregory W. and Randolph A. McBride (1998). "Louisiana barrier islands and their importance in wetland protection: forecasting shoreline change and subsequent response of wave climate." *Journal of Coastal Research* 14(3): 900–915.
[41] http://www.habitat.noaa.gov/abouthabitat/barrierislands.html

Appendix B: Approaches and Tools for Monetizing Impacts

Fact Sheet B-1: FEMA Hazus-MH Flood Model

The FEMA Hazus-MH Flood Model uses GIS technology to monetize losses from flooding for a variety of different impacts. Hazus can operate at three levels depending on the needs and expertise of the user. A Level 1 analysis uses default data and models. In a Level 2 analysis, the user can supply custom data, such as depth-damage curves and infrastructure valuation, to perform a more accurate and detailed analysis. In a Level 3 analysis, the user can import the highest level of custom data, including hydrologic data, to produce the most precise and sophisticated, albeit most resource-intensive, analysis. This tool is not specifically tailored to address sea-level rise; however, using scenarios developed in Step 1, this tool can monetize losses for user-provided levels of flooding.

Impacts Monetized

Primary Impacts: Residential building damage, commercial building damage, special facility damage (potable water, wastewater treatment, oil, natural gas, electric power, and communication systems), essential facility damage (hospitals, fire, police, schools, universities), building content loss, vehicle damage, bridge damage, and crop loss.

Secondary Impacts: Relocation costs, business interruption loss through wage loss, rental income loss, and displaced households (measured quantitatively—not monetized), and debris cleanup (from damaged structures only).

Indirect Impacts: Demand and supply of products, change in employment, and change in tax revenues.

Level of Effort and Expertise Needed

This varies from a Level 1 to Level 3 analysis. To perform a Level 1 analysis, someone unfamiliar with the tool could use it after reading the user guide or participating in some basic training. However, it is recommended that someone with more experience using Hazus assist in performing Level 2 and 3 analyses. The Hazus user guide estimates it takes about one to six months to collect input data for a Level 2 analysis and six months to two years to collect the appropriate input data for a Level 3 analysis.

Process to Perform This Approach

Step 1: Download the free model: Set up an account by calling 1-877-336-2627 and access it online by visiting the FEMA Map Service Center (MSC) at msc.fema.gov.

Step 2: Determine the level of analysis you would like to perform and provide someone to train to use the tool or find someone with the appropriate level of expertise.

Step 3: Gather or create the necessary input data for your community to run the tool. This is minimal for Level 1 and just includes a digital elevation model, which is available through NOAA's

Digital Coast or you can create your own. Level 2 and 3 analyses require collecting a longer list of custom inputs that require a much higher level of effort to locate.

Step 4: Run the model. See the user manual and technical manual for FEMA's Hazus-MH Flood Model for more details.

How This Approach Fits Into the Framework of This Guide

This is a very powerful tool, particularly for those performing a holistic approach to monetizing damage to a wide variety of infrastructure for a given water-level increase. This monetization approach makes less sense if you are monetizing damage for a few priority infrastructure elements because it requires that extra resources be used to monetize damages for the rest of the community, which will not change as a result of moving or reinforcing one piece of infrastructure.

This comprehensive tool assesses the depth of water around infrastructure, as is done in Step 1, Task 3, and monetizes impacts of your no-action scenario, as is done in Step 3, Task 2. It can also assess the depth of water around infrastructure in your action scenario if you provide the new water-level increase associated with implementing your action scenario, as is done in Step 2, Task 2. Finally, if you are performing a Level 2 or 3 analysis, you can provide custom data, including new depth-damage curves for reinforced infrastructure, or updated GIS infrastructure maps for a relocated or raised structure to monetize the damages in your action scenario (as is also done in Step 3, Task 2). This approach could be used to perform an impact assessment or risk assessment.

Limitations

- Default data are older (early 2000s) and incomplete for performing Level 1 analyses.
- Processing time can be several days, and custom data collection can take many months when performing Level 2 and 3 analyses.

Key Resources

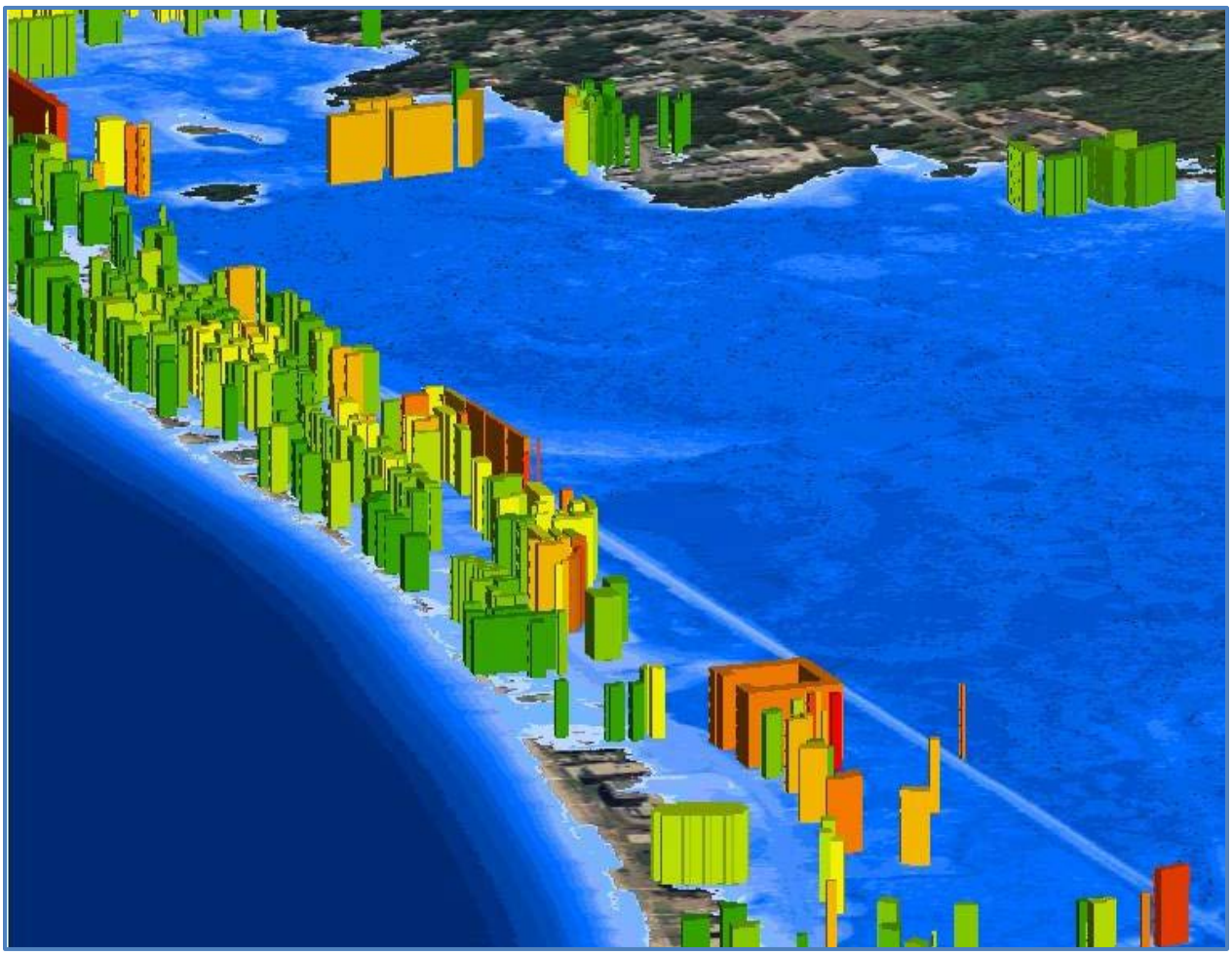
Case Study:

- *The Role of Land Use in Adaptation to Increased Precipitation and Flooding: A Case Study in Wisconsin's Lower Fox River Basin* provides an example of Level 2 FEMA Hazus-MH Flood Model analysis estimating future losses from flooding in the Lower Fox River Basin of Wisconsin. This Resources For the Future paper also provides some of the pros, cons, and additional insight involved in using this tool to monetize projected flooding losses.

Fact Sheet B-2: COastal Adaptation to Sea level rise Tool (COAST)

The New England Environmental Finance Center (NEEFC) developed the COastal Adaptation to Sea level rise Tool (COAST), which measures physical damage (based on real estate costs) from storm surge and sea-level rise. COAST uses three-dimensional, structure-level outputs to show building-level damage and to break down the losses based on the contribution of storm surge and sea-level rise. For example, Figure B-1 shows how three-dimensional, color-coded outputs are used to present the extent of damage at the building level. This tool incorporates both baseline losses and losses after implementing hypothetical action scenarios.

Figure B-1. COAST Three-Dimensional Building Damage Output



Impacts Monetized

Primary Impacts: Residential building damage, commercial building damage, special facility damage (potable water, wastewater treatment, oil, natural gas, electric power, and communication systems), essential facility damage (hospitals, fire, police, schools, and universities), and building content loss.

Level of Effort and Expertise Needed

Some users will have success with the Web-based tool without prior experience, while others may need expert help; however, you will likely want some GIS expertise to help you obtain the necessary input data.

Process to Perform This Approach

Step 1: Visit the New England Environmental Finance Center website to find the free Web-based tool.

Step 2: Obtain the necessary input data. This typically includes a base land-elevation dataset defining the area, a vector layer defining the assets and asset values, depth-damage function (DDF) for assets (see Key Resources for Fact Sheet B-3 for some sources of depth-damage curves), probability exceedance curves for storm surge, sea-level rise scenarios, and adaptation strategy.

Step 3: Run the tool.

How This Approach Fits Into the Framework of This Guide

This is a very powerful tool, particularly for those performing a holistic approach where you are trying to monetize damage to a wide variety of infrastructure. If you are comfortable using the tool, it can also be quite useful for the priority infrastructure approach. This comprehensive tool helps you assess the depth of water around infrastructure, as is done in Step 1, Task 3; reassess the depth of water around infrastructure based on your action scenario, as is done in Step 2, Task 2; and monetize the impact of flooding in your action and no-action scenarios, as is done in Step 3, Task 2. It is also tailored to incorporate SLR scenarios and different storm types, allows you to input the cost of your action scenario, and provides some summary cost and benefit outputs, which help you compile your net benefits in Step 4. This approach could be used to perform an impact assessment or risk assessment.

Limitations

- Limited to monetizing structural impact damage and building content loss.

Key Resources

Case Study:

- *COAST in Action: 2012 Projects from Maine and New Hampshire* provides some case studies of how the use of COAST is integrated into local decision-making for some Maine and New Hampshire towns. This includes further information about data requirements, outputs, and limitations of the tool.

Fact Sheet B-3: Overlay Infrastructure-Level Economic Data on Flood-Depth Data

This approach involves overlaying economic data about infrastructure values on data about the depth of flooding in Step 1, Task 3. For the holistic approach, you can do this with GIS flood and economic data layers, which is the same basic methodology used in existing comprehensive tools (FEMA Hazus and COAST). For the priority infrastructure approach, you follow the same basic framework; however, you can often do this without GIS data. This approach involves determining the depth of water around your assets, determining how badly the water damages your assets, and determining the value of your assets. This general three-step approach can also be used to estimate the damage to your community's vehicles. The U.S. Army Corps of Engineers (USACE) provides resources for determining the number of vehicles, distribution of vehicles, and value of vehicles in a community.

Impacts Monetized

Primary Impacts: Residential building damage, commercial building damage, special facility damage, essential facility damage, building content loss, and vehicle damage.

Level of Effort and Expertise Needed

The holistic approach requires a very high level of effort and extensive GIS experience. The priority infrastructure is much less time-consuming and can typically be performed without GIS experience because it only requires elevation data of your selected infrastructure.

Process to Perform This Approach

Step 1: Determine the height of the water around your assets.

Option A: holistic approach
Develop a GIS flood layer containing information about exposed infrastructure and the depth of flooding around each infrastructure for each water-level increase selected. See the NOAA *Mapping Coastal Inundation Primer* for more detailed information about creating these mapping layers.

Option B: priority infrastructure approach
Determine the height of water relative to the base of your infrastructure for a given level of flooding. This typically just requires a digital elevation map or elevation data about your infrastructure, as is outlined in Step 1, Task 3.

Step 2: Determine how badly the water damages your assets.
Create or find depth-damage curves—functions that show the percent of damage to your assets—to determine the relationship between flooding height relative to the base of the infrastructure and percent of damage relative to the total value of the asset. The holistic and priority infrastructure approaches involve slightly different processes for this step:

Option A: holistic approach
Consider using generic depth-damage curves developed by USACE to minimize the effort in creating

custom curves for your many types of buildings. The "Key Resources" below link to a variety of depth-damage curves for a range of building types, vehicles, and building content.

Option B: priority infrastructure approach
Consider consulting with local building experts or people familiar with the building content to generate your own curves to provide more precise data. For example, you may have a lot of expensive equipment in the basement, or your building may be relatively flood-proof, which can dramatically affect the depth-damage curves.

Step 3: Determine the value of your assets.
Obtain data with information about the value of each building. Check with your town or city assessor's office to see if you can obtain useful data on the assessed value of buildings. If assessed values are not available, check to see if your community can gain access to building or building content insured values that could also be used. You can calculate the damage amount by multiplying the asset value by the percent damage at a given level of flooding that you obtained from the depth-damage curve. The format of the desired data will differ slightly between the holistic and priority infrastructure approach.

Option A: holistic approach
Work with your GIS expert to obtain an economic data layer that can be integrated with your flooding layer.

Option B: priority infrastructure approach
Work closely with people familiar with the infrastructure to obtain detailed information about the infrastructure and content value.

How This Approach Fits Into the Framework of This Guide

This is an alternative approach to using comprehensive tools in determining the monetized costs of buildings and building content (Step 3, Task 2). This general three-step process is applicable to both the **holistic approach** and the **priority infrastructure approach.** It can be used to perform an **impact assessment** or **risk assessment**.

Limitations

- Infrastructure-level valuation data may be difficult to obtain, particularly in a useful format compatible with GIS use. Ensure that you can obtain such data before becoming too invested with this approach.

Key Resources

Depth-Damage Curve Library:

- USACE's *Generic Depth-Damage Relationships for Residential Structures with Basements*
- USACE's *Generic Depth-Damage Relationships for Residential Structures with No Basements*
- USACE's *Analysis of Nonresidential Content Value and Depth-Damage Data*

- USACE's *Depth-Damage Relationships for Structures, Contents, and Vehicles and Content-to-Structure Value Ratios (CSVR) in Support of the Donaldsonville to the Gulf, Louisiana, Feasibility Study*
- USACE's *Generic Depth-Damage Relationships for Vehicles*

Fact Sheet B-4: Use General Economic and Flood Data to Estimate Primary Damage

This approach uses the same basic three-step approach as monetizing infrastructure-level data; however, it provides some lower-resource alternatives if you don't have appropriate infrastructure-level data or are just looking for a quicker means for developing a preliminary estimate of the monetized damage impacts. For example, you may not have data showing the height of water around your infrastructure, which would require you to estimate a depth-damage function, or you may not have infrastructure-level economic valuation data, which might require you to apply a generic economic value such as average building value per square foot or average price per building. Take advantage of your available economic expertise to help you consider and perform alternatives, but remember that more estimates and generic data typically yield less informative and compelling results.

Impacts Measured

Primary Impacts: Residential building damage, commercial building damage, special facility damage, essential facility damage, and building content loss.

Level of Effort and Expertise Needed

The level of effort varies depending on how detailed your available data are; however, the level of effort required is substantially less than the infrastructure-level approach. Some GIS experience may be necessary, and economic expertise is recommended for this approach.

Process to Perform This Approach

Step 1: Determine the height of the water around your assets, or at least identify exposed assets.
Develop a GIS flood map containing information about which infrastructure elements are flooded, and preferably the depth of flooding around each infrastructure for each water-level increase selected. See NOAA's *Mapping Coastal Inundation Primer* for more detailed information about creating these mapping layers. An even lower-resource approach would just be to estimate the number or percent of buildings that are inundated from a quick view of your flood map.

Step 2: Determine how badly the water damages your assets.
Create or find depth-damage curves—functions that show the percent of damage to your assets (in this case building structure or content)—to determine the relationship between water-level height and percent of damage relative to the total value of the asset. Consider using generic depth-damage curves developed by U.S. Army Corps of Engineers (USACE) (see "Key Resources") for many different building types. If your flood map does not contain information regarding the depth of flooding around infrastructure, you may want to try to estimate the average flood depth around buildings and apply the appropriate depth-damage percent to all buildings.

Step 3: Determine the value of your assets.
Obtain generic economic data about the value of your assets (e.g., average price per square foot, average price per building) that makes sense to apply to your flood map. Only use an estimate of the price per square foot if you can assume how many square feet of the building are flooded. It will

increase the accuracy of your estimate if you can obtain more specific values for different building types, such as the average price per commercial, residential, and industrial building.

How This Approach Fits Into the Framework of This Guide

This might be a preliminary approach to approximating monetized damage to infrastructure using the holistic approach. If you are performing the priority infrastructure approach, however, you should probably spend the time finding infrastructure-level data. This approach could be appropriate to monetize the damage of a few water-level increases if you are performing an impact assessment; however, if you are spending the resources to perform a risk assessment, you would probably want to use a more robust approach to monetize primary impacts.

Limitations

- Accuracy: this is more of a "back of the envelope" approach that is only recommended for preliminary assessments or in the absence of more specific data.

Key Resources

Depth-Damage Curve Library:

- USACE's *Generic Depth-Damage Relationships for Residential Structures with Basements*
- USACE's *Generic Depth-Damage Relationships for Residential Structures with No Basements*
- USACE's *Analysis of Nonresidential Content Value and Depth-Damage Data*
- USACE's *Depth-Damage Relationships for Structures, Contents, and Vehicles and Content-to-Structure Value Ratios (CSVR) in Support of the Donaldsonville to the Gulf, Louisiana, Feasibility Study*

Fact Sheet B-5: Monetize Business Interruption Loss

Business interruption loss is typically caused by inaccessible roads, lack of essential utilities, or damage to buildings or equipment. The basic approach for determining the monetized loss is to estimate how long a business is inoperable and multiply that by an economic indicator of the business's output such as wages or sales. While this might be an oversimplification, it provides a general approach to approximate business loss without becoming overly resource intensive. Work with your economist to determine how detailed and robust you want to make this analysis. It is worth noting that the FEMA Hazus-MH Flood Model monetizes business interruption loss through wage loss if you choose to use that comprehensive tool.

Impacts Measured

Secondary Impacts: Business interruption loss.

Level of Effort and Expertise Needed

The level of effort increases as you try to assess infrastructure (business)-level losses. You will need economic expertise for this approach.

Process to Perform This Approach

Step 1: Determine the amount of time a business is inoperable.
For floods where substantial building damage is expected, the loss of business due to damage or destroyed buildings and equipment may be a substantial component of business interruption. See Table 14.12 of the FEMA Hazus-MH Flood Model technical manual for the expected restoration time of various building types due to flooding. This can help you estimate how long a business may be out of operation after a flood event.

It is also possible that the primary business interruption may be caused by inaccessible roads or lack of electricity or water while crews are working to get utilities back up. In this case, you might expect businesses to be inoperable for several days to more than a week while the floodwaters retreat, utilities get back up, and businesses clean up from the flood. In this case, you may want to generate some more general assumptions, perhaps using data from historic storms, for the amount of time you can expect your businesses to be inoperable.

Step 2: Determine the wages or output of a business.
In Table 14.14 of the Hazus-MH Flood Model technical manual, FEMA provides data about the expected wages, income, and sales output per building type per square foot. You can multiply any of these variables by the number of days a business is inoperable to estimate business loss. Additionally, the Bureau of Labor Statistics (BLS) Quarterly Census of Employment and Wages and the Census Bureau County Business Patterns provide data on the number of establishments and employees and total wages by industry type. The BLS data are released sooner and offered at the county level each quarter of the year, while the Census data are annual but offer the advantage of being released at the ZIP Code and county level. You could multiply the wage data by the length of

time a certain number or percent of businesses in each industry is inoperable to estimate lost wages due to business interruption.

How This Approach Fits Into the Framework of This Guide

This helps you monetize one of the major secondary impacts (business operation loss) in Step 3, Task 2 of this framework.

Limitations

- The economy is very complex, and in the longer term, businesses may start to shift production to neighboring facilities or workers may find new work, which can often offset some of the business loss impacts.

Fact Sheet B-6: Non-Market Valuation Methodologies

These methodologies measure the value of goods, services, or states of nature not traded on the market. Many of these non-market valuation studies require implementing surveys or gathering substantial data, which is one reason why many environmental impacts, other costs, and benefits are often only considered qualitatively. The methodologies are described below; however, the processes for performing the methodologies are not outlined. Be sure to consult your experienced economist if you choose to perform any of these methodologies.

Description

Travel Cost Method: Uses travel costs such as hotel, transportation, and entrance fees to approximate the value of a coastal resource. This also typically includes a survey of a sample of people who have used the resource to estimate the difference between what the consumer actually paid for the resource and what they would be willing to pay.

Hedonic Price Method: Models how the price of a private good, such as real estate, relates to the attributes that might affect price, such as beach proximity and flooding resilience. To use this method in the context of coastal flooding, you would look at how one attribute (e.g., an elevated house better protected from coastal flooding) would change the price of the house.

Willingness to Pay: Surveys how much people say they would be willing to pay for an environmental improvement or to avoid a decrease in environmental quality.

Avoided Cost Methodology: Estimates the economic value of an environmental resource or service based on additional costs that would be placed on society if the resource or service no longer existed.

Impacts Measured

These methodologies can be used to measure just about any **environmental cost, other cost,** or **benefit.**

Level of Effort and Expertise Needed

These methodologies typically involve somewhat resource-intensive surveys or data collection and would require someone with a high level of economic expertise.

How These Approaches Fit Into the Framework of This Guide

These methodologies help you monetize environmental impacts, other costs, and benefits in Step 3, Task 2 of this framework.

Key Resources

- NOAA's *Introduction to Economics for Coastal Managers* further explains many of these approaches and provides several case studies.
- The National Ocean Economics Program's Environmental & Recreational (Non-Market) Values—Research Methodologies provides additional details about these and many other non-market valuation techniques.

Fact Sheet B-7: Benefits Transfer

Benefits transfer is an approach that borrows economic values from one study to apply to your own parallel situation. It is a reasonably low-resource method for monetizing impacts because you are not implementing the methodology for collecting the local data; however, it typically provides less informative and compelling data than gathering data specific to your local situation.

Impacts Measured

This approach can be used to measure just about any type of **primary impact, secondary impact, environmental impact, other cost,** or **benefit**. It is best used to monetize smaller impacts that you might otherwise not have the resources to monetize at all; therefore, you might want to avoid using this method to monetize your most substantial impacts.

Level of Effort and Expertise Needed

Benefits transfer typically requires a low level of effort. It should include someone with some basic economic understanding.

Process to Perform This Approach

Step 1: Find existing studies monetizing the specific type of impact you want to monetize in your community.

Step 2: Evaluate how well the studies transfer to your situation. Try to find one with many similarities to your local conditions.

Step 3: Evaluate the quality of the study from a research and methodology perspective.

Step 4: Use the previous two steps to identify the best study. Consider tailoring the value to your community by adjusting the monetized value based on differences in the area of study and your community.

How This Approach Fits Into the Framework of This Guide

This helps you monetize just about any impact for which you find it too resource intensive to create your own study in Step 3, Task 2 of this framework.

Limitations

The more similar the study's local conditions are to your own community, the more reliable the estimate will be. However, it is less informative and compelling than gathering local data.

Key Resources

- *Introduction to Economics for Coastal Managers* includes some case studies using benefits transfer.
- The National Ocean Economics Program's benefit transfer website provides additional details about this methodology as well as several case studies.

Fact Sheet B-8: Input-Output Models to Measure Indirect and Induced Impacts

Indirect impacts are a measure of the value of the inputs used by firms that are called on to produce additional goods and services for those firms first impacted by coastal flooding. For example, if hotels are damaged and inoperable for a period of time due to coastal flooding, firms that normally provide food and other supplies to the hotel will not be doing so, while some construction firms may increase their output by fixing the building. The indirect impacts are these increases or decreases in output of the firms that service the entities affected by coastal flooding.

Induced effects are related to individuals and businesses that receive added or reduced income as a result of local spending by firms and plants that are affected by the direct and indirect impacts of coastal flooding. For example, coastal flooding may result in reduced tourism for a period of time and negatively affect local hotels. Employees of these hotels might receive decreased pay as a result, and the induced impacts are the reduced sales, jobs, and outputs in the local economy as a result of less tourist money flowing in.

Typically, indirect and induced impacts are relatively small compared to the primary impacts of coastal flooding; thus, based on your resource availability, you may choose to consider this type of modeling as a supplementary type of analysis if the results are still very unclear after monetizing the primary impacts, secondary impacts, environmental impacts, other costs, and benefits. The primary tools that can be used to perform this input-output indirect and induced modeling include the Impact Analysis for Planning (IMPLAN) and the Bureau of Economic Analysis Regional Multipliers from the Regional Input-Output Modeling System (RIMS II).

Impacts Measured

Indirect and Induced Impacts

Level of Effort and Expertise Needed

These models require a high level of effort, need to be purchased, and require someone with economic modeling experience.

Process to Perform This Approach

Step 1: Identify someone with expertise in using these input-output models.

Step 2: Purchase and download the models. The links are shown in the “Key Resources” section below.

Step 3: Run the models. Consult user guides and your available economic expertise accordingly.

How This Approach Fits Into the Framework of This Guide

These input-output models help you monetize indirect and induced impacts in addition to the types impacts monetized Step 3, Task 2 of this guide.

Limitations

These models are technical and resource-intensive. Depending on the results of your analysis, the additional monetized impacts from using these models may or may not impact the ultimate decision. Thus, consider using these tools for supplementary analysis when resources allow.

Key Resources

- IMPLAN: Further information and how to order.
- BEA's RIMS II: Further information, how to order, and access to the user guide.

Appendix C: Relevant Case Studies

***Title* and Organization**	**Geographic Area**	***Methodology* and Key Findings**	**Keywords**
		United States Case Studies	
Climate Change and Coastal Flooding in Metro Boston: Impacts and Adaptation Strategies[42] Journal: Climate Change	New England	*Used GIS to model flood elevation versus flooded area curve, and used bootstrapping of historical sea-level data and Monte Carlo simulation to project sea levels and impacts for the next century. Used per linear meter cost from U.S. Army Corps of Engineers to estimate cost of resilient infrastructure.* • Performed risk-based analysis to show the cumulative 100-year economic impacts on developed areas from increased storm surge due to sea-level rise. • Concluded that it is advantageous to use expensive structural protection in highly developed areas and land management approaches in less developed or environmentally sensitive areas. • Determined that approximately 40 percent of the residences in the 100-year floodplain and 25 percent in the 100- and 500-year floodplains get flooded during an event in the Boston Metro area. • Determined that damages averaged between $7,000 and $18,000, depending on location.	Grey Infrastructure, Seawalls, Metropolitan Areas, Inundation, Property Damage, GIS, Land Use Management, Climate Change, Sea-Level Rise

[42] Kirshen, Paul, K. Knee, and M. Ruth. (2008). Climate Change and Coastal Flooding in Metro Boston: Impacts and Adaptation Strategies. *Climatic Change* 90:453–473.

Appendix C: Relevant Case Studies

***Title* and Organization**	**Geographic Area**	***Methodology* and Key Findings**	**Keywords**
COAST in Action: 2012 Projects from New Hampshire and Maine[43] New England Environmental Finance Center	New England	*Used the **CO**astal **A**daptation to **S**ea-Level Rise **T**ool (COAST)* • Estimates the economic costs and benefits of adaptation—specifically regarding the use of sea walls—under various sea-level rise and adaptation scenarios in several New England towns. • Assessed impacts of three sea-level rise scenarios (none, low, and high). • Includes detailed estimates from architectural engineering firms broken down by labor and equipment. • Assumed a discount rate of 3.5 percent, or 1 percent higher than projected inflation.	Sea-Level Rise, Storm Surge, Inundation, Grey Infrastructure, Flood Walls

[43] Merrill, S., P. Kirshen, D. Yakovleff, S. Lloyd, C. Keeley, and B. Hill. (2012). COAST in Action: 2012 Projects from New Hampshire and Maine. New England Environmental Finance Center Series Report #12-05. Portland, Maine.

Appendix C: Relevant Case Studies

***Title* and Organization**	**Geographic Area**	***Methodology* and Key Findings**	**Keywords**
Simplified Method for Scenario-Based Risk Assessment Adaptation Planning in the Coastal Zone[44] Journal: Climate Change	New England	*Used scenario-based risk assessment based on developing exceedance curves of flood elevations. This methodology was incorporated into the more user-friendly Coastal Adaptation to Sea level rise Tool (COAST).* • Investigated beach nourishment as a mitigation option for sea-level rise and beach erosion. • Concluded that beach nourishment up to the present 100-year flood elevation is estimated to cost $3,280 per linear meter ($1,000 per linear foot). • Assumes that 75 percent of the nourished beach must be redone every 10 years. • Calculated estimates of flood damages to buildings and contents using the generic depth-damage relationships for residential structures with basements from the U.S. Army Corps of Engineers, which are based on building replacement values derived from assessors' tables. • COAST is intended for local and regional planners, municipal officials, university extension agents, and other decision-makers to help them understand the potential economic impacts of different scenarios of sea-level rise and the associated costs of different adaptation strategies.	Beach Erosion, Beach Nourishment, COAST tool

[44] Kirshen, Paul, et al. (2012). Simplified method for scenario-based risk assessment adaptation planning in the coastal zone. Climatic Change 1–13.

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***Title* and Organization**	**Geographic Area**	***Methodology* and Key Findings**	**Keywords**
Assessing Future Risk: Quantifying the Effects of Sea Level Rise on Storm Surge Risk for the Southern Shores of Long Island, New York[45] Journal: Natural Hazards	Mid-Atlantic	*Used hazard analysis tools such as FEMA's HAZUS tool, USGS's asymmetric mapping tool, storm surge impact zone developed via National Hurricane Center's SLOSH model and builds upon NOAA's Community Vulnerability Assessment Tool (CVAT) methodology.* • Followed a risk assessment approach that integrated and expanded on the functionality of readily available, low-cost, or free, frequently used tools. • Outlined steps for measuring and mapping exposure, vulnerability, and overall risk from a category 3 storm surge in Suffolk County on Long Island, New York. • Examined elevated risk when factoring sea-level rise as projected by 2080.	Storm Surge, Sea-Level Rise, Exposure Index, GIS, Publicly Accessible Tools
Risk Increase to Infrastructure Due to Sea Level Rise. Climate Change and a Global City: An Assessment of the Metropolitan East Coast Region[46] Columbia Earth Institute for the U. S. Global Change Research Program	Mid-Atlantic	*Used the FEMA flood insurance map to identify vulnerable areas of the city. Used total costs from past category 1–4 storms, and scaled benefit of mitigation options based on asset density in the New York City metropolitan area.* • Provided a general risk assessment of the potential damage of category 1–4 hurricanes that could hit New York over the next 100 years. • Looked at overall insured value of New York City, used total losses from past storms in other areas, and projected sea-level rise to estimate what losses would be in New York for a comparable storm. • Evaluated types of grey infrastructure, such as sea walls and dykes, and also weighed land-use management and retreat as viable mitigation options.	Sea-Level Rise, Storm Surge, Hurricanes, Metropolitan Area

[45] Shepard, Christine C., et al. (2011). Assessing Future Risk: Quantifying the Effects of Sea Level Rise on Storm Surge Risk for the Southern Shores of Long Island, New York. *Natural Hazards* 1–19.
[46] Jacob, K. H., N. Edelblum, and J. Arnold. (2000). Risk Increase to Infrastructure Due to Sea Level Rise. Climate Change and a Global City: An Assessment of the Metropolitan East Coast (MEC) Region.

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***Title* and Organization**	**Geographic Area**	***Methodology* and Key Findings**	**Keywords**
Measuring the Impacts of Climate Change on North Carolina Coastal Resources[47] National Commission on Energy Policy	Eastern Seaboard	*Used high-resolution topographic LIDAR (Light Detection and Ranging) data, MAGICC/SCENGEN Global Climate Model, the hurricane wind speed model (HURRECON), property values data from North Carolina county tax offices, and other available GIS data.* *Used hedonic property model, nested logic demand models, NLOGIT econometric software, National Marine Fisheries Service (NMFS), and Marine Recreational Fishery Statistics Survey (MRFSS) willingness to pay surveys, and extrapolated from data collected from past storm events.* *Used U.S. Army Corps of Engineers "rule-of-thumb" of 1 cubic yard per running foot of beach to estimate cost to replace each foot of eroding beach, at an average cost of $6 per cubic yard for East Coast barrier beaches in 2004 dollars.* • Assessed inundation and storm surge vulnerability for New Hanover, Dare, Carteret, and Bertie Counties of North Carolina. • Estimated potential decrease in residential property values, lost recreation and tourism income, and costs of business interruption, including the agriculture, forestry, and commercial fisheries industries. • Estimated a potential loss of nearly 50 percent in recreational revenues in 2080 due to beach erosion. • Concluded that the economic impacts of sea-level rise on these four coastal North Carolina counties could be significant if not mitigated. • Concluded that annual beach nourishment costs to mitigate sea-level rise from 2004 to 2080 is $348 million per year when discounted at a 2-percent rate.	Green Infrastructure, Inundation, Storm Surge, Sea-Level Rise, Beach Erosion, Hedonic Property Model, Nested Logic Demand Model, Willingness-to-Pay Surveys, Beach Nourishment

[47] Bin, Okmyung, Chris Dumas, Ben Poulter, and John Whitehead. (2007). Measuring the Impacts of Climate Change on North Carolina Coastal Resources: Final Report. National Commission on Energy Policy.

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Title and Organization	Geographic Area	*Methodology* and Key Findings	Keywords
Estimating the Vulnerability of U.S. Coastal Areas to Hurricane Damage[48] Francis Marion University Quality Enhancement Plan	Southeast United States	*Used multi-attribute utility theory(MAUT) to formulate a hurricane vulnerability index (HVI) using seven indicators: population, number of housing units, house value, probability of hurricane strike, building code effectiveness, building age, and vulnerability to sea-level rise. Used 2000 U.S. Census data for population and housing values.* • Calculated an HVI to rank the susceptibility of coastal areas to hurricane damage and provided necessary equations. • Ranked 11 U.S. counties in terms of vulnerability, with Miami-Dade ranking the most vulnerable. • Identified the top 10 U.S. counties in terms of cumulative exposure in coastal Florida (6), North Carolina (3), and Louisiana (1). • Identified three key elements—the level of exposure, the physical susceptibility to the hurricane, and the frequency and intensity of hurricanes—that contribute to the degree to which communities experience hurricane damage. • Considered wetlands, levees, sea walls, and storm-resilient construction as viable infrastructure options. • Stated that coastal Louisiana wetlands provided $452 acre/year in storm reduction benefits.	Vulnerability Index, Sea-Level Rise, Climate Change, Storm Surge, Hurricanes, Event Probability, Grey Infrastructure, Green Infrastructure
An Adaptive Regional Input-Output Model and its Application to the Assessment of the Economic Cost of Katrina[49] Journal: Risk Analysis	Gulf of Mexico	*Uses the Adaptive Regional Input-Output (ARIO) Model to estimate indirect costs. Also provides a methodology for converting national-level BEA input-output tables to regional-level input-output tables for use in the ARIO model.* • Derived regional-level input-output tables from Bureau of Economic Analysis national-level input-output tables to simulate the response of the economy of Louisiana to the landfall of Katrina. • Considers damage from Katrina as a whole—primarily from, but not specific to, inundation.	Hurricane Katrina, Input-Output Models, Storm Surge

[48] Pompe, Jeffrey and Jennifer Haluska. (2011). Estimating the Vulnerability of U.S. Coastal Areas to Hurricane Damage.
[49] Hallegatte, S. (2008). An adaptive regional input-output model and its application to the assessment of the economic cost of Katrina, Risk Analysis.

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***Title* and Organization**	**Geographic Area**	***Methodology* and Key Findings**	**Keywords**
The Socio-Economic Impact of Sea Level Rise in the Galveston Bay Region[50] Environmental Defense Fund	Gulf of Mexico	*Used FEMA HAZUS Multi-Hazard MR3 ArcGIS Extension.* • Illustrated the impact that climate change will have on communities in the Galveston Bay region using two scenarios of sea-level rise: 0.69 meters and 1.5 meters. • Estimated impact on displaced populations; residential structures; industrial facilities, hazardous waste, Superfund, and solid waste sites; water treatment plants; and building-related economic losses. • Found that, under the 1.5 meter scenario, almost 99,000 households would be displaced and more than 75,000 structures impacted in the region. • Did not estimate the impact on municipal and county governments, as they deal with infrastructure loss, moving populations, and potentially decreasing tax base. • Looked only at the losses assuming no mitigation is performed.	Gulf of Mexico, Inundation, Storm Surge, Hurricanes, Sea-Level Rise
The Role of Land Use in Adaptation to Increased Precipitation and Flooding: A Case Study in Wisconsin's Lower Fox River Basin[51] Resources for the Future	Great Lakes	*Used HAZUS and national databases of the inventory of structures at the census block level from the U.S. Bureau of the Census and Dun & Bradstreet to estimate depth damage curves, debris generation, indirect losses (such as loss of income or relocation expenses), and displacement of people.* • Examined flooding losses and mitigation benefits for the Lower Fox River basin from central Wisconsin to Green Bay. • Investigated land-use options as an alternative to traditional grey infrastructure mitigation. • Considered traditional grey infrastructure such as reservoirs, levees, flood walls, and dams, as well as land-use regulations for increasing wetland areas and removing or mitigating the influence of drainage ditches in agricultural lands. • Estimated losses, but not benefits, of mitigation options. • Focused primarily on regulating land use as a mitigation option.	Land Use, Inundation, Water Quality, Great Lakes, Wetlands, Recreation, Climate Change, Grey Infrastructure, Green Infrastructure

[50] Yoskowitz, David, et al. (2009). The Socio-Economic Impact of Sea Level Rise in the Galveston Bay Region. Environmental Defense Fund.
[51] Kousky, Carolyn, et al. (2011). The Role of Land Use in Adaptation to Increased Precipitation and Flooding: A Case Study in Wisconsin's Lower Fox River Basin. Resources for the Future.

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***Title* and Organization**	**Geographic Area**	***Methodology* and Key Findings**	**Keywords**
Potential Impacts of Increased Coastal Flooding in California Due to Sea-level Rise[52] Journal: Climatic Change	California	*Used GIS database with inundation maps combined with FEMA HAZUS; data from the U.S. Census, TeleAtlas, the California Office of Health Planning, and power plants from the California Energy Commission; and information on hazardous materials sites from U.S. EPA.* • Assessed the potential impacts from projected sea-level rise if no actions are taken to protect the coast, focusing on impacts to the state's population and infrastructure. • Discussed beach erosion impacts, effects on wetlands, costs of coastal defenses, and issues of social and environmental justice related to sea-level rise. • Considered the replacement value of structures by intersecting the inundation layers with year 2000 census block data, assuming that building value data is distributed uniformly over a census block's area. • Provided detail on the timing and degree of vulnerability for different levels of rise. • Quoted other existing research and literature for some basic estimates of physical adaptation options, including building or strengthening seawalls and levees.	Sea-Level Rise, Beach Erosion, Environmental Justice, Grey Infrastructure, GIS

[52] Heberger, Matthew, et al. (2011). Potential impacts of increased coastal flooding in California due to sea-level rise. *Climatic Change* 1–21.

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***Title* and Organization**	**Geographic Area**	***Methodology* and Key Findings**	**Keywords**
		European Case Studies	
Assessing Climate Change Impacts, Sea Level Rise and Storm Surge Risk in Port Cities: A Case Study on Copenhagen[53] OECD Environment Working Papers, OECD Publishing	Europe/Scandinavia	*Used statistical data available from past storm scenarios, combined with GIS analysis of the population and asset exposure in the city, for various sea levels and storm surge characteristics.* • Estimated economic impacts of climate change on Copenhagen, Denmark, focusing on sea-level rise and storm surge. • Assessed exposure by mapping population and industry distribution data onto a Digital Terrain Model (DTM) (exposure data came from risk management software). • Estimated direct and indirect losses as part of a risk analysis due to climate change and sea-level rise.	Inundation, Storm Surge, Sea-Level Rise, Climate Change, Sea Walls, Risk Analysis

[53] Hallegatte, S. et al. (2009). Assessing Climate Change Impacts, Sea Level Rise and Storm Surge Risk in Port Cities: A Case Study on Copenhagen. OECD Environment Working Papers, No. 3, OECD Publishing.

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***Title* and Organization**	**Geographic Area**	***Methodology* and Key Findings**	**Keywords**
Impacts of Sea Level Rise Towards 2100 on Buildings in Norway[54] Journal: Building Research and Information	Europe/Scandinavia	*Used the Norwegian Building Matrix and a custom GIS program to perform vulnerability assessment and develop a model (Rahmstorf [2007]) for future global sea level rise and the "business-as-usual" emissions scenario from the IPCC.* • Assessed the impact of sea-level rise on grey infrastructure along the Norwegian coastline. • Estimated that more than 100,000 buildings are located less than 1 meter above typical sea level, including more than 2,000 hotels and restaurants, 6,000 residences, 500 buildings related to communications infrastructure, 270 buildings vital to energy supply, 160 schools, and 20 health care facilities. • Calculated the total potential costs of the expected sea-level rise by estimating an average cost per building for several building types and then multiplying that estimate by the number of structures per category. • Concluded that improved building codes that encourage structures resistant to natural stressors, increased drainage, installation of pumps, and relocating vulnerable structures could greatly reduce costs.	Sea-Level Rise, Storm Surge, Inundation, Grey Infrastructure, Climate Change, GIS

[54] Almas, Anders-Johan and Hans Olav Hygen (2012). Impacts of Sea Level Rise Towards 2100 on Buildings in Norway. *Building Research and Information* 40:3, 245–259.

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***Title* and Organization**	**Geographic Area**	***Methodology* and Key Findings**	**Keywords**
		Asian Case Studies	
An Assessment of the Socio-Economic Impacts of Floods in Large Coastal Areas[55] Asia-Pacific Network for Global Change Research	Southeast Asia	*Used the Urban Flood Risk Analysis (URFA) model, the Institute of Industrial Science Distributed Hydrological Model (IISDHM), and a hydrodynamic model developed by the Public Work Research Institute.* • Examined the socio-economic impact of floods exacerbated by climate change in six countries in South and Southeast Asia. • Developed GIS database of hydrologic characteristics and socioeconomic conditions. • Adapted existing tools and methodologies to simulate and assess flooding under long-term climatic change and rise in sea-level, and estimated socio-economic impacts and vulnerability. • Identified existing policy gaps. • Developed strategies to better communicate with the public. • Did not consider the economic impacts of sea-level rise on ecosystems, tourism, fishing, and other coastal industries.	Land-Use Management, Asia, Climate Change, Sea-Level Rise. GIS, Inundation, Buildings, Industrial and Commercial Vulnerability

[55] Hallstrom, D.G. and V.K. Smith, V.K. (2005). Market responses to hurricanes. *Journal of Environmental Economics and Management* 50: 541–561.

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Title and Organization	Geographic Area	*Methodology* and Key Findings	Keywords
The Economic Impact of Sea-Level Rise on Nonmarket Lands in Singapore[56] Ambio: A Journal of the Human Environment	Southeast Asia	*Used a travel cost and contingent valuation study to estimate the value of nonmarket land.* • Discussed nonmarket lands, such as beaches, marshes, and mangrove estuaries, and revealed that consumers in Singapore attach considerable value to beaches. • Looked at the cost of protection given different sea-level rise scenarios and the nonmarket value of beaches, marshes, and mangrove estuaries. • The contingent valuation study also placed high value on marshes and mangroves, but this was not supported by the travel cost study. • States that, although protecting nonmarket land uses from sea-level rise is expensive, highly valued resources, such as Singapore's popular beaches, should be protected. • Presented method for estimating costs of beach protection, including the construction costs of the underwater hard structures, the cost of sand, and the maintenance costs. The cost of sand is estimated to be $30 per cubic meter, and the maintenance costs are assumed to be 4 percent of construction costs.	Beach Erosion, Beach Nourishment, Nonmarket Valuation, Land-Use Management, Sea-Level Rise, Recreation

[56] Ng, W. and R. Mendelsohn (2006). The Economic Impact of Sea-Level Rise on Nonmarket Lands in Singapore. *Ambio,* 35 (6), 289–296.

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***Title* and Organization**	**Geographic Area**	***Methodology* and Key Findings**	**Keywords**
Flood Risks, Climate Change Impacts and Adaptation Benefits in Mumbai: An Initial Assessment of Socio-Economic Consequences of Present[57] Organization for Economic Cooperation and Development (OECD)	India/Asia	*Used the Storm Water Management Model (SWMM) to assess vulnerability. Used three types of data to estimate direct costs: 1) actual data from the 2005 flood, 2) insured value data, and 3) average data for generic industrial, commercial, and residential facilities. Used the Adaptive Regional Input-Output (ARIO) model to estimate indirect costs.* • Provided summary information for unprecedented flooding experienced in Mumbai, India, in 2005. The event caused direct economic damages estimated at nearly $2 billion (U.S. dollars) and caused 500 fatalities. • Discussed relationship between direct and indirect costs. • Concluded that by the 2080, in a SRES A2 scenario (an "upper bound" climate scenario), the likelihood of a 2005-like event would more than double. • Estimated that total losses (direct plus indirect) associated with a 1-in-100 year event could triple due to climate change. • Investigated the benefits of upgrades to the city's drainage system. • Did not take into account population and economic growth. • SWMM model is not applicable to typical sea-level rise and storm-surge vulnerability assessments.	Direct Costs, Indirect Costs, Grey Infrastructure

[57] Hallegatte, S. et al. (2010). "Flood Risks, Climate Change Impacts and Adaptation Benefits in Mumbai: An Initial Assessment of Socio-Economic Consequences of Present and Climate Change Induced Flood Risks and of Possible Adaptation Options," OECD Environment Working Papers, No. 27, OECD Publishing.

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***Title* and Organization**	**Geographic Area**	***Methodology* and Key Findings**	**Keywords**
Predicted Impact of the Sea-level Rise at Vellar-Coleroon Estuarine Region of Tamil Nadu Coast in India: Mainstreaming Adaptation as a Coastal Zone Management Option[58] Journal: Ocean & Coastal Management	India/Asia	*Used the Digital Elevation Model (DEM) derived from SRTM 90M (Shuttle Radar Topographic Mission) data, along with GIS techniques, to identify an area of inundation in the study site. Effects of inundation are discussed using GIS-based land-use land-coverage (LULC) and hamlet mapping.* • Assessed the impacts of sea-level rise on coastal natural resources and dependent social communities in the low-lying area of Vellar-Coleroon estuarine region of the Tamil Nadu coast, India. • Discussed a number of types of grey and gray infrastructure (but these are not incorporated in the model). • Calculated vulnerability of coastal areas to inundation based on projected sea-level rise scenarios of 0.5 and 1.0 meters.	Sea-Level Rise, Grey Infrastructure, Green Infrastructure, GIS
Other Regional Case Studies			
Assessing the costs of sea-level rise and extreme flooding at the local level: A GIS-based approach[59] *(26)* Journal: Ocean & Coastal Management	Israel	*Used GIS modeling to create inundation increment maps and spatially distributing assets and population to generate a comprehensive picture of local socio-economic costs.* • Used a method of performing vulnerability assessment that is generic and transferable. • Estimated costs related to different scenarios of permanent inundation and periodic flooding. • Inventoried various tools available for assessing the impacts of natural processes at the local level. • Identified the various types of capital stocks at risk.	Inundation, Sea-Level Rise, Climate Change, GIS

[58] Saleem Khan, A., et al. (2012). Predicted Impact of the Sea-level Rise at Vellar-Coleroon Estuarine Region of Tamil Nadu Coast in India: Mainstreaming Adaptation as a Coastal Zone Management Option. *Ocean & Coastal Management*.
[59] Lichter, Michal and Daniel Felsenstein (2012). Assessing the costs of sea-level rise and extreme flooding at the local level: A GIS-based approach. *Ocean & Coastal Management* 59 (2012): 47–62.

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***Title* and Organization**	**Geographic Area**	***Methodology* and Key Findings**	**Keywords**
The Vulnerability of Caribbean Coastal Tourism to Scenarios of Climate Change Related Sea Level Rise[60] *(41)* Journal of Sustainable Tourism	Caribbean	*Predicted flooding using a digital terrain model (DTM), and overlaid inundation area with the location of coastal resorts.* • Created a geo-referenced database of more than 900 major coastal resort properties in 19 Caribbean countries to assess their potential risk from a scenario of 1 meter of future sea-level rise.	Inundation, Tourism, Sea-Level Rise
Impacts of Climate Change and Sea-Level Rise: A Case Study of Mombasa, Kenya[61] *(19)* University of Southampton, School of Civil Engineering and the Environment, Southampton, UK.	Kenya	*Used GIS analysis to assess the number of people and associated economic assets exposed to inundation by comparing elevation data with gross domestic production and population data to identify vulnerable assets. Used four sea-level rise scenarios and two population growth projections to determine how larger population will affect economic projections.* • Captured baseline scenario of projected economic damage from sea-level rise and storm surge in Mombasa, Kenya. • Calculated vulnerable assets based on number of people that would be exposed multiplied by the per capita GDP of the country. • Did not investigate adaptive infrastructure or other mitigation options.	Inundation, Sea-Level Rise, GIS, Developing Countries

[60] Scott, Daniel, Murray Charles Simpson, and Ryan Sim (2012). The vulnerability of Caribbean coastal tourism to scenarios of climate change related sea level rise, *Journal of Sustainable Tourism,* 20:6, 883–898.
[61] Kirshen, Paul, K. Knee, and M. Ruth. (2008). Climate change and coastal flooding in Metro Boston: impacts and adaptation strategies. *Climatic Change* 90:453–473.