CLIMATE CHANGE
Installation Adaptation and Resilience

PLANNING HANDBOOK

January 2017

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Naval Facilities Engineering Command

CLIMATE CHANGE PLANNING HANDBOOK
INSTALLATION ADAPTATION AND RESILIENCE

FINAL REPORT

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CLIMATE CHANGE PLANNING HANDBOOK
INSTALLATION ADAPTATION AND RESILIENCE

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INTRODUCTION

Background

The U.S. Department of Defense (DoD) 2014 Climate Change Assessment Roadmap lists four primary **climate change** phenomena likely to affect the Department's activities:

- Rising global temperatures
- Changing precipitation patterns
- Increasing frequency or intensity of extreme weather events
- Rising sea levels and associated storm surge

These climate change phenomena translate into **hazards** and **impacts** at military installations. The Roadmap lists possible impacts to Plans and Operations, Testing and Training, Built and Natural Infrastructure, and Supply Chain and Acquisition. The occurrence and severity of these impacts will likely increase as the **climate** continues to change. (Words bolded in **red** throughout the Handbook are included in **Appendix A**.)

In accordance with Unified Facilities Criteria (UFC) 2-100-01, Installation Master Planning , and other DoD guidance, Navy Master Development Planners are directed "to consider" climate change in the development of Master Plans and projects. This Handbook provides the analytical framework, as well as tools and other guidance, to help planners understand *how* to consider climate change in their plans and projects for installation infrastructure. More specifically, this document leads planners through the process of identifying and assessing possible adaptation **action alternatives**, or methods for adapting to the impacts of climate change. These adaptation measures are intended to improve their installation's **resiliency**, or capability to anticipate, prepare for, respond to, and recover from significant hazards.

Anthropogenic climate change is caused by the increase in concentration of **greenhouse gases** (GHG) in the atmosphere since the start of the industrial era. Efforts to reduce GHG emissions are often in the news. Scientific research has confirmed the link between global warming and accumulated levels of atmospheric GHGs from anthropogenic sources. Efforts relating to the reduction of GHGs (e.g., switching to renewable energy sources) are referred to as "**mitigation**." As discussed in the 2014 Climate Change Adaptation Roadmap referenced above, the impacts of climate change are already affecting Navy installations. Accumulated GHGs will persist for decades in the atmosphere, and will continue to drive the warming processes affecting climate, even if significant emission reductions are achieved in this century. Efforts to adjust to the impacts of climate change are referred to as "**adaptation**."

Federal agencies are implementing various plans that incorporate elements of both mitigation and adaptation. These efforts are being undertaken in response to several Executive Orders and in light of agencies' own **risk** management processes. **Appendix B** contains a list of policies or directives requiring that federal agencies assess and adapt to the impacts of climate change. The emphasis in these directives is on integrating climate risks into existing risk management frameworks, rather than developing separate climate change adaptation plans.

About this Handbook

This section describes the intent of the Handbook, target audience, focus, layout, and desired outcome after application of the Handbook to evaluate possible climate adaptation action alternatives.

Intent: The intent of this Handbook is to provide the analytical framework and methodology to help Navy Master Development Planners understand how to consider climate change in their plans and projects. A series of Stages are provided to help planners identify and assess adaptation action alternatives to manage potential impacts to current and planned infrastructure. This Handbook is designed to be a desktop reference that can serve as a companion tool throughout the planning process, especially the analysis phase of the Navy Installation Development Plan (IDP) process. The intended output is a portfolio of possible adaptation action alternatives that can be incorporated into alternative courses of action, along with other considerations, in the IDP and other decision support processes.

Target Audience: Navy Master Development Planners are the target audience for this Handbook.

Focus: The focus of this Handbook is the development of potential adaptation action alternatives that address the physical impacts of climate change to both **built** and **natural infrastructure** at the installation level. As a planner, you may wish to consider specific assets or possibly various infrastructure sectors, such as Buildings and Urban Structures, Transportation, Energy, Telecommunications, Water and Wastewater Systems, and Natural Infrastructure and Ecosystems. These sectors include three types of infrastructure: horizontal, vertical, and natural. Most of the examples provided in this Handbook illustrate climate change impacts and potential adaptation measures focused on coastal hazards (e.g., **flooding** and **storm surge** damage) and their impacts on infrastructure. With assets located along coastlines, it is anticipated that many Navy installations will experience coastal climate hazards.

Planners may consider a range of adaptation action alternatives. These are briefly described in the Fact Sheets provided in **Appendix D**, which address four broad categories of adaptation approaches:

Structural – approaches that use a built structure to achieve flood damage reduction for an area, such as levees or storm surge barriers.

Natural and Nature-based – approaches that use constructed or modified natural features to reduce the impacts of storm surge or other flooding, such as dunes, tidal marshes, or coastal vegetation.

Facilities – approaches that modify a structure to withstand potential flooding, such as building to a new standard that accounts for changing flood risk, constructing smaller scale protective structures such as a berm to deflect floodwater around a building, and making physical alterations to an existing structure to reduce flood damage.

Non-facilities – approaches that rely on changes in siting, management, or maintenance of infrastructure to reduce flood damage, such as land use planning that locates future development out of flood prone areas, acquisition of land or easements to facilitate other adaptation measures, and increasing maintenance.

Handbook Organization: The main body of the Handbook is composed of an introductory section and four Stages. **Table IN.1** provides an overview of the Stages, with a listing of their intent and associated steps and worksheets; all the worksheets referenced are located in **Appendix F**.

Stages in Adaptation Planning Handbook

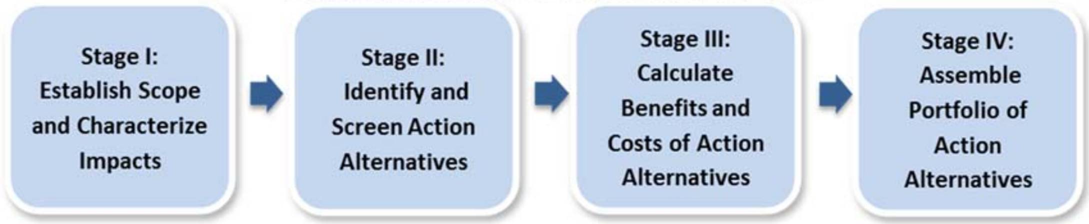

Table IN.1 Overview of Handbook Stages and Steps

	STAGE I	STAGE II	STAGE III	STAGE IV
INTENT	Identify the focus of your analysis or assessment and gather information about the current and future impacts of climate change on the infrastructure of concern. Assess, describe, and characterize current and future climate impacts on your focus area. Develop a problem statement to form the basis of action alternative selection in Stage II.	Select a preliminary set of adaptation action alternatives to address the impacts to infrastructure you identified in Stage I. Assess them to see if they are feasible and appropriate given your situation.	Develop life cycle costs, apply cost effectiveness analyses, and identify monetized and non-monetary benefits for the action alternatives selected in Stage II. Conduct benefit/cost evaluations, including a benefit cost ratio and net present value, to enable development of a portfolio in Stage IV.	Review non-monetized aspects and compile action alternatives into a portfolio summary worksheet. Review other considerations that might be useful as you move forward.
STEPS	① Determine Assessment Scope ② Identify and Evaluate Information ③ Describe and Characterize Impacts ④ Develop Problem Statement	① Identify Potentially Suitable Adaptation Actions ② Identify Benefits and Limitations ③ Evaluate Feasibility ④ Evaluate Appropriateness ⑤ Characterize Strategic Approach to Decisions under Uncertainty	① Gather and Assess Physical Performance Metrics and Estimate Life Cycle Costs ② Preliminary Economic Screening: Apply Cost Effectiveness Analysis ③ Complete Impact Analysis Framing ④ Select Benefits Monetization and Action Alternatives Costing Tools ⑤ Determine Costs and Benefits to be Monetized and Perform Calculations	① Assemble Portfolio Summary ② Identify Key Future Variables ③ Re-evaluate Strategic Approach to Decisions under Uncertainty ④ Characterize Risk Approach ⑤ Relate Results to the Installation Development Plan
WORKSHEETS	WS I.1 - Assessment Scope WS I.2 - Site Information Quality Assessment WS I.3 - Historical Weather Event and Impacts Information WS I.4 - Climate Information Requirements and Attributes WS I.5 - Current and Plausible Future Conditions WS I.6 - Existing Assessment Evaluation WS I.7 - Impact Description and Characterization	WS II.1 - Potential Action Alternatives	WS III.1 - Life Cycle Cost Analysis WS III.2 - Cost Effectiveness Analysis WS III.3 - Benefits WS III.4 - Benefit Cost Ratio and Net Present Value	WS IV.1 - Portfolio Summary

Eight appendices provide supporting material:

- Appendix A – Acronyms and Glossary
- Appendix B – Federal, DoD, and Navy Requirements Relating to Climate Change
- Appendix C – Climate Science, Data, and Projections presents basic concepts related to climate science, climate models, and climate projections, lists information sources for climate data, and provides sample output and a discussion on how to align climate projection values to your site reference datum.
- Appendix D – Adaptation Action Alternatives Fact Sheets – contains Fact Sheets that describe different adaptation techniques or technologies.
- Appendix E – Economic Analysis Tools and Resources Fact Sheets - contains Fact Sheets referenced in Stage III to assist with economic analyses.
- Appendix F – Worksheets for Stages I – IV - an accompanying Microsoft Excel spreadsheet that contains worksheet templates and formulas referenced in Stages I through IV.
- Appendix G – Completed Worksheets for a Notional Installation - contains a completed set of worksheets for the Notional Installation example used throughout the Handbook.
- Appendix H – Sources Cited

Handbook Use: This Handbook does not replace the shore infrastructure planning process, but rather provides a mechanism for gathering additional information that could inform an Installation Development Plan. The Stages and Steps in this Handbook are intended to be iterative such that, depending on the results of your analysis or the level of detail required, you might be able to proceed with preliminary information at a particular point, ascertain what kind of information that yields, and repeat the process with more detailed information or better capabilities at a later date.

The scope of your assessment depends on your purview and purpose. You may be interested in assessing possible adaptation action alternatives for a specific asset, such as a building or a transportation support structure (e.g., railroad, group of piers). Alternatively, you may be assessing impacts to all of the physical elements of a system, such as all components related to the power generation and distribution system. Or, you may be tasked with performing an assessment of climate change impacts to all physical assets at your installation.

It is likely that you will repeat all or some of the Stages in the Handbook, perhaps several times, as the level of detail desired in the assessment evolves.

Prior to delving into the process, you may find it useful to review all of the Stages to get a full understanding of how each Stage prepares you for the subsequent Stages. Depending on where you are in your planning process and the information you already have, you may be able to 'skip' to particular steps. Perhaps you have already gathered significant information on climate data (current and projected future conditions); if you have a clear understanding of the purpose of your assessment, you may be able to go directly to worksheets in Stage I, Step ② that help you assess and document the breadth and usefulness of the data.

Furthermore, though the framework and Stages in the Handbook are designed to remain basically the same, recognize that over time the references and appendices herein is subject to change to reflect new information about climate projections, potential impacts, and adaptation action alternatives.

Desired Output: **At the completion of the steps in this Handbook, you should have developed a portfolio of potential climate change adaptation action alternatives that can be taken into consideration in the IDP process.** A portfolio contains a list of viable action alternatives, some of which can be implemented alone or as a group. In addition, each Stage in the Handbook yields completed worksheets and support materials (e.g., maps and other documentation) useful during your next steps **(Figure IN.1)**.

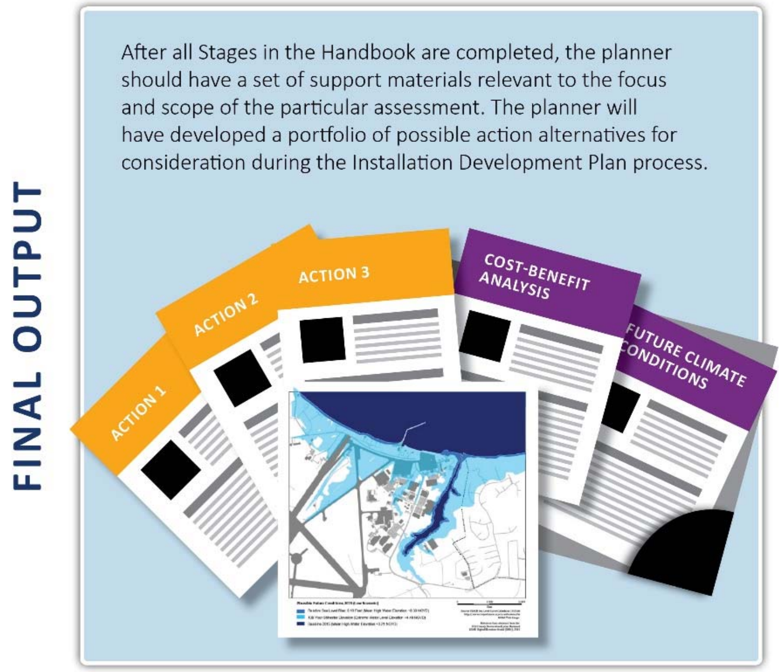

Figure IN.1 Final Output after Completion of All Stages

Because of the inherent uncertainties in projecting climate conditions in the future, the goal of the iterative analytical process is to develop (and periodically update) a portfolio of adaptation action alternatives that can be modified as strategic objectives change, technology or adaptation methods change, or new information about climate change and possible impacts is obtained. **Figure IN.2** illustrates how the output from this Handbook process feeds into the IDP process.

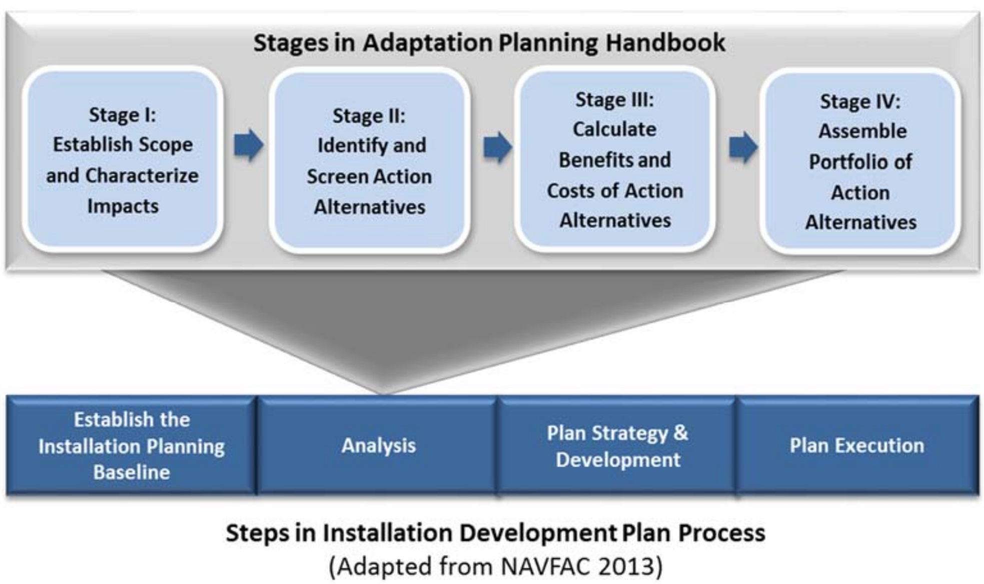

Figure IN.2 Relation of the Output from the Adaptation Planning Handbook Process to the Installation Development Plan Process

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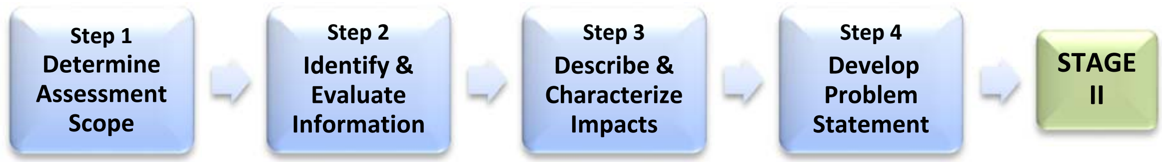
STAGE I – ESTABLISH SCOPE AND CHARACTERIZE IMPACTS



Introduction

This section sets up and guides the preliminary research steps needed to develop a ***problem statement****, the output of this stage. You will first determine your assessment scope by examining parameters such as: the geographic extent of the subject area, intended lifespan of the infrastructure, the* ***climate phenomena*** *and hazards of interest, and the kind of decision to be supported. You will then identify and evaluate relevant information and use tools and worksheets in* ***Appendices A****,* ***C****, and* ***F*** *to assess, describe, and characterize current and future climate impacts on your focus area. Prior to advancing to Stage II and starting to identify potential action alternatives, you will develop a problem statement that succinctly characterizes the issues to be addressed.*

Before starting this stage, you should have:

- An understanding of why you are initiating this activity

Resources, skills and tools you may need:

- Inventory of installation infrastructure
- Geographic Information System (GIS) software, spatial data layers, and expertise
- Literature reviews of historical weather, hazards, **vulnerability assessments**, and **impact assessments**
- Climate data, scenarios, and projections
- Infrastructure engineering and design experts

Key concepts you will encounter:

- Differentiation between weather and climate phenomena, hazards and impacts
- **Climate scenarios** and **climate projections**

At the end of this stage, you will be able to:

- Understand how to scope your assessment and identify and evaluate information resources useful for characterizing and describing climate impacts on infrastructure,
- Complete impact description and characterization worksheets by using tools and analyzing information,
- Explain technical assumptions and information uncertainties, and
- Develop a problem statement that succinctly defines the type and magnitude of issues to be addressed.

Output: Problem statement that characterizes the type and magnitude of potential impacts to infrastructure. This problem statement will guide and bound the identification and evaluation of possible responses to potential impacts, leading to the development of a portfolio of action alternatives. The problem statement essentially describes the magnitude of impacts to the infrastructure of concern from specific climate or weather hazards and sets the context for proposing action alternatives. The problem statement should set the goal of the adaptation strategy, such as preserving the infrastructure in its current location or preserving the functions of the infrastructure but in a different location. This Handbook follows a sample problem statement throughout all the Stages to illustrate the process.

Preliminary Climate Basics

It is important, before you proceed, to understand the differences between weather and climate. According to the National Snow and Ice Data Center, weather is the day-to-day state of the atmosphere in a particular place, and its short-term variation is in minutes to weeks. Climate is the weather of a place averaged over a period of time, often 30 years. Weather phenomenon examples include a snowfall or rainfall event, storm surge, thunderstorms, tornado, and heat or cold waves. Climate phenomena include components such as sea level, precipitation, annual average temperature, and extreme temperatures.

It is also important to be able to distinguish between a hazard and an impact. A hazard – such as flooding and wave or wind damage – is *how* we experience the weather or climate phenomenon. An impact is a *positive or negative effect* on the natural or built environment (e.g., infrastructure damage, power outage) caused by exposure to a hazard.

Scientists can provide historical data and future projections for climate phenomena. Currently storm surge levels are derived statistically from historical data; research is ongoing to develop projections. Users apply this information to determine the hazards and impacts experienced or that could be experienced at their installation. **Table I.1** provides examples of weather and climate phenomena, associated hazards, and impacts to infrastructure. Note the distinction made here between *temporary* flooding, **nuisance flooding** (e.g., recurrent flooding that takes place at high tide), and permanent inundation. Also note that hazards may be caused or exacerbated by more than one phenomenon.

Table I.1 Phenomena, Hazards, and Impacts Examples

Weather Phenomenon	Hazard	Impacts
Storm Surge	Flooding, wave damage	Undercutting, erosion or failure of facility or road foundation
Thunderstorm	Flooding, wind damage	Power outages, infrastructure damage
Tornado	Wind damage	Power outages, infrastructure damage
Heat or Cold Wave	Heat stress, stress to equipment	Electrical or equipment failure, curtailment of building operations
Climate Phenomenon	**Hazard**	**Impacts**
Sea Level Change	Nuisance flooding, permanent inundation	Temporary or permanent loss of access to structures or roads; loss of lower floor contents
Precipitation Changes	Flooding, lightning damage, wildfire, drought	Power outages, inaccessible roads, loss of built structures to fire
Annual Average Temperature Increase	Wildfire, changes in ecology	Unhealthy natural infrastructure (e.g., forest buffer), loss of built structures
Extreme Temperatures	Heat stress, stress to equipment, drought	Electrical or equipment failure, curtailment of building operations, lack of water

You might find it helpful to refer to **Appendix C - Climate Science, Data, and Projections** and **Appendix A - Acronyms and Glossary** to learn about or review background information on basic concepts related to climate science, climate models, and climate projections.

Step ①: Determine Assessment Scope

In this step, you will determine or confirm your assessment scope.

The assessment scope and underlying assumptions should be as clear as possible because they will help maintain focus and discipline throughout a complex analytical process, and guide the preliminary research steps needed to develop a problem statement, which is the output of this stage.

☐ Use **Worksheet I.1 - Assessment Scope** to document your answers and assumptions to the worksheet questions and considerations. This will help you develop an assessment scope which informs the types of data and information you will need for later analysis and serves as the basis for the example problem statement to be used throughout this Handbook. Did someone direct you to complete the study for a particular purpose?

- Note: The questions do not need to be answered in the order they are presented, but each question should be answered. If someone directed you to complete a study for a particular purpose, the worksheet will ensure you are not missing useful scoping information. Information not obtainable should be documented as well.

Worksheet I.1 poses the following types of questions and considerations, also depicted on **Figure I.1**. For the purpose of generating an example assessment scope, each question contains hypothetical answers and assumptions for a notional installation called Naval Station A. (Throughout this Handbook, text in *blue italics* font denotes information related to the sample notional installation; blue italics font is used in the Notional Installation worksheets as well. A set of completed notional installation worksheets is in **Appendix G**; a blank set are in **Appendix F**.

- **What** do you wish to assess? Impacts to the entire installation? A portion of the installation? A particular infrastructure sector? A particular system or asset within a sector?

  Example answer: *Potential negative impacts to existing and planned infrastructure across the entire installation.*
  Example assumption: *Current land use will not significantly change; there is some flexibility in siting planned infrastructure.*

- What **hazards** do you wish to assess? Flooding? Permanent inundation? Heat stress? Erosion? Drought? The answer to this question defines the **hazard of concern,** which will also be used in subsequent worksheets.

  Example answer: *Permanent inundation and flooding.*
  Example assumption: *Naval Station A is located along the coast and has experienced flooding impacts due to storm surge in the past. Assets located at lower elevations would be impacted by sea level change.*

- What **weather or climate phenomena** are associated with the hazard of concern you wish to address? For example, sea level change? Storm surge? Changes in precipitation or temperature? Possibility of heavy or reduced precipitation events? Others?

Example answer: *Sea level change and storm surge (the 1%* ***annual chance event*** *or* ***100-year storm event)****.*
Example assumption: *These are the weather and climate phenomena that correlate to the hazards of concern - permanent inundation, and flooding.*

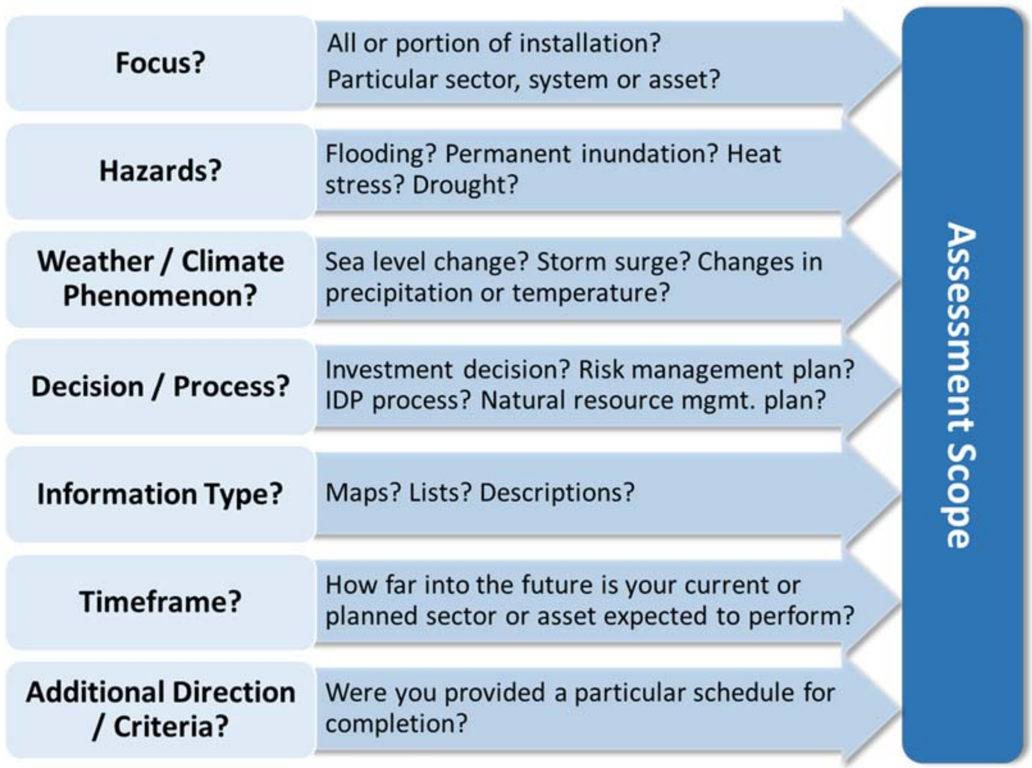


Figure I.1 Assessment Scope Parameters

- What do you wish to **inform**? An investment decision? A risk management plan? Installation development planning process? A natural resource management plan? A constraints map?

  Example answer: *Installation development planning.*
  Example assumption: *This is the best method to capture long-term actions and there is time to feed into the next IDP iteration.*

- What **type of information** does that decision/process **need**? A map with flooding demarcation? A list of impacts to particular infrastructure?

  Example answer: *Installation infrastructure map; maps with current and future flooding elevations and extent; description of impacts to site infrastructure.*
  Example assumption: *The visualization of flooding and permanent inundation changing over time will allow planners to better understand the potential negative impacts and develop potential adaptation action alternatives.*

- Over what **timeframe** do you wish to assess impacts? Things to consider - how far into the future is your current or planned sector, system, or asset expected to perform?

  Example answer: *Over the next 100 years.*

Example assumption: *Naval Station A will be sustained in its current location for the long term.*

- Is there any **additional direction or criteria** that should be included in your assumptions? Were you provided a particular schedule for completion?

  Example answer: *No additional direction.*
  Example assumption: *NA.*

Once completed, your **Worksheet I.1 - Assessment Scope** will contain the answers and assumptions needed to generate an assessment scope. The assessment scope is most helpful if it is succinct.

The example assessment scope for notional installation Naval Station A is:

Given the stated assumptions in Worksheet I.1, determine how we can protect the installation infrastructure from damage due to flooding and permanent inundation over the next 100 years.

Step ②: Identify and Evaluate Information

*In this step, you will identify and evaluate information for your assessment (e.g., installation site information, impacts during historical weather events, and climate information requirements). Before you start this step, you should have a completed **Worksheet I.1 - Assessment Scope** from Step ①.*

During this step, you will use the following four worksheets to identify and determine the type and quality of information you need and who might have the necessary skills to help retrieve and/or understand and apply the data. All of this information will be used in Step ③ to complete **Worksheet I.7 - Impact Description and Characterization**.

- **Worksheet I.2 - Site Information Quality Assessment**
- **Worksheet I.3 - Historical Weather Event and Impacts Information**
- **Worksheet I.4 - Climate Information Requirements and Attributes**
- **Worksheet I.5 - Current and Plausible Future Conditions**

You might use **Worksheet 1.6 - Existing Assessment Evaluation** if you have an existing impact, vulnerability or hazard assessment.

☐ Use **Worksheet I.2 - Site Information Quality Assessment** to identify and assess necessary datasets, information, and expertise to evaluate impacts on the focus area established during your assessment scope development. You will likely need to understand the physical attributes of your location and the type and spatial arrangement of the infra structure to conduct the analyses required for **Worksheet I.7**. You should also identify and document sources of information relating to previous extreme weather events or existing impact, vulnerability or hazard assessments to help complete additional worksheets.

- Remember to focus on the answers and assumptions you recorded in answer to the question - *What type of information does that decision/process need?* (**Worksheet I.1**)
- Your existing IDP may serve as a good place to start.
- You can also determine whether your installation has existing impact, vulnerability or hazard assessments that could be useful.

- This is also the time to identify local expertise, such as: a GIS expert to understand the type and quality of available data layers and existing modeling capabilities; the emergency management staff to understand previous weather event impacts and location of after action reports; the operations and maintenance staff to understand past impacts and what planned repairs or existing work arounds are in place; and engineering and design experts to assist in understanding infrastructure impacts.
- Vertical land elevation is an important factor in understanding your **reference datum** and assessing flood risk. The resolution of land elevation information should be appropriate to your focus area and your GIS analyst's expertise is essential. Ideally, for coastal areas, you have available topographic contours at 1 foot intervals. If this information is not available within existing installation systems, please consider reviewing *Regional Sea Level Scenarios for Coastal Risk Management* (Hall et al. 2016). This report serves as the foundation for the DoD Regionalized Sea Level Change and Extreme Water Scenarios, a DoD For Official Use Only (FOUO) internal database and contains several sections on this topic, including land elevation data sources on pages 3-4 and 3-5.

For the notional installation example, the focus *is on permanent inundation and storm surge across all of Naval Station A. Our assumptions include: "installation has experienced flooding impacts due to storm surge in the past" and visualization of these impacts would be advantageous. Thus, we should identify sources of information relative to past weather events. Additionally, access to local GIS expertise including experts in the GeoReadiness Center (GRC) could be very beneficial. The following lists some of the information needed in order to understand the effects of past and possible future events;* ***Appendix G*** *provides completed worksheets for the notional installation. Note: the notional installation example comprises an ideal set of information, not all of which you may have. At a minimum, you should identify what you need for your scope.*

- *GIS expertise to help determine type of data layers available, installation standards, resolution, etc.*
- *Baseline maps with vertical and horizontal infrastructure, most likely from the Common Installation Picture (CIP)*
- *Topographic map or vertical elevation data*
- *Capability to determine flooding height and extent at different flooding scenarios (hydrologic map)*
- *GIS layers or the capability to produce layers that show current flood elevations and extent and the capabilities of existing flood control mechanisms*
- *Existing design elements, such as design storm elevation of existing seawall and finished floor elevation of existing buildings without flood proofing*
- *Erosion*
- *Access to emergency management and operations and maintenance personnel for their knowledge and access to after action reports and maintenance records*

☐ Use **Worksheet I.3 - Historical Weather and Impacts Information** to learn about and record information regarding past events and their impacts on the focus area identified in the assessment scope. Historical event information can provide some sense of how susceptible or sensitive the site and its infrastructure have been and shed light on how future events may impact the focus area. This information may be helpful as you complete **Worksheet I.7 - Impact Description and**

Characterization. You can proceed without completing **Worksheet 1.3** if you have a good understanding of past impacts or they are already documented in existing reports available to you.

- If you proceed with **Worksheet 1.3**, you should complete one for each type of past event, or in lieu of completing a worksheet for every past event of a particular type, you may choose to complete a worksheet for a representative past event. For example, those in the New Orleans area might reference Hurricane Katrina, whereas those in the Northeast might reference Hurricane Sandy.
- If little is known about past events, the U.S. Air Force 14th Weather Squadron can provide historical weather observations and **extreme events** information, including drought indices for the last 50 years for DoD installations. This information may help determine whether past events occurred with sufficient severity to have caused impacts. Their website is Common Access Card (CAC)-enabled - https://climate.af.mil.
- Once you determine when and what type of events occurred, you may gather information by researching and reviewing information from:
    - Public Works maintenance logs, after action reports, studies that have been performed on your installation (e.g., erosion study, impact or vulnerability assessments), or other local resources.
    - The results of the DoD Screening Level Vulnerability Assessment Survey (SLVAS), conducted by each U.S. Military Service at sites worldwide in 2015, may also be helpful if no other record exists. Recognize that the content and quality of the survey information varies from site to site and has not been validated.

☐ Use the definitions contained in **Table I.2** to populate the *Impact Magnitude* cells with the order of magnitude (i.e., 1-Insignificant, 2-Minor, 3-Moderate, 4-Major, or 5-Catastrophic) that best describes the impact magnitude of the current hazard conditions.

Table I.2 Impact Magnitude

5	Catastrophic - Permanent damage and/or loss of infrastructure service.
4	Major - Extensive infrastructure damage requiring extensive repair.
3	Moderate - Widespread infrastructure damage and loss of service. Damage recoverable by maintenance and minor repair.
2	Minor - Localized infrastructure service disruption. No permanent damage.
1	Insignificant - No infrastructure damage.

Adapted from CSIRO 2007.

For the notional installation example, the focus is on permanent inundation and storm surge across the entire installation; additionally, we know that Naval Station A has experienced storm surge flooding in the past. The following types of information and activities could be useful:

- *14th Weather Squadron extreme weather information*
- *Damage Assessment Teams (DAT) After action reports*
- *Interviews with staff present at the time (e.g., emergency response, operations and maintenance)*
- *Public Works maintenance logs around the time of the most impactful event*
- *SLVAS responses*

Completing **Worksheets I.4** through **I.7** requires a basic understanding of climate science, models, and projections. Refer to **Appendix C - Climate Science, Data, and Projections** and **Appendix A - Acronyms and Glossary** to aid your understanding. **Appendix C** is divided into three sections. Section 1 provides rudimentary information about several basic climate science concepts that will aid installation development planners, particularly with regard to understanding, choosing, and using climate projections data. Section 2 provides online resources that may be helpful in enhancing knowledge of climate science, models, and climate data, including the sources of information you will refer to in completing **Worksheets I.4 - Climate Information Requirements and Attributes** and **I.5 - Current and Plausible Future Conditions**. Section 3 presents example data from one of the information sources - the DoD Regional Sea Level Change and Extreme Water Level Scenarios Database.

☐ Use **Appendix C, Section 1** and **Appendix A - Acronyms and Glossary**, to learn about or review background on basic concepts related to climate science, climate models, and climate projections. This will help you work through the questions to consider, noted below.

☐ Refer to **Appendix C, Section 2,** to review possible information sources you can use to meet the climate information needs of the weather and climate phenomena and hazard(s) of concern identified in your assessment scope and to complete **Worksheet I.4**.

Questions to consider regarding the climate data you are reviewing:

- Does the information you are examining relate to extreme events, such as heat waves or storm surge, or to gradual changes, such as slowly rising sea levels?
- What baseline period was used for comparing projected future changes for a specific climate phenomenon? A “good” baseline period for climate observations usually requires at least 20-30 years of high quality observational data from a trustworthy source, such as weather readings over several decades at the same weather station.
- Pay attention to the details regarding a specific climate phenomenon. For example, is the temperature projection for average annual temperature for the whole globe for a certain time period, such as 2100, or is it a regional projection for a certain part of the United States? Or is the projection for a change in the number of extremely hot days per year? In other words, it is not sufficient to say merely “temperature projections.” Note the details.
- Pay attention to annual versus seasonal averages. For example, average annual precipitation data may indicate a + or – 5 percent (%) difference from the baseline period. It is difficult to determine what the effects might be with annual averages. The same dataset might also provide average seasonal precipitation data that might show a 25% reduction in precipitation in summer, a more specific difference that a planner can use.
- Is the climate projection *qualitative* or *quantitative*? Depending on the level of assessment, qualitative results may be sufficient to guide a planner’s efforts. For example, that an installation is “very likely to have increased chances of erosion from inland flooding and storm surge” may be sufficient to plan adaptation strategies that guard against erosion impacts at important facilities. In other situations, such as the siting (or re-siting) of very valuable coastal assets, planners may need to access more localized and quantitative data on sea level change and storm surge projections.

- How many models were used in the *model* ***ensemble*** to develop the projections? In general, a larger number of models will increase the confidence in the results produced.

- What type of ***emissions scenarios*** were used to develop the climate projections – the **Special Report on Emissions Scenarios (SRES)** or **Representative Concentration Pathways** (RCPs)? Emission scenarios are based on assumptions about future worldwide changes in demographic development, socio-economic development, and technological change that result in different greenhouse gas concentrations in the atmosphere. Take note of which specific emission scenarios were used (e.g., SRES B1, RCP 8.5, etc.)? You should have an understanding of the assumptions behind the emission scenarios so that you can determine what type of outlook it represents (e.g., a more conservative or more optimistic outlook) and how that might affect your scenario selection. Please see **Appendix C, Section 2** for more details.

- What is the spatial *resolution* of the climate projection? Climate model input may cover a very large area (e.g., a single sea level value for the entire American East Coast) or it could be more granular (e.g., sea level value for Miami). Modelers refer to "grid size," such as 50 kilometers (km) x 50 km, when describing the granularity of data. The larger the grid size, the more "generic" the modeling results. Will a global projection suffice for your assessment or do you need down-scaled regional, or even local, information?

- Take note of the reported values for projections. Model results are often distributed across a range of values. In some cases, a median value is reported. In some cases, low values, middle values, and high values are provided. For example, if 60 different model runs are made using different assumptions in the model runs, 60 results may be generated. If these 60 results are arranged from low to high, the lowest 10% and the highest 90% may be reported as the "low" and "high" ranges respectively, with the rest of the results between those two values as the "middle" range. If you want a very conservative estimate (or a plausible worst-case figure), you may choose to use the "high" estimate.

- Be aware of differences in *confidence* for different types of projections; for example researchers are confident about evidence for, and projections of, changes in the number of heatwaves in the future, but much less confident about projected changes in the occurrence of typhoons. Our understanding of the climate science behind different components of the climate system is not necessarily equal.

☐ Use **Worksheet I.4 - Climate Information Requirements and Attributes** to identify and record which climate data are needed to delineate and evaluate the hazards of concern and weather/climate phenomena identified in the assessment scope and **Worksheet I.1**, and to document the sources, climate data attributes, quality and fitness of use. This worksheet also serves as place to document what you need but do not yet have.

- **Consider using "scenarios" rather than "probabilistic projections"**. An evolving practice in the risk management world is to use one or more climate scenarios to describe plausible futures. This approach of proposing a range of possible scenarios removes some of the uncertainty inherent in **probabilistic projections** that specify a certain amount of future climate change, such as rising sea level, with a specified probability of occurrence. In fact, as is done with the notional installation example followed throughout this Handbook, the use of more than one scenario to assess potential impacts in the future is recommended as there is more flexibility and less risk of maladaptation if you consider multiple plausible future scenarios and establish robust plans that address a variety of potential outcomes. This contrasts with restricting your analysis to a "most likely" probabilistic climate change projection, with its inherent uncertainties, and planning toward an "optimized solution" specific to this chosen projection. **Figure I.2** contains a brief discussion.

The data source chosen for the notional installation example [*Regional Sea Level Scenarios for Coastal Risk Management* (Hall et al. 2016) and accompanying database] recommends the use of scenarios rather than probabilistic projections as a way to manage uncertainties. In addition, the reference recommends the use of multiple scenarios to consider a range of possible futures, such as sea level rise in the range of 2 to 3 feet by the end of the century. In general, the use of higher climate scenarios is appropriate (and more conservative) when the asset of concern is valuable, critical to the mission, or both. Timeslices further away in the future (e.g., 2100) are also recommended for this type of situation and when major new construction is planned or structures cannot be "moved" without enormous cost. Hall et al. 2016 provide background on the selection of scenarios in accordance with a user's specific situation. In particular, the following sections of the document referenced above may be helpful in selecting scenarios to use in assessing hazards to infrastructure of concern:

- Section 2.5 Decision Framing: A Brief Description (1 page)
- Section 3.3 Global Scenarios (8 pages)
- Section 5.3 Scenario Application and Decision-Making under Uncertainty (17 pages, especially 5.3.3)

TERMINOLOGY

Climate Projections and Climate Scenarios

Climate scientists use climate models that attempt to simulate multiple aspects of a very complex climate system. Modeling the greenhouse gases present in the atmosphere at various concentration levels enables scientists to make "projections" about possible future climate conditions. The different greenhouse gas concentration levels used in these modeling runs are called "emissions scenarios" and are based on assumptions about future worldwide changes in population, land use, economy, technology, and policy choices.

Climate scenarios, which are based on climate projections, are plausible future conditions, but have no associated probabilities. Instead of asserting an estimate with a specific probability of occurrence, scenarios are used to pose "what if" situations for planning purposes. For example, "If sea level rises 2.0 meters by 2100, what will be impacted and what should be done?"

Figure I.2 Climate Projections and Climate Scenarios

- **Consider the less severe but more frequent events.** You may want to prepare for a specific extreme event, such as the 1% annual chance event (also called the 100-year storm event), but you should also consider the less severe storms, such as the 5% and 20% annual chance events (also called the 20-year and 5-year events, respectively). Flooding experienced during these events may become more frequent in the future; recurrent flooding may have significant impacts on infrastructure. In addition, as sea levels rise, high tides (especially the highest high tides, or king tides) are extending farther inland, causing nuisance flooding, also called sunny-day flooding because this flooding occurs as a result of tides, not storm events.

*For the notional installation example, we chose the DoD Regional Sea Level Change and Extreme Water Level Scenarios Database (**Appendix C, Section 3** contains example data) as our source of climate data because it is a credible, authoritative source and contains the necessary climate phenomenon information identified in **Worksheet I.1 - Assessment Scope**: site-specific sea level change scenarios and storm surge or the 1% annual chance event (known in this database as **extreme water levels** (EWL)) values for approximately 1,800 military sites worldwide.*

*In **Worksheet I.4 - Climate Information Requirements and Attributes**, under the Future Conditions section, we document that we can choose future values based on:*

- *up to three time periods (2035, 2065, 2100) – noted as "Future Timeslices" in the worksheet*
- *up to five sea level change scenarios (lowest to highest) – noted as "Future Climate Scenarios or Weather Events" in the worksheet. The five scenarios each correlate with emissions scenarios*
- *extreme water levels for four different annual chance events (20%, 5%, 2%, 1%) – also noted as "Future Climate Scenarios or Weather Event"*

Under the Current Conditions section, we document that 'mean sea level' is the data needed rather than 'sea level change' as a value for mean sea level is necessary to serve as a baseline for future sea level change. Therefore, "Emissions Scenarios," "Future Timeslices," and "Future Climate Scenarios or Weather Events" are "NA."

We also document additional metadata such as, spatial resolution, reference datum, baseline year, and limitations. The EWL figures reported in the DoD regional scenario database do not change over time because research does not yet support a specific rate of rise over time. Instead the statistically determined EWL for the specific location is added on top of sea level rise to reflect the combination of sea level change plus a specific annual chance event at that location. This is referred to as the Combined Scenario Value because it is an EWL scenario added onto a sea level change scenario. Note: the EWL figures also do not include wave run-up (see Figure 3.12 in Hall et al. 2016).

☐ Use **Worksheet I.5 - Current and Plausible Future Conditions** to confirm important site reference information (e.g., **site reference datum** and unit of measure) and document current and plausible future condition information, for hazard(s) of concern identified in Worksheet I.1.

- It is important to identify your preferred site reference datum and which unit of measure (feet or meters) you wish to use to ensure that all values reference the same datum and are in the same unit.
- This worksheet can also be used to document the offset values between various water elevation measurements (e.g., site reference datum, **mean sea level**, **mean higher high water** (MHHW)) and use the offset in order to calculate values that align with your site reference datum. Your GIS analyst should be familiar with this issue.
    - o Proper application of sea level change and extreme water level projections for risk management requires anchoring these inundation heights to a common vertical datum. To map inundation from projected changes in sea level and storm surge, this common vertical datum must also match that used to anchor the site's available geospatial data (e.g., GIS). Depending upon the information sources used for each elevation value, this may require an

alignment of disparate datums through a conversion process. Refer to **Appendix C, Section 3** for a discussion on how to align climate projection values to your site reference datum.

- Remember to collect and maintain the documentation generated from the information sources or tools you used.

For the notional installation example, we chose to include values for sea level change and the 1% annual chance event over the three available time periods (2035, 2065, 2100) in order to see plausible impact trends over time. Of the five available sea level change scenarios (lowest to highest), we chose the low (0.5 meter rise by 2100) and highest (2.0 meters rise by 2100) scenarios to assess potential impacts if a future with significant GHG emission reductions is envisioned (low scenario) and impacts that reflect a plausible worst-case future without significant GHG emission reductions (highest scenario). Data for the notional installation are below and reflect data converted to the site reference datum.

One observation of note is that the sea level change in the highest scenario in 2035 is marginally higher than the low scenario in 2065, as shown in the highlighted cells. This illustrates how scenario choice can impact the timeline for experiencing greater sea level change and storm surge impacts. The 1% annual chance event is one focus of our assessment; that value is 3.9 feet and is added to the sea level change value to calculate the combined value. Note: the DoD Regional Sea Level Change and Extreme Water Level Scenarios Database generates this calculation automatically. The other annual chance events (2%, 5% and 20%) are also readily accessible in this database if you wish to compare the values.

Excerpt from Worksheet I.5 for Notional Installation (Units are in Feet)

Current Conditions		**Plausible Future Conditions**			
2016		*2035*			
		Low scenario		*Highest scenario*	
	1% annual chance event	*Sea level change*	*Sea level change + 1% annual chance event*	*Sea level change*	*Sea level change + 1% annual chance event*
	3.9	*0.5*	*4.4*	*1.5*	*5.4*

Plausible Future Conditions							
2065				*2100*			
Low scenario		*Highest scenario*		*Low scenario*		*Highest scenario*	
Sea level change	*Sea level change + 1% annual chance event*	*Sea level change*	*Sea level change + 1% annual chance event*	*Sea level change*	*Sea level change + 1% annual chance event*	*Sea level change*	*Sea level change + 1% annual chance event*
1.2	*5.1*	*3.5*	*7.4*	*2.2*	*6.1*	*8.2*	*12.1*

Step ③: Describe and Characterize Impacts

In this step, you will conduct analyses and complete an impact description and characterization worksheet describing current and future impacts and categorizing the magnitude of those potential impacts on the infrastructure identified in Step ①.

After conducting Steps ① and ② you have:

- identified your focus area(s) through **Worksheet I.1 - Assessment Scope**,
- identified and collected information relative to your focus area (e.g., maps, plans) through **Worksheet I.2 - Site Information Quality Assessment**,
- developed an understanding of how events in the past impacted your focus area through **Worksheet I.3 - Historical Weather Event and Impacts Information**,
- described the type of climate data required for your assessment and its attributes through **Worksheet I.4 - Climate Information Requirements and Attributes**, and
- documented baseline and projected climate data relative to the climate phenomena and hazards of concern through **Worksheet I.5 - Current and Plausible Future Conditions**.

Much of this information will be included or used to complete **Worksheet I.7 - Impact Description and Characterization**. You may also utilize **Worksheet I.6 - Existing Assessment Evaluation** if there is adequate information available about the source and quality of the assessment.

☐ Use **Worksheet I.6 - Existing Assessment Evaluation** if you have an existing impact, vulnerability or hazard assessment. You may have already referred to and utilized information from an existing assessment during completion of prior worksheets. The worksheet questions may help you determine if an existing assessment provides useful analysis of the hazard of concern or information relevant to the decision or process being informed. If you do not have this type of information, proceed to **Worksheet I.7**.

For the notional installation example, we evaluated whether the Shoreline Stabilization Project Summary could be useful. We determined that while it was helpful in documenting the impacts of a historical event (e.g., Hurricane Isabel) and a project to stabilize the shoreline, it did not contain any other information relevant to future events.

In order to complete **Worksheet I.7**, you will need to conduct analyses, describe the current and future impacts on your focus area, and categorize the magnitude of the potential impacts. The sections below outline activities and examples to help you accomplish this task.

☐ Review **Worksheet I.7** and enter in some of the required information as noted from previous worksheets - **Worksheets I.1** (assessment scope), **I.3** (historical impacts), and **I.5** (current and plausible future conditions). This will serve as good overview in advance of taking the next steps to complete the rest of the worksheet.

- You may decide to complete more than one **Worksheet I.7** for any number of reasons. You may find it useful to address one infrastructure category per sheet. You may decide you wish to have only one timeframe per sheet. You may wish to address different types of hazards and associated climate phenomena on the same sheet (e.g., flooding and temperature changes).

How do I assess my impacts?

During Step ① you documented your answers and assumptions to the question "What type of information does that decision/process need?" This should help you identify the *types* of documentation that will be necessary for the decision or process in question. In many cases, *visualizing* impacts through a map or series of maps can be very powerful.

For our example assessment scope, the answer was: Installation infrastructure map; maps with current and future flooding elevations and extent; and description of impacts to site infrastructure. The assumptions were: The visualization of flooding and permanent inundation changing over time will allow planners and operations and maintenance staff to better understand the impacts and develop potential adaptation action alternatives.

☐ Generate maps to depict the amount of exposure to the hazard of concern by delineating the extent of flooding or inundation at your focus area. This will help you later complete **Worksheet I.7 - Impact Description and Characterization**, as you will need to identify and document potential hazards, impact magnitude, and impact descriptions. Refer to **Worksheet I.7** in **Appendix G** to review the notional installation hazards and impact descriptions.

- You should have identified your GIS expertise during the completion of **Worksheet I.2 - Site Information Quality Assessment**. They should have access to GIS spatial analysis tools and inundation models that can use the climate data to identify potentially impacted site areas and infrastructure. Several tools in **Appendix C, Section 2**, such as the Climate Resilience Toolkit Explorer tool or the U.S. Army Corps of Engineers (USACE) Sea Level Rise Curve Calculator, can also be used to generate maps illustrating potential inundation.
- You may wish to review "Section 5.0, Case Studies and Additional Considerations" (Hall et al. 2016) to understand the influence of physical setting and data availability and quality; in particular, a case study discussing the effects of topographic data quality on inundation mapping (Section 5.2.3).
- Generate maps representing the extent of different sea level change elevations from multiple timeframes and maps depicting different annual chance events (without sea level change). Then generate maps depicting the combined scenario values (e.g., sea level change plus an annual chance event elevation). This series of maps will illustrate how potential sea levels and extreme water levels may change over time.
- Your GIS analyst may already know how to depict inundation extent, perhaps by depicting Federal Emergency Management Agency (FEMA) flood zones or potential surge data, perhaps by using the National Weather Service (NWS) Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model. **Worksheet I.4 - Climate Information Requirements and Attributes** should contain the quality and attributes of the climate data. Your GIS analyst should be able to document the quality (accuracy, precision, and resolution) and usability (fitness, limitations) of the site elevation and modeling tools.
- A formal **vulnerability assessment** may be needed depending upon the complexity of the land use, infrastructure composition and extent of the area exposed to the hazard(s) of concern.
- Consultation with other subject matter experts (e.g., geographers, infrastructure designers, or engineers) may be appropriate to fully understand impacts to your site infrastructure.
- Recognize that other climate phenomena (e.g., changes in temperature and precipitation) might necessitate different types of analyses. Precipitation changes and the potential impacts of

intense rainfall events may use similar inundation models as noted above or require more sophisticated hydrologic models to fully comprehend the overland depth and movement of rainfall. Temperature changes may not require spatial data but rather analyses of the impacts on systems (e.g., building thermal envelope, potable water, electricity loads, infrastructure impacts due to lowered water tables or distorted roads and runways due to high heat).

How do I document my impacts?

Enabling others to understand fully the impacts and their context will help significantly in selecting potential adaptation approaches in Stage II. You already entered some information into **Worksheet I.7**; in this section you will complete this worksheet, focusing on documenting the hazards, impact magnitudes, and impact descriptions.

☐ Use the generated maps and consultation with subject matter experts enter information into the appropriate cells in **Worksheet I.7**.

- "Current & Potential Hazards" row. Enter short descriptors of the hazards (e.g., flooding, wave damage, debris) causing the current or potential impacts (e.g., loss of road access, structural failure, loss of habitat). Remember a hazard is how we experience the weather or climate phenomenon. For example, we may experience flooding due to storm surge or flooding due to changes in precipitation patterns that yield heavier rainfall events.
- "Current & Potential Impacts Descriptions" rows. List the sectors or infrastructure assets impacted, each in a separate row, including the sectors or assets identified in **Worksheet I.3 - Historical Weather Event and Impacts Information** if you were able to document historical impacts. Describe in each row the current and potential impacts under the appropriate scenario heading (Current Condition and/or Plausible Future Conditions).
    - The impact descriptions should be sufficiently detailed to enable identification of appropriate adaptation action alternatives. At this stage of analysis, it would be most useful if the potential impacts were described in as much detail as possible. Details to include are the number and type of facilities within the impact area, the likely physical effects, the secondary impacts, and what services and functions would be impacted or compromised by the loss of that facility.
    - Although the text descriptions are essential, supporting documentation and maps developed during your analyses are also very important and should be kept as part of the record.
- "Impact Magnitude" cells. Use the definitions contained in **Table I.2** (that you might have used for **Worksheet I.3 - Historical Weather Event and Impacts Information**) to populate the *Impact Magnitude* cells with the order of magnitude (i.e., 1-Insignificant, 2-Minor, 3-Moderate, 4-Major, or 5-Catastrophic) that best describes the impact magnitude of the plausible future conditions. You should choose the magnitude presuming no adaptation activities have occurred between now and the time period being addressed in your scope. This lessens the amount of uncertainty and ensures that all infrastructure sector, asset or area impacts are evaluated similarly. For example, two types of sectors could potentially be impacted similarly; however, you categorize the potential impact to sector B lower than sector A because you believe an activity might take place in the future to lessen the impact to Sector B. That anticipated activity should be documented in Stage II, as an action alternative to address the impact, not become an unstated assumption in Step ③. It is useful to estimate impact magnitude so that users of this

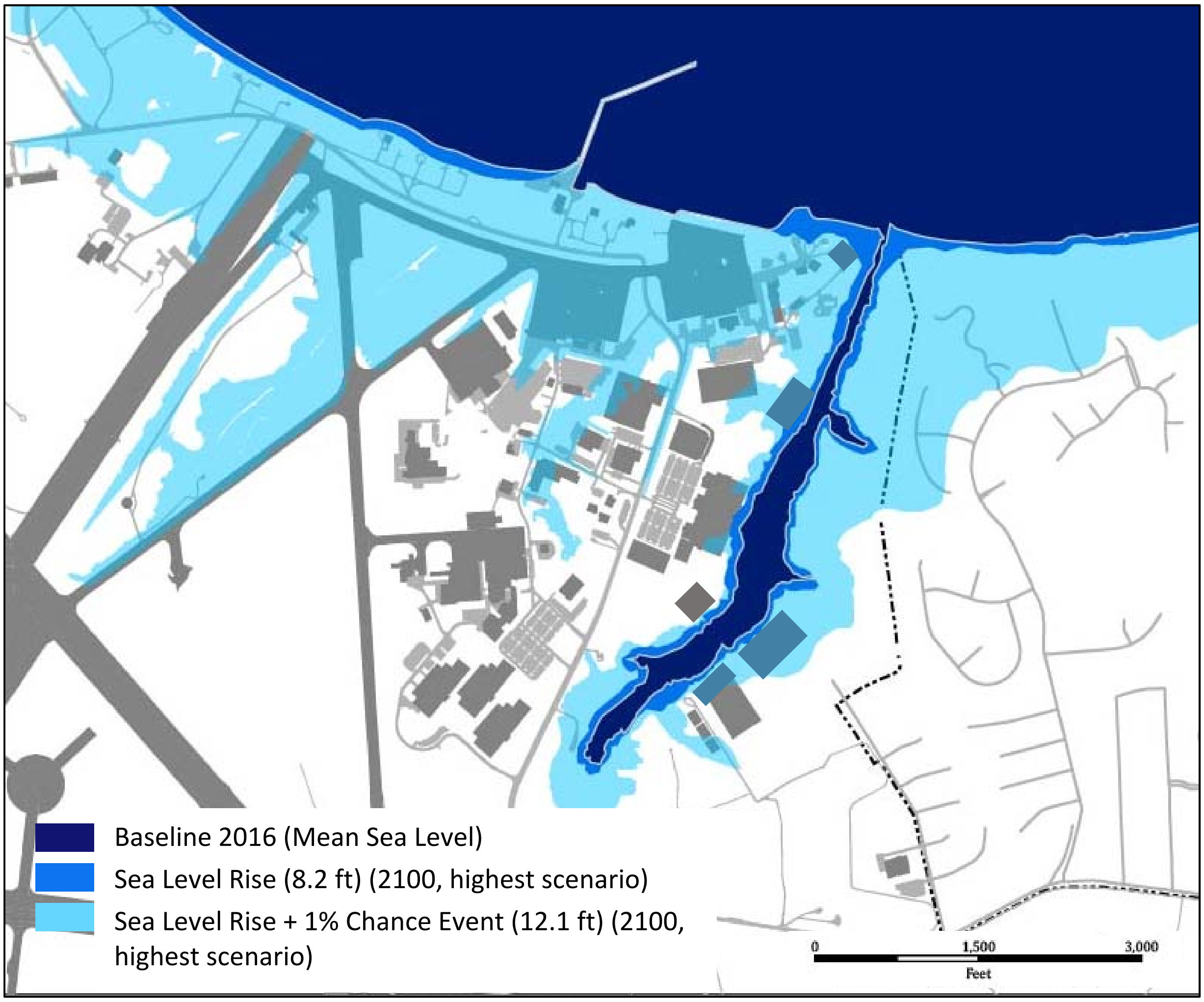
information can readily see trends over time and understand which infrastructure sectors have been or could be impacted the most.

- In assessing the magnitude of impacts to infrastructure, you may wish to assess the potential for impacts to multiple parts of a system or network of infrastructure assets. Even if exposure to hazards may vary, multiple components of systems may be affected.

Figure I.3 *represents illustrative information for the notional installation example. It is a depiction of the 2100 timeframe: the highest scenario for sea level change of 8.2 feet (medium blue) and sea level change + the 1% annual chance event of 12.1 feet (lightest blue). The dark blue represents current water levels. The excerpt from* ***Worksheet I.7*** *below reflects these same scenarios.* ***Appendix G*** *contains the complete notional installation impact descriptions for all the scenarios. This text will serve as a starting point for development of a Problem Statement in Step ④.*

Excerpt from Worksheet I.7 for Notional Installation

	Plausible Future Conditions	
	2100	
Info Source & Parameters:	*Highest Scenario*	
DoD Regionalized Sea Level Change and Extreme Water Scenarios	***Sea level change (ft)***	***Sea level change + 1% annual chance event (ft)***
	8.2	*12.1*
Current & Potential Climate Hazards	*flooding, wave damage, permanent inundation*	*flooding, wave damage, debris*
Impacted Infrastructure / Focus Area	**Impact Magnitude**	
Buildings	*4-Major*	*4-Major*
Natural Infrastructure & Ecosystems	*3-Moderate*	*3-Moderate*
Transportation	*4-Major*	*4-Major*
Current & Potential Impact Descriptions	*Potential for:* *- permanent loss of 1,000 LF roadway* *- permanent inundation of 80,000 sq ft of building basements and 50,000 sq ft of building first floors (including the Hospital, HQ Complex, several RDT&E facilities)* *- Impaired drainage and system outages due to stormwater outfalls #3 and #4 permanently underwater* *- permanent inundation of 125 acres of fresh water marsh* *- permanent loss of all salamander critical habitat*	*In addition to assets already permanently inundated, potential for:* *- temporary flooding of additional 300,000 sq ft of building basements and 200,000 sq ft of building first floors, 3 taxiways with 1,200,000 sq ft and aprons with 243,000 sq ft* *- debris accumulation on several roads, limiting access* *- additional 5000 LF roadway may be subject to wave erosion damage* *- stormwater outfall #10 would be below flood stage, impairing drainage*



Permanent Inundation Impacts from Sea Level Rise (8.2 ft):

- Loss of 1000 linear feet (LF) of roadway
- Inundation of 80,000 square feet (sq ft) of building basements and 50,000 sq ft of building first floors [Hospital, Headquarters (HQ) Complex, several Research, Development, Test, and Evaluation (RDT&E) facilities]
- Impaired drainage and system outages due to stormwater outfalls #3 and #4 underwater
- Inundation of 125 acres of freshwater marsh

Baseline and **Climate data**: DoD Regionalized Sea Level Change and Extreme Water Scenarios Database, accessed 9/1/16
Elevation data: USGS Sandy Restoration Hydro Flattened LiDAR DEM, 2015
Modeling performed by G. Wizard on 9/10/16
Note*: all figures adjusted to align to reference datum, see Worksheet I.5.*

Flooding Impacts when 1% Annual Chance Event (3.9 ft) added to Sea Level Rise (total = 12.1 ft)

- Impacts noted above, plus
- Temporary flooding of: additional 300,000 sq ft of building basements; 200,000 sq ft of building first floors; 3 taxiways with 1.2 M sq ft and aprons with 243,000 sq ft
- Debris accumulation on several roads, limiting access; additional 5,000 LF of roadway subject to wave erosion damage; stormwater outfall #10 would be below flood stage, impairing drainage.

Figure I.3 Notional Installation Depicting Permanent Inundation and Flooding under Plausible Future Condition in 2100 (using Highest Scenario)

Step ④: Develop Problem Statement

In this step, you will review all the information collected and develop problem statement(s) to be addressed in Stage II – Identify & Screen Action Alternatives.

At the conclusion of Step ③, you will have generated at least one **Worksheet I.7 - Impact Description and Characterization** documenting current and future climate impacts on your focus area from multiple plausible future conditions. Now you will translate that information into one or more problem statements - a statement that succinctly defines the type and magnitude of potential impacts and issues to be addressed. A problem statement contains the following components:

1) infrastructure scope,
2) hazard,
3) timeframe,
4) weather or climate phenomena,
5) timeslice and climate scenario, and a
6) description of the potential impacts on infrastructure types as a result of the analyses.

☐ Review the information in your completed **Worksheet I.7** and accompanying documentation.

☐ Confirm which component details you wish to include in your problem statement.

- **Infrastructure scope**. Identified in your assessment scope at the beginning of Stage I. However, while your assessment scope might have asked you to analyze the whole installation, analyses might lead you to focus on a particular part of the installation because the impacts are greater in one area than another.
- **Hazard(s)**. Identified in your assessment scope. You may wish to develop separate paragraphs within your problem statement to distinguish between different types of hazards. In the notional installation example below, permanent inundation and flooding (with permanent inundation) are described separately.
- **Timeframe**. Identified in your assessment scope. While your assessment scope might have asked you to address a particular timeframe, you may choose to present additional shorter or longer timeframes to illustrate potential impacts over time.
- **Weather or climate phenomena**. Identified in your assessment scope. You may wish to develop separate paragraphs within your problem statement to distinguish between different phenomena. In the notional installation example below, impacts from sea level change is described in one paragraph and the impacts of sea level change, together with storm surge, are described in another.
- **Timeslice and climate scenario**. Choose the timeslice(s) and climate scenario(s) relevant to your assessment scope. For example, you may choose to focus on the latest timeslice because your assessment scope identified a need to understand impacts over the next 100 years and/or the infrastructure under analysis is critical and cannot be allowed to fail. Choose the climate scenario or scenarios that align best with your assessment scope and risk management style of your installation. As stated earlier, it might be prudent to be conservative and choose to present impacts from the highest climate scenarios (i.e., the highest scenario will reflect the greatest potential for significant impacts so is the "worst case").

- Determine which **impacts and infrastructure types** should be included. For example, you may choose to focus on the sectors with the highest ranking impacts by magnitude or choose to consolidate all the impacts into one problem statement. Or you may choose to present all the potential impacts from one timeslice and climate scenario.

To develop a problem statement for the notional installation, we reviewed the assessment scope - ***Given the stated assumptions in Worksheet I.1, determine how we can protect the installation infrastructure from damage due to flooding and permanent inundation over the next 100 years*** – and developed a problem statement appropriate to both the permanent inundation effects of sea level change and the additional effects of flooding from a 1% annual chance event (100-year storm) for that area:

*If Naval Station A must remain in its current location, the following facilities and ecosystems may be impacted by permanent inundation by 2100 based on a projected **sea level change** scenario of 8.2 feet adjusted to a common vertical datum: permanent loss of 1,000 LF of roadway; permanent inundation of 80,000 sq ft of building basements and 50,000 sq ft of building first floors (including the Hospital, HQ Complex, and several RDT&E facilities); stormwater outfalls #3 and #4 permanently underwater; permanent inundation of 125 acres of fresh water marsh; and permanent loss of all salamander critical habitat.*

*The potential impacts increase in damage and loss values when the 1% annual chance event of just under 4 feet in **storm surge** is added to the sea level scenario. Potential for: temporary flooding of an additional 300,000 sq ft of building basements and 200,000 sq ft of building first floors, 3 taxiways with 1,200,000 sq ft and aprons with 243,000 sq ft; debris accumulation on several roads; an additional 5000 LF roadway may be subject to wave erosion damage; and storm water outfall #10 below water level.*

What actions could we take to address the potential impacts identified above to the infrastructure at Naval Station A to ensure continued service in this location given the potential impacts and losses?

Regardless of the number of problem statements developed, the worksheets and accompanying data and maps should remain part of the project documentation. Seeing the impacts over time, from one or more scenarios, enhances the ability to develop phased adaptation approaches.

Stage I Output

At the completion of Stage I, you should have one or more problem statements, completed impact description and characterization worksheets, and associated documentation and maps.

Completion of the accompanying worksheets and generation of relevant maps clarify the scope of the potential problem to be addressed, the type of infrastructure affected, and the potential magnitude of climate impacts to the infrastructure of concern. This information also serves as the rationale for the development of your problem statements. The problem statements, and accompanying background information in the worksheets, will serve as the basis for identifying and assessing possible action alternatives in Stages II – IV.

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STAGE II – IDENTIFY AND SCREEN ACTION ALTERNATIVES

Introduction

In Stage II, you will begin to develop a list of potential action alternatives. Using the resources and tools cited in ***Appendix D*** *you will identify adaptation actions that are suitable, feasible, and appropriate responses to the installation impacts identified in the problem statement from Stage I. You will also document each action alternative's benefits and limitations and characterize how each of the potential actions responds to decisions under uncertainty.*

Before starting this stage, you should have:

- Problem statement, completed impact description and characterization worksheets (**Worksheet I.7 - Impact Description and Characterization**), and associated documentation and maps that describe the nature (e.g., type and magnitude) of the current and potential future impacts.

Resources, skills, and tools you may need:

- Appendix D: Adaptation Action Alternatives Fact Sheets
- Literature reviews and case studies of applied adaptation actions.

Key concepts you will encounter:

- Adaptation approaches
- Benefits, collateral benefits
- Feasibility analysis
- Suitability analysis

At the end of this stage, you will be able to:

- Understand how to identify suitable adaptation actions,
- Identify benefits of suitable action alternatives, and
- Produce a preliminary list of action alternatives with sufficient detail to perform a more detailed cost/benefit analysis in Stage III.

Output: Preliminary list of action alternatives to address problem statement(s). This preliminary list of action alternatives is a screened list and includes those options deemed suitable for addressing the potential impacts identified in Stage I; feasible to accomplish with respect to technical, financial, and legal considerations; and appropriate, given the overall planning context of the Navy installation. The list of action alternatives will be characterized more fully with respect to costs and benefits in Stage III. In Stage IV, additional relevant factors, including benefits that cannot be monetized, will be assessed to determine the final output from the Handbook process – a portfolio of action alternatives to be considered in the IDP process.

Step ①: Identify Potentially Suitable Adaptation Actions

In this step, you will develop a preliminary list of action alternatives and evaluate them for suitability, feasibility, and appropriateness.

With the information in the impact description and characterization worksheet (**Worksheet I.7 - Impact Description and Characterization**) developed in Stage I, you will use **Worksheet II.1 - Potential Action Alternatives** to document a range of potential adaptation actions.

The process of developing a range of action alternatives to consider for the installation begins with a "long list" of potential action alternatives, similar to the results of a brainstorming session. Ideally, you should propose approaches that have been tested in conditions similar to yours or that can be modified to suit your conditions and that address the impacts identified in Stage I. The impact of climate change varies from one infrastructure sector to another, and the potential adaptation action alternatives should include measures that respond to the type of impact anticipated for each sector. **Figure II.1** depicts how this initial list of action alternatives will be further defined and screened throughout Stage II to culminate in a list of screened action alternatives that will be further analyzed in Stage III.

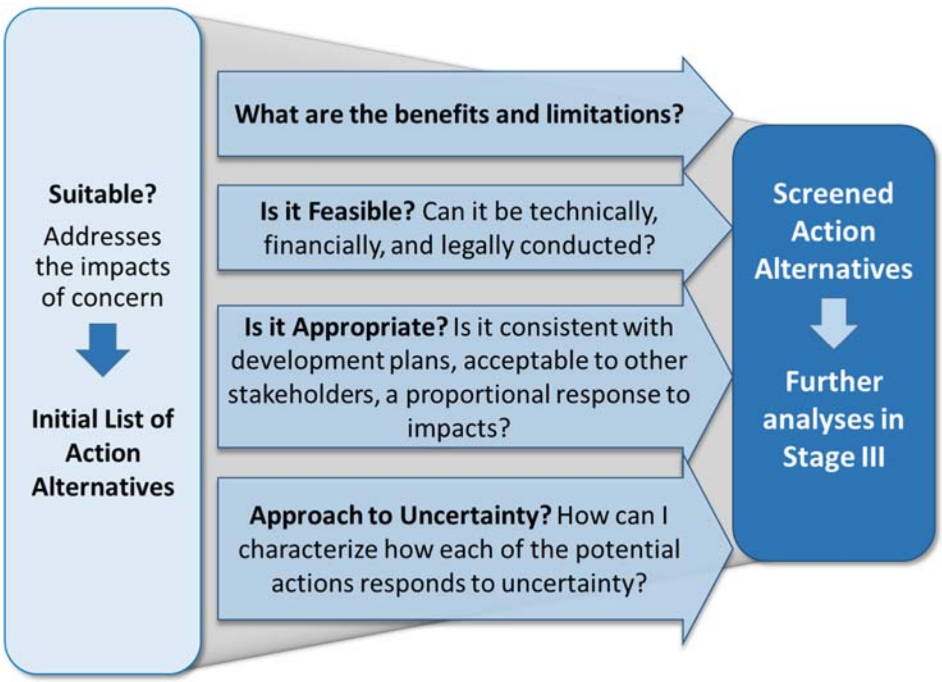


Figure II.1 Depiction of Stage II Screening Process

What action alternatives are available?

Adaptation measures to address sea level rise and flood risk exist at many scales, from large structural flood barriers to simple work-arounds, such as sandbags. Literature on the range of available measures is extensive and the nomenclature varies from source to source. USACE is an authoritative source of information on adaptation measures for sea level rise so it is useful to understand the way USACE categorizes the available approaches.

USACE defines **structural approaches** as adaptation actions that employ a built structure to alter the flow of floodwater to protect a large area from inundation. Examples are typically large civil works such as levees and storm surge barriers. USACE recognizes **natural and nature-based approaches** as another way to protect large areas by constructing or modifying natural features such as dunes, tidal marshes, living shorelines, or other coastal vegetation to attenuate the impact of storm surge or to hold floodwaters away from facilities and infrastructure.

Facilities approaches include construction solutions such as building to a new standard that accounts for changing flood risk, constructing smaller scale built structures designed to protect an asset, such as a berm or flood wall, and making physical alterations to an existing asset to reduce flood damage. Retrofit techniques include flood proofing, retrofitting with flood resistant materials, and physically relocating an asset or its vulnerable components out of the flood plain. **Non-facilities approaches** include a range of techniques that rely on changes in siting, management, or maintenance of infrastructure to reduce flood damage. **Figure II.2** provides a summary of these approaches.

Action alternatives in each of these categories are briefly described in the Fact Sheets in **Appendix D**, which provide an overview of the approach, discussion of appropriate applications and limitations, and references for further information.

TERMINOLOGY

Adaptation Approaches (USACE classification)

Structural
Employs a built structure to alter the flow of floodwater to protect a large area from damage (e.g., levee, storm surge barrier)

Natural and Nature-Based
Employs natural features to enhance resiliency (e.g., dunes, beaches, salt marshes, oyster and coral reefs, barrier islands, forests, shade trees)

Facilities
Employs construction techniques to reduce flood damage to a specific asset (e.g., flood-proofing, building to a more resilient standard, small-scale structures such as a berm)

Non-facilities
Employs non-construction techniques such as infrastructure siting, management, or maintenance to reduce flood damage (e.g., land use modifications, real estate actions, community coordination, operational changes, modified maintenance routines)

Figure II.2 Adaptation Approaches (USACE classification)

In Stage I, you used **Worksheet I.7 - Impact Description and Characterization** to identify the magnitude of the impacts expected at your installation. The action alternatives you select for consideration should be suitable (i.e. adequate and proportionate responses to the magnitude of the impacts identified in Stage I). If the installation is anticipating coastal erosion, stabilization of the shoreline with vegetation, attenuating wave impact with offshore oyster reefs, and construction of a seawall may all be suitable action alternatives. If coastal erosion is anticipated to be minor, construction of a seawall may not be proportionate. If coastal erosion could impact other facilities and have a major impact, a seawall may be an adequate and proportionate response. If existing facilities will be past their service life before they are impacted by coastal erosion, replacement of facilities in a new location could be an approach that is suitable for your installation. Consider the:

- planning horizon
- value of the asset(s)
- the intended lifespan of the asset(s) at risk

Your description of each alternative should include sufficient detail to facilitate further analysis of the alternatives that you identify from this review of the literature.

☐ Use Column A in **Worksheet II.1 - Potential Action Alternatives** to document and organize your preliminary selection of adaptation actions. These adaptation actions can be categorized according to the approaches listed above (i.e., Structural, Natural and Nature-based, Facilities, and Non-facilities).

- You may want to use the Fact Sheets in **Appendix D** to identify potential actions that could be effective in your circumstances.
- It may be necessary to engage subject matter experts such as civil engineers, coastal hazard mitigation specialists, and wetland restoration specialists to evaluate the options presented in the Fact Sheets or other resources and to identify actions that address the identified impacts.
- You should consider a range of approaches from the Structural, Natural and Nature-based, Facilities, and Non-facilities categories. Multiple approaches may address the same impact or accomplish the same resiliency benefit.
- Consult with personnel who are familiar with the installation's inventory of assets, internet Navy Facilities Asset Data Store (iNFADS) database, and history of asset use and condition. In additon, Stage III provides additional guidance summarized in **Economic Analysis Tools and Resources Fact Sheets** in **Appendix E** that will help you in facility evaluations.

*For the notional installation, we identified eight suitable action alternatives organized by the type of approach. The table below is an excerpt from **Worksheet II.1** in **Appendix G**, illustrating the type of information listed in Column A of the worksheet.*

Excerpt from Worksheet II.1 for Notional Installation

Column A - Action Alternatives	
Alt ID #	**Action Alternative Description**
	Structural Approaches
1	*Build a seawall*
2	*Partner with County to install flood gate at mouth of river*
3	*Install offshore breakwater to attenuate wave height*
	Natural and Nature-based Approaches
4	*Restore and expand fresh water marsh ecosystem*
5	*Accommodate expansion of natural marsh buffer by removing hardened shoreline structures and replacing finger piers with adjustable floating piers*
6	*Install oyster reef breakwater at mouth of river to attenuate wave impact on salamander habitat*
	Facilities Approaches
7	*Relocate HQ Complex from existing operational area to land reserved outside flood plain*
	Non-facilities Approaches
8	*Increase maintenance of drainage system to reduce nuisance flooding*

Step ②: Identify Benefits and Limitations

In this step, you will determine the benefits and the limitations or drawbacks of each action alternative in your preliminary list.

In Step ① you generated a list of adaptation measures that address the anticipated impacts for your installation in Stage I. In this step, you will summarize the benefits and limitations or drawbacks of each of these potential actions. This will allow you to evaluate the action alternatives. Your description should summarize the reasons you selected the alternative for consideration and record the limitations that you are aware of related to the approach. The Fact Sheets in **Appendix D** identify some limitations but your description should also identify installation-specific limitations as well. It may be useful to circle back to this step after completing Stage II in order to capture limitations related to feasibility and appropriateness. The summary recorded in this worksheet will serve as a reference in the future even for actions that are not carried forward at this time; thus it is important to include as full a description as possible to aid in future reconsideration of all the action alternatives documented.

☐ Use Column B in **Worksheet II.1 - Potential Action Alternatives** to summarize the benefits and limitations of each of the action alternatives. Use the same resources listed in Step ① if necessary.

Many types of benefits can result from adaptation actions. The primary benefit of each action should be the **direct benefit** that you will examine from an economic point of view in Stage III. This type of benefit can be easily given a direct monetary value (or monetized) as an **avoided loss** based on the extent of property and assets that are protected by the action. To permit economic analysis in Stage III, it is essential to identify the direct benefit of each action alternative using a metric such as square feet (sq ft) of buildings, acres, or linear feet (LF) of shoreline protected.

Other benefits, referred to as **indirect benefits**, may result from an action alternative separate from the primary effect of protecting specific features from loss. These benefits may be more readily described in qualitative terms since assigning a monetary value to them can be a complex process that may not be possible. For example, the full habitat value of **ecosystem services** provided by constructing wetland acres can be determined by economic specialists (see example **Worksheet III.3 - Benefits**). However, the benefit of habitat enhancement and other benefits, such as operational efficiency or positive community and public relations, can be identified as benefits without a full economic evaluation. Ancillary aspects of the wetlands construction project, such as building pedestrian and bike paths around the wetlands, may provide benefits to the community beyond ecosystem services. Additional recreational opportunities and improved connection paths between neighborhoods can be viewed as indirect benefits. It is important to keep track of these indirect benefits and include them in your evaluation of potential action alternatives. You may encounter a number of terms used to describe indirect benefits, including **collateral**, **ancillary benefits**, and **co-benefits**.

It is also important to identify the limitations of each action alternative. These may include considerations related to feasibility, appropriateness, or external effects or spillovers (also referred to as **externalities**), which can be both positive and negative or result in **maladaptation**. Air pollution is an example of an externality that is a **disbenefit** or external cost imposed on others that would be cited as a limitation. The **Adaptation Action Alternatives Fact Sheets** in **Appendix D** identify "Limitations" for each action alternative that may be helpful.

*For the notional installation, we listed the benefits and limitations for each of eight suitable action alternatives. The table below is an excerpt from **Worksheet II.1 - Potential Action Alternatives** in **Appendix G**, and includes one action alternative and its benefits and limitations as an example of the type of information listed in Column B of the worksheet.*

Excerpt from Worksheet II.1 for Notional Installation

Column A - Action Alternatives		Column B - Benefits & Limitations (Disbenefits)	
Alt ID #	**Action Alternative**	**Benefits**	**Limitations (Disbenefits)**
1	*Build a seawall*	• *Protects 2,000,000 SF of landward shore from erosion and flooding* • *Protects 30 buildings, major shoreline road, historic officer's quarters and associated landscape (protects 1,200,000 SF of buildings)* • *Modern equipment can be integrated into new structure, improving efficiency*	• *Visual impacts* • *Reduced/impaired waterfront access* • *Hardened shoreline increases wave height and number of exceedance events, increases erosion on the seaward side potentially exacerbating loss of near-shore ecosystem* • *Extensive environmental review process*

Step ③: Evaluate Feasibility

In this step, you will evaluate the feasibility of the potential adaptation action alternatives and eliminate any that do not warrant further consideration. Before starting this step, you should have completed Column B in ***Worksheet II.1*** *to identify the benefits and limitations of your preliminary selection of action alternatives.*

☐ Use Column C in **Worksheet II.1** to note whether a potential action alternative is feasible or describe why it is not feasibile under the current conditions. Document the screening criteria you used and the results of your screening analysis.

- Using the feasibility criteria below, identify actions that should be dismissed from further consideration based on feasibility considerations and provide a brief explanation of why the action alternative was dismissed. Actions that are currently infeasible may become feasible as technology or knowledge is improved. Retaining a record of the long list and the reason each action alternative has not been further evaluated will allow the full range of action alternatives to be reevaluated in the future if information or resources change. A record of dismissed alternatives may also be necessary during environmental compliance analysis of alternatives that are selected.

Feasibility Criteria

Technical

- Is the solution technically feasible? Do we have the capacity/capability to implement?
- Is available information sufficient to determine feasibility, or is an engineering study required?
- Can the environmental parameters be met for this approach? For example, is a sustainable source of sand available if beach nourishment is being considered?
- Is available acreage sufficient to install the approach, or to relocate facilities or plan retreat?

Financial

- Is there a current Installation Development or Master Plan that includes programmed projects that cannot be relocated?

- Does the planning, funding, and construction timeline allow sufficient lead time to complete the project in time to realize its benefits? For example, long lead time measures such as surge barriers that require complicated permitting, community involvement, and funding may not be feasible if the surge barrier cannot be built before unacceptable impacts occur.

Legal

- Do any legal or regulatory plans, policies, regulations, or design standards impede use of the action alternative?

*For the notional installation, we documented whether each of eight suitable action alternatives was deemed feasible or not feasible. The table below is an excerpt from **Worksheet II.1 - Potential Action Alternatives** in **Appendix G**, and includes two action alternatives and their feasibility as an example of the type of information listed in Column C of the worksheet.*

Excerpt from Worksheet II.1 for Notional Installation

Column A - Action Alternatives		Column C - Feasibility
Alt ID #	**Action Alternative**	
4	*Restore and expand fresh water marsh ecosystem*	*Feasible. Advance to WS III.2 - CEA*
5	*Accommodate expansion of natural marsh buffer by removing hardened shoreline structures and replacing finger piers with adjustable floating piers*	*May not be technically or politically feasible; marsh would encroach on operational areas and strategy would require expansion south of current fence line. Do not advance to WS III.2-CEA*

Step ④: Evaluate Appropriateness

*In this step, you will evaluate the appropriateness of the remaining potential adaptation actions identified in Column A. Before starting Step ④, you should have completed Column C in **Worksheet II.1** to identify infeasible approaches among your action alternatives.*

Appropriateness is a reflection of how well the solution fits into the overall planning context of the installation. Planning issues will be addressed in depth during the IDP process, but even at this point it should be possible to eliminate some obvious "poor fit" approaches. An example of an obvious poor fit is an offshore breakwater across a boat basin access route. Potential actions should be, to the greatest extent possible, consistent with the Installation Vision Plan goals and objectives. It is likely that adaptation measures will change the installation's long-term planning vision and goals; feasible approaches that merely require integration into the plan should not be considered inappropriate unless the action would contradict many or most of the installation's other planning goals. Give no further consideration to any action that does *not* merit further consideration or detailed **benefit cost analysis** (BCA).

☐ Use Column D in **Worksheet II.1** to note whether a potential action alternative is appropriate or describe why it is not appropriate in the current conditions. Document the screening criteria you used and the results of your screening analysis.

- Using the appropriateness criteria below, identify actions that should be dismissed from further consideration based on appropriateness considerations and provide a brief explanation of why the action alternative was dismissed. Actions that are currently inappropriate may become appropriate. Retaining a record of the long list and the reason each action alternative has not been further evaluated will allow the full range of action alternatives to be reevaluated in the future if information or resources change. A record of dismissed alternatives may also be necessary during environmental compliance analysis of alternatives that are selected.

Appropriateness Criteria

- Is the action consistent with planning goals and objectives identified in the Installation Development Plan?
- Does the solution take planned and programmed development into consideration?
- Will the solution unreasonably/disproportionately alter the setting?
- Would the solution have an adverse impact on natural or cultural resources or on other infrastructure? Refer to the **Adaptation Action Alternatives Fact Sheets** in **Appendix D** to identify appropriate conditions for each type of approach.
- Are multiple organizations required to implement the approach? Are established relationships or working groups already in place?
- Would the approach generate controversy or inconvenience to others?

*For the notional installation, we documented whether each of eight suitable action alternatives was deemed appropriate or not appropriate. The table below is an excerpt from **Worksheet II.1 - Potential Action Alternatives** in **Appendix G**, and includes two action alternatives and their appropriateness as an example of the type of information listed in Column D of the worksheet.*

Excerpt from Worksheet II.1 for Notional Installation

Column A - Action Alternatives		Column D - Appropriateness
Alt ID #	**Action Alternative**	
2	*Partner with County to install flood gate at mouth of river*	*Appropriate. Advance to WS III.2 - CEA*
3	*Install offshore breakwater to attenuate wave height, reduce likelihood of exceedance of seawall design elevation*	*Not currently appropriate due to interference with harbor channel navigation. Reevaluate if harbor channel use changes.*

Step ⑤: Characterize Strategic Approach to Decisions under Uncertainty

*In this step, you will characterize how each of the potential actions addresses the uncertainty inherent in making decisions using projections about future climate conditions. Before starting this step, you should have determined the appropriateness of feasible approaches among your action alternatives in **Worksheet II.1**.*

In the previous steps you completed a description of the potential adaptation actions you are considering and evaluated which are feasible and appropriate. In this step, you will characterize how each of the potential actions addresses the uncertainty inherent in making decisions using projections about future climate conditions. One source of uncertainty is natural variability in the behavior of natural systems. While sea level rise is occurring now, the rate and extent of the change in mean sea level is determined by many variables. Unknown future events could influence these variables and result in a change in sea level that is not anticipated in even the most robust climate models. Another source of uncertainty is a result of imperfect knowledge. Climate change projections are subject to change over time as knowledge and tools evolve. It may be possible to more accurately determine the rate and extent of sea level rise or other climate change phenomena as knowledge improves. It may also be possible to improve the degree of confidence in the future conditions driving planning decisions as more robust analysis is possible at your installation. While it is possible to be relatively confident in the decision to make an investment based on certain future conditions such as the end of the service life of an infrastructure system, confidence in the decision to invest is lowered when the exact design or performance parameters are not certain (Hallegatte et al. 2012).

Despite this uncertainty however, it is important for planners to consider the potential for impacts to important infrastructure and assess alternative means of addressing those impacts. Decisions must be made in light of uncertainties about the future – as is often the case. **Table II.1** describes four strategies for making decisions about investments under conditions of uncertainty. Indicating which strategy best characterizes a specific action alternative can facilitate the process.

Table II.1 Categories of Strategies to Address Uncertainty

Type of Strategy	Characteristics	Examples
No-regrets	• Yields benefits even if climate does not change to the degree projected • May address impacts already occurring that will only become worse if not addressed	• Controlling leakages in water pipes • Land use policies that limit development in flood-prone areas, especially in areas already experiencing flooding
Reversible and flexible	• Minimize the cost if climate impacts are not as severe as expected • Can be reversed without significant economic loss or risk	• Insurance and early warning systems that can be adjusted annually in response to new information • Restrictive urban planning
Safety margin	• Reduce vulnerability at negative, null, or negligible cost • Design parameters for new construction include safety cushion to allow for increased capacity/need in the future (i.e., overdesigning now may be much less expensive than re-building or responding to failure later)	• Building new drainage system to accommodate runoff figures larger than current level is less expensive than modifying system after it is built • Conservatively estimating maximum storm in the future and building to withstand those conditions
Reduced time-horizons	• Reduce lifetime of investments • Avoid long-term commitment and choose shorter-lived decisions • Deliberately planning for the short-term to avoid uncertainties of long term	• Switching forestry operation to shorter-lived species • Use of temporary structures • If developing in areas potentially vulnerable in the future, opt for less expensive investments with a shorter lifespan

Adapted from Hallegatte et al. 2012

☐ Use Column E in **Worksheet II.1 - Potential Action Alternatives** to characterize each potential action alternative in terms of how it addresses the decisions under uncertainty surrounding climate change.

*For the notional installation, we described under the appropriate column headings (e.g., no regrets, reversible flexible) how each of eight suitable action alternatives could be characterized. The table below is an excerpt from **Worksheet II.1** in **Appendix G**, and includes two action alternatives and* *descriptions in the appropriate columns as examples of the type of information for Column E of the worksheet.*

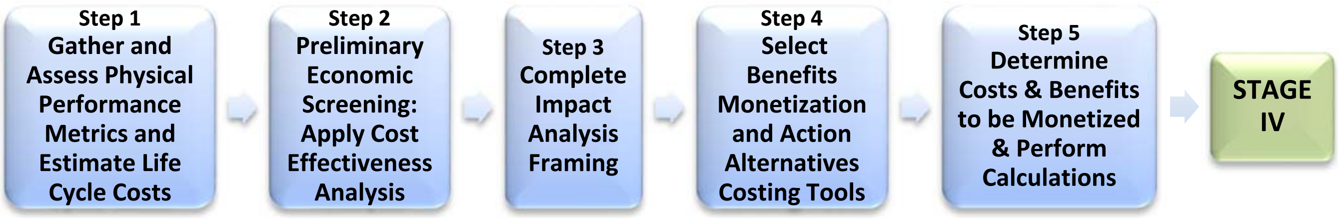
Excerpt from Worksheet II.1 for Notional Installation

Column A - Action Alternatives		**Column E - Characterize Strategic Approach to Decisions under Uncertainty**			
Alt ID #	**Action Alternative**	**No Regrets**	**Reversible Flexible**	**Safety Margin**	**Reduced Time Horizon**
1	*Build a seawall*	*Shore facilities modernization already planned for 2045. Incorporating seawall adds minor cost*	*Seawall can be designed to allow future increase in height as sea level rises*		
2	*Partner with County to install flood gate at mouth of river*	*Floodgate can be used to impound fresh water to supplement fresh water supply*	*Floodgate allows flexible operation*		*Reduced time horizon - avoids commitment to relocating HQ Complex*

Stage II Output

At the completion of Stage II, you should have a list of adaptation action alternatives deemed suitable to addressing the potential impacts for your installation, and that are also feasible and appropriate approaches. You have also documented each action alternative's benefits and limitations and characterized how each of the potential actions responds to decision uncertainty. Completion of the accompanying **Worksheet II.1** documents the range of possibilities in sufficient detail for further analysis. The worksheet also provides a record of the reasons for excluding some alternatives from further consideration based on current conditions; these "rejected" alternatives may be reconsidered at a later date if conditions or information change in the future.

STAGE III – CALCULATE BENEFITS AND COSTS OF ACTION ALTERNATIVES



Introduction

In Stage III, you will assemble the information and available data for each action alternative in your list after completion of Stage II and develop a preliminary portfolio of action alternatives. Using the information resources and tools cited, you will set up and complete the ***benefit cost analysis*** *(BCA) and perform the calculations necessary to arrive at measures of* ***adaptation intervention merit****. These measures of merit - including* ***benefit cost ratios*** *(BCR),* ***net present values*** *(NPV), and* ***internal rates of return*** *(IRR) - will provide monetized metrics that can be used to preliminarily rank action alternatives. You may not be able to monetize all benefits and costs for the action alternatives identified in Stage II. These non-monetized qualitative benefits and costs, some of which may be intangible, will still be carried over to Stage IV, as they may be instrumental in providing cohesion to the portfolio's strategic objectives. In Stage IV you will apply additional decision lenses that will be useful in portfolio construction.*

Before starting Stage III, you should have:

- A preliminary list of feasible and appropriate action alternatives from Stage II

Resources and tools you may need:

- Appendix E: Economic Analysis Tools and Resources Fact Sheets
- Conceptual costing aids and tools, life cycle costs
- Benefits monetization tools

Key concepts you will encounter:

- Monetized and non-monetized benefits
- **Cost effectiveness analysis** (CEA)
- Avoided costs/damages = Resiliency benefits
- Benefits categories and nomenclature used in hazard analysis and climate change adaptation
- **Depth damage functions**
- Effective annual benefits (e.g., taking into account probability of flood risk and future sea level change)
- **Life cycle cost analysis** (LCCA)
- Measures of adaptation intervention merit (e.g., BCA, IRRs, NPVs, and Payback Periods)
- Adaptive management

At the end of Stage III, you will:

- Be familiar with the range of cost benefit methods and hazard analysis tools, and determine which is most suited for evaluating a range of proposed adaptation action alternatives,
- Understand and communicate how a BCA can show which adaptation alternatives are most cost-effective and generate the greatest resiliency value,

- Have the ability to preliminarily rank and prioritize action alternatives that will protect and mitigate against the future adverse impacts of climate hazards facing the installation, and
- Have data on monetized costs and benefits that will aid the action alternative rankings process.

Output: Preliminary list (or portfolio) of action alternatives characterized by measures of adaptation intervention merit. This list of action alternatives is further evaluated in Stage IV to assess any non-monetized and non-quantified costs and benefits.

Step ①: Gather and Assess Physical Performance Metrics and Estimate Life Cycle Costs

In Stage II, you developed a list of feasible and appropriate preliminary action alternatives and assembled and documented non-monetized benefits. In this step, you will use these non-monetized benefits as performance metrics, and estimate and assemble life cycle costs for each action alternative.

During Stage II you assembled and documented non-monetized benefits in **Worksheet II.1 - Potential Action Alternatives, Column B**. These benefits were quantified in terms of some physical unit of measurement or **performance metric**. Examples include linear feet of shoreline protected, square feet of building area, acres of wetlands providing storm surge protection and habitat, million gallons per day (mgd) of wastewater treatment, kilowatt hours (kWh) of power provided, and miles of roadway. In Stage III, these non-monetized benefits are used as performance metrics in two worksheets: **Worksheet III.1** - **Life Cycle Cost Analysis** and **Worksheet III.2 - Cost Effectiveness Analysis**.

In addition, in Step ① you will estimate and assemble life cycle costs for each alternative. LCCA is an economic efficiency tool that evaluates the full set of costs over an asset's lifespan. LCCA can be applied to evaluate the full array of costs associated with alternative adaptive resiliency investments being considered for an installation. The life cycle costs of the given action alternative will likely consist of a series of:

- upfront capital construction costs
- annually recurring, long-term operation and maintenance (O&M) and periodic replacement costs
- periodic rehabilitation and/or replacement or renewal costs
- end of life decommissioning, disposal and/or resource recovery costs

> It is important to note that with this Handbook's structured staging process, you can apply several forms of **preliminary economic analysis <u>before</u>** embarking on a comprehensive **benefit cost analysis**. In simple terms, you can choose to make use of the information you have gathered to date. Many types of economic analyses are reviewed in detail in Naval Facilities Engineering Command (NAVFAC) Pub 442 (including BCA), and can be implemented before you have to expend resources to monetize benefits in dollar terms. For example, benefits can be analyzed and compared at their physical units, without being converted into monetary benefits in dollars. Where you can access performance metrics associated with each alternative, these metrics can be compared to the life cycle costs of alternatives that perform similar protective, mitigation, or adaptive functions to see which alternative is the most cost-effective to meet the same objective.

LCCA can be applied to buildings, facilities, and infrastructure projects (across sectors) and can be applicable to any long-lived asset. The development of conceptual life cycle costs will be necessary inputs to both the preliminary CEA and the more detailed and resource-intensive full benefit cost analysis (BCA).

The **Life Cycle Cost Analysis Fact Sheet** in **Appendix E** provides an example of applying LCCA to compare two alternative cost streams for a bulkhead investment, using fictitious data unrelated to actual engineering-based cost estimates. LCCA can be applied to evaluate alternatives that have higher initial costs but lower operating (annually recurring) costs over the project life compared to a lower up front cost alternative. The tool is typically applied during the preliminary design phase of project alternatives analysis before the full set of economic benefits is compared to life cycle costs during the BCA.

☐ Use **Worksheet III.1 - Life Cycle Cost Analysis** to develop and document conceptual costs for the action alternatives that were deemed feasible and appropriate through Stage II. Life cycle costs are necessary for determining the "hard" costs of structural approaches. This worksheet should contain your cost estimate assumptions, parameters, and data for the total life cycle costs for each action alternative. These will include cost information for capital costs, typically funded by military construction (MILCON) funds, operations and maintenance costs, typically funded by operations and maintenance funds, and replacement and rehabilitation costs, typically funded by Sustainment, Restoration, and Modernization funds.

- These costs are used for an initial screening using CEA in Step ② and also entered later into **Worksheet III.4 - Benefit Cost Ratio and Net Present Value** to calculate a BCR. The necessary input data may come from tools or other parametric cost estimation programs such as R.S. Means (https://www.rsmeans.com/), or from existing feasibility or design studies.
- Consult your installation's cost engineer and refer to **Fact Sheet 4: Costing Tools and Resources** in **Appendix E**. This fact sheet describes some widely used tools and resources that are applied to estimate costs, and provides additional information telling the planner where they can access resources to develop cost estimates for alternative adaptation measures. The tools and resources described are applicable mostly to construction measures, but some of the techniques can also be applied in cost estimates for non-facilities measures as well. During the life cycle costing and life cycle analysis phase of the BCA (Step ⑤), it is necessary that you coordinate with costing engineers, estimators, and other personnel who are familiar with the physical properties of sustainable materials and resources used to construct resiliency investments. Engaging engineers at this stage will ensure that alternative inputs and best design practices are integrated into the action alternative that is being subjected to the BCA. Some material inputs may appear to be relatively costly to procure and install, but may last longer and provide more enduring and durable resiliency and mitigation benefits over the complete economic life of the asset.

Investment staging (or the timing and sequence associated with alternatives implementation) is another consideration that goes into the life cycle costing analysis phase of the BCA. It may make more sense to *adaptively manage* the timing and implementation of capital investments over the planning horizon to ensure that resources are optimally tied to the resiliency need based on uncertainty and the review of climate projection scenarios. In an adaptive management approach, additional input is fed into an iterative decision-making process such that strategies can be adjusted as necessary to reflect the new information, including strategic objective changes or updated climate projections.

For the notional installation, Naval Station A, one of the eight possible action alternatives, Alternative 5, was deemed not technically feasible and appropriate during Stage II, and therefore is not brought forward to Stage III. For the other alternatives, typically life cycle costs would be generated for those seven action alternatives. ***Worksheet III.1 - Life Cycle Cost Analysis*** *in* ***Appendix G****, shows life cycle costs for only four alternatives (1, 2, 4, and 6) in order to illustrate later in Step ⑤ that using a grouping of action alternatives is a viable strategy. Thus, the example worksheet, labeled "Strategy Grouping: Multiple Lines of Defense" contains an example of the costing of capital construction costs, operational and maintenance costs, and periodic replacement / renewal costs for multiple climate proofing / installation hardening alternatives based upon the notional installation.*

Step ② Preliminary Economic Screening: Apply Cost Effectiveness Analysis

In this step, you will conduct a preliminary screening of your list of action alternatives by applying CEA, using information from ***Worksheets II.1 - Potential Action Alternatives*** *and* ***III.1****. Using this type of analysis before a full benefit cost analysis can inform an objective decision-making process. Before beginning this step, you should be familiar with the terms described in Step ①.*

This step includes a helpful tool called cost effectiveness analysis, which allows you to evaluate the cost effectiveness of potential action alternatives during a preliminary screening exercise. CEA (also sometimes called least cost analysis) uses conceptual costs and performance metrics (i.e., the physical units of measure, such as acres or linear feet) of assets and land area protected to assess climate adaptation options that achieve a given objective or performance target. CEA is useful in eliminating some options from consideration and in identifying a more effective short-list that can then be evaluated using a full BCA. CEA is also useful in comparing actions across various project scales. This preliminary screening step can save the installation analytical resources, time and effort, and is widely practiced by many agencies (e.g., USACE) in completing feasibility studies. Note that CEA is also useful in comparing some identified benefits that are difficult, expensive, impractical, or simply impossible to value or monetize in dollar terms.

You identified and documented non-monetized benefits of the action alternatives in **Column B** of **Worksheet II.1**. Some of these non-monetized benefits are quantified and measured in terms of some physical unit of improvement or performance metric (e.g., LF of shoreline, sq ft of facilities). These can serve as performance metrics in this step and be compared to the available costs of alternatives to determine a cost per unit.

☐ Use **Worksheet III.2 - Cost Effectiveness Analysis** to assemble and document the data needed to conduct this analysis by following the steps below.

- Transfer the life cycle costs recorded in **Worksheet III.1 - Life Cycle Cost Analysis** for each action alternative being proposed. It is recognized that at this stage you may only have access to order of magnitude conceptual level costs if you have not performed a detailed cost analysis. Order of magnitude costs can still be used as inputs to the CEA.

- In order to allow for comparison, you must identify a physical unit of measurement common to all alternatives to be evaluated. This will allow you to establish a common performance metric. You already identified benefits in Stage II and some of those benefits were expressed in physical terms (e.g., square feet of facilities protected, kilowatt hours of power service maintained, number of port service hours or days of uninterrupted operations, miles of roads protected, etc.). The performance metric you select represents the unit against which the life cycle costs will be compared. For example, in **Worksheet III.2 – Cost Effectiveness Analysis** for the notional installation, we chose square feet of buildings protected as the performance metric.
- Generate a cost per unit for each alternative (cost divided by performance metric). The lower the cost per unit, the better. You may choose to also generate a graph to illustrate the results (see **Figure III.1**).
- Identify the least cost alternatives or select a short list of action alternatives and carry over these alternatives to the full BCA in **Worksheet III.4 - Benefit Cost Ratio and Net Present Value**. Note, a Worksheet III.4 should be completed for each carried over alternative. In our example there are five Worksheets III.4.1-III.4.5 included.
- Give no further consideration alternatives that are inefficient/too expensive and do not provide the best level of protection for the cost.

For the notional installation we chose to conduct a CEA on seven possible action alternatives, including Alternative (Alt) 7, which was deemed not appropriate during Stage II but was carried over because personnel were curious about how the unit cost would compare to the other alternatives. (Alt 5 was dismissed after Stage II because it was not technically feasible, and not worth the effort of estimating associated life cycle costs.) Using the excerpt from ***Worksheet III.2 - Cost Effectiveness Analysis*** *for the notional installation as an example, the CEA should enable you to determine the following:*

1. *For competing adaptation action alternatives, the same level of output or service level could be protected by another action alternative at less cost (Compare Alt 1 to Alts 6 and 4)*
2. *A larger output/service level could be protected at the same cost (No alternatives below satisfy this condition, but planner should follow this CEA rule in selecting effective alternatives in actual installation studies)*
3. *A larger output/service level could be protected at less cost (in this example, compare Alt 3 to Alts 1, 4 and 6)*

Figure III.1 *illustrates an excerpt of data shown in the* ***Worksheet III.2*** *and shows that among the seven remaining alternatives proposed to protect the shoreline, marsh restoration has the lowest per unit cost.*

- *The first pass analysis allows us to exclude Alts 3, 7, and 8, because either they do not meet one of the CEA criteria above (i.e., a larger output/service level of protection can be achieved for less cost; compare Alt 3 to Alt 1, 4, and 6), or they are an order of magnitude more expensive than other alternatives (see Alts 7 and 8, with associated higher costs).*
- *However, suppose the installation was also interested in combining several of these alternatives into a multiple lines of defense grouping. Alt 1 could be combined with Alts 2, 4, and 6 to provide additional synergistic and backup protection, at a combined cost that is still less than the cost of either Alt 7 or Alt 8. Despite Alt 1's relatively high costs (compared to Alts 4 and 6 that deliver the same level of output), it can also be brought over into the*

benefit cost analysis (BCA) in Step ⑤ to assess whether the combined monetized benefits and cumulative net present value may be worth this larger investment, either as a stand-alone alternative, and/or in combination with the other alternatives that could form the grouping.

Excerpt from Worksheet III.2 for Notional Installation

Action Alternatives	NPV Life Cycle Costs of Action Alternatives	Performance Metric (Square feet of buildings protected)	Cost per Unit
Alt 1 Seawall	*$5,776,874*	*1,200,000*	*$ 4.81*
Alt 2 Flood gate	*$144,421*	*600,000*	*$0.24*
Alt 3 Breakwater	*$6,500,000*	*600,000*	*$10.83*
Alt 4 Restore Marsh	*$225,438*	*500,000*	*$0.45*
Alt 6 Oyster reef	*$1,535,642*	*1,200,000*	*$1.28*
Alt 7 Relocate HQ Complex	*$15,000,000*	*600,000*	*$25.00*
Alt 8 Increase maintenance of drainage system	*$15,000,000*	*2,250,000*	*$6.67*

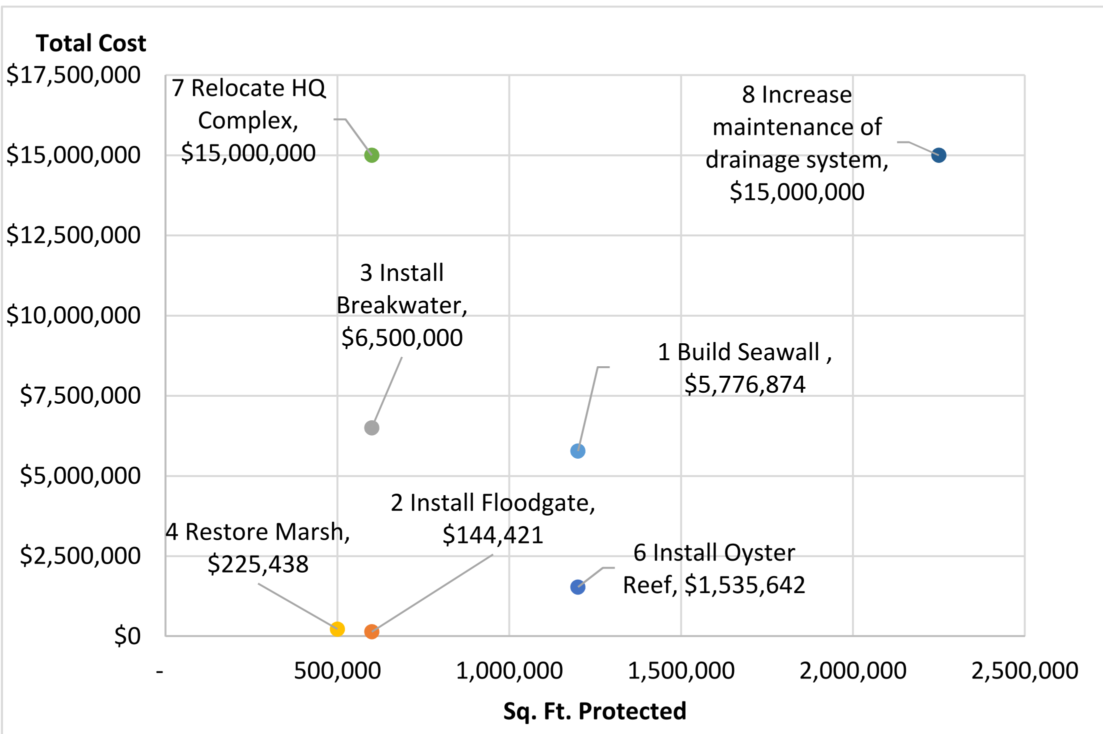


Figure III.1 Cost Effectiveness Analysis of Preliminary Alternatives

Step ③: Complete Impact Analysis Framing

*This step introduces concepts you will need to properly select the correct monetization tools and set up the framing that will take place in Steps ④ and ⑤ - the **project resource statement** and the **with or without framework**.*

What is a project resource statement?

A project resource statement is a table or matrix used to organize and array the identified costs and benefits associated with an action alternative, arranged by year over time, for the full life cycle of the investment. It clearly shows which costs are upfront (one time), which ones are annually recurring, and which are periodic or end of life. This type of table illustrates the concept of "net benefits" (benefits less costs) and the benefit / cost ratio. It also reinforces the life cycle concepts and shows which cost elements would occur where, and when, over time. This is important for adaptive management and investment phasing. You can see which years the costs would occur, their sequence, and which years would generate the deferred benefits.

In NAVFAC Pub-422, Economic Analysis Handbook, the project resource statement corresponds to the *Cash Flow Discount Table with Economic Indicators*. The BCR compares the cumulative discounted benefits (B) over the time horizon (T) to the cumulative discounted life cycle costs (C) over time. **To be cost-effective or economically feasible, the action alternative must have a BCR greater than 1.0.**

In this Handbook, **Worksheet III.4 - Benefit Cost Ratio / Net Present Value** is the project resource statement. **Table III.1** illustrates a conceptual project resource statement, with check marks to show where you would enter numerical data to prepare a detailed benefit cost analysis. This conceptual chart is similar to **Worksheet III.4**, except that the rows and columns have been transposed for ease of reviewing. You should recognize the life cycle cost categories, as they are the same as those used in **Worksheet III.1 - Life Cycle Cost Analysis** – capital costs, annual operational and maintenance costs, and periodic replacement and renewal costs. The benefits categories are familiar and are discussed in great detail in Step ④.

Note: NAVFAC Pub-442, Economic Analysis Handbook, also referred to as ECONPACK, is an economic analysis tool that you may already be familiar with and use for benefit cost analysis. ECONPACK is broadly compatible with the costing tools listed in **Appendix E**. You will need to first extract benefit streams estimated from the other specialized hazard evaluation software and then input these annual values into ECONPACK's input and output templates for final analysis. The tools listed in **Appendix E**, however, offer specialized capabilities beyond ECONPACK that will aid you in completing the climate change adaptation BCA necessary to appraise these specific asset investments. This Handbook follows consistent economic analysis process steps that are also built into ECONPACK. You should continue to use economic analysis tools that you are comfortable with, but recognize that some additional specialized benefit monetization aids are necessary in the flood / sea level change risk analysis area.

Table III.1 Typical Project Resource Statement Layout

	Time Horizon: n = 50						
	2016	**2017**	**2018**	**2019**	**2020**	**………**	**2066**
Life Cycle Costs:							
Initial Capital Costs							
Alt 1 & 2. Seawall with flood gate	√	√					
Alt 4. Vegetation / plantings for marsh		√					
Alt 6. Reefs for oyster bed		√	√				
Annual Operations and Maintenance (O&M) Costs			√	√	√	√	√
Periodic Replacement / Renewal Costs (various years; example: reseeding reefs)				√		√	
Total Costs	√	√	√	√	√	√	√
Benefits:							
I. Resilience Values							
a. Avoided damages to structures			√	√	√	√	√
b. Avoided damages to building contents			√	√	√	√	√
c. Avoided damages to vehicles			√	√	√	√	√
d. Avoided damages to critical infrastructure			√	√	√	√	√
e. Others…							
II. Economic Revitalization Values			√	√	√	√	√
III. Social and Installation Community Values			√	√	√	√	√
IV. Environmental / Ecosystem Values			√	√	√	√	√
V. Others…			√	√	√	√	√
Total Benefits			**√**	**√**	**√**	**√**	**√**
Net Benefits (Benefits less Costs)	**—√**	**—√**	**√**	**√**	**√**	**√**	**√**
Cumulative Present Value of Net Benefits	**+ √**						
Benefit Cost Ratio (BCR) = Σ B / Σ C	**1.45**						

Figure III.2 shows how the two worksheets containing costs and benefits populate **Worksheet III.4 – Benefit Cost Ratio and Net Present Value.** The life cycle costs associated with your preliminary action alternatives that you just completed in Step ② form part of the project resource statement. The benefits element (e.g., **Worksheet III.3**) will be populated by applying tools and procedures described in Steps ④ and ⑤.

☐ Review the preliminary information and data (e.g., life cycle costs) that you have already gathered, recognizing that these

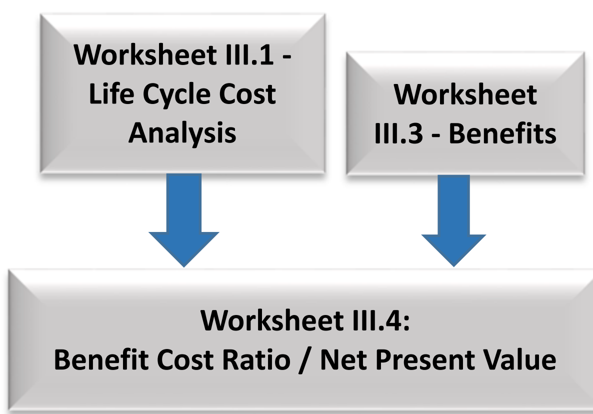


Figure III.2 Worksheets as Inputs to BCR/NPV Worksheet (Project Resource Statement)

data can be updated, modified, and refined in subsequent steps. Some of the data gathered in Step ② may help you select the most appropriate monetization tools in the next step.

Apply the With / Without Framework

This framework asks the planner to envision two futures - a *future without adaptation* and a *future with adaptation*. The future *without adaptation* is a scenario where none of the adaptation action alternatives you selected in Stage II are implemented – no set of specific hardening, protective, climate proofing and mitigation investments, proactive actions, and policies take place. All of the adverse impacts you outlined in Stage I and described in **Worksheet I.7 - Impact Description and Characterization** could occur. The *future with adaptation* is a future investment is implemented, benefits are provided by the action alternatives, and not all of the potential adverse impacts occur; in other words, these damages are avoided. It is important to understand that, in economic analysis, an avoided cost is considered a benefit. Thus, the adverse impacts (i.e., damages) from climate change-related hazards (e.g., inundation, high winds, and fires) are monetized as benefits in Stage III.

Figure III.3 contrasts potential climate change-related damage impacts over time for the two conceptual futures (i.e., with and without adaptation investment). The graph shows that as time goes on, damages and costs increase in the future *without adaptation* investment, whereas costs and damages decrease in the *with adaptation* future. Note that some damages can be expected even with adaptation responses and investments. These impacts may be unavoidable and associated with severe 100-, 200-year and 500-year types of events, for example. However, these impacts would be much worse had the adaptation investment or strategy not been implemented. These unavoidable damages, called **residual damages** in climate change economics, are represented by the area below the *With Adaptation Investment* line on **Figure III.3**.

The utility of this concept is that you can consider the full impact's extent (damages and losses) of a *without adaptation* future at your installation and compare the lesser amount of impacts (damages) with each adaptation action alternative or groupings of alternatives. This type of comparison may help you consider whether to protect a specific asset at the installation, a portion or swath of vulnerable or exposed assets, or the full installation. This information is useful in Step ④ during monetization tool selection as some tools may be more appropriate to apply to an entire installation or regional coastal area, and some may be more appropriate for specific buildings or structures, to be evaluated in isolation.

☐ Review the concepts above to inform your considerations prior to proceeding to Step ④.

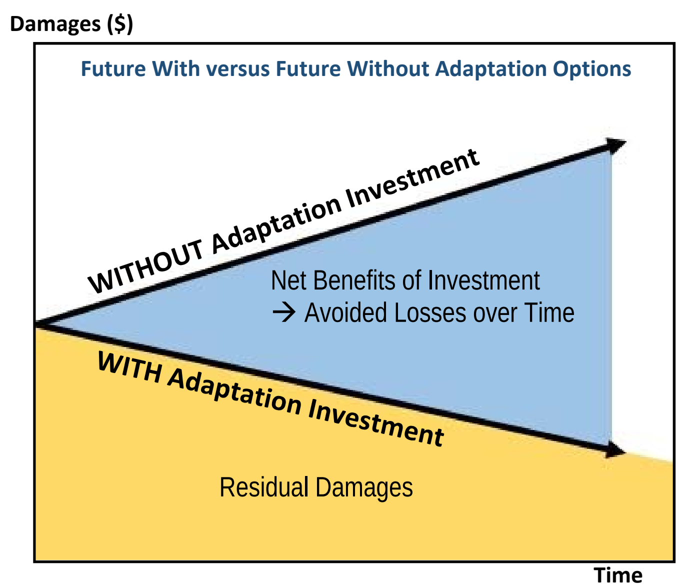


Figure III.3 Contrast of Potential Climate Change-Related Damage Impacts over Time

Step ④: Select Benefits Monetization and Action Alternatives Costing Tools

*In this step, you will determine the most appropriate analytical tools to acquire and apply to help you complete the BCA of the preliminary action alternatives. The choice of tools depends on whether the impacts are to a broad swath or area of your installation or to specific identified vulnerable assets or systems. Before starting this step, you should have a good grasp of the potential physical impacts (and their breadth and scale) to your installation from a variety of future climate-related events (reference **Worksheet I.7 - Impact Description and Characterization**).*

Benefits Monetization Tools

A variety of tools exist that can enable you to quantify and monetize the impacts associated with various adaptation investments and actions or avoided losses. However, some of these tools are designed for a more holistic assessment of impacts that may be installation- or even region-wide in scope and coverage. In addition, some of the tools are specifically designed and adapted for coastal environments. As an analyst, you will have to decide which tool is most relevant to your installation's measurement and benefit monetization needs and requirements, and most practical given the availability of data. If the focus is on a specific asset, then you may not need to acquire a comprehensive tool that has wider spatial capabilities. This step will assist you in understanding the array of available tools, help you make a decision about tailoring the tools to your needs, and provide information on the data inputs, expertise, and disciplines needed to effectively apply the tools. **Fact Sheet 2: Benefits Monetization Tools** in **Appendix E** lists some readily available tools and provides information and guidance on situations where these tools can be useful to you in monetizing benefits for the BCA. The selected list is not exhaustive but provides a good starting place for measuring and monetizing benefits.

What follows is a general discussion of types of benefits and categories that appear in many of the adaptation programs and tools referenced above. Recognizing these terms will aid you in determining which software packages have the capabilities to monetize these benefits and also alert you to additional resources you may need to access, and further analysis you may need to complete to monetize these potential **benefit streams**.

Categories of Benefits

Within the climate change and sea level change resiliency community, there are specific categories and a specific nomenclature for categorizing benefits. The conceptual project resource statement refers to these general categories. You may already be familiar with many of these benefits, which can also be classified by the sustainability categories of economic, social/community, and environmental factors. However, because the Handbook recommends tools and resources that will help you quantify these benefits, it is necessary to review specific terms you will encounter. Many of the specialized benefit monetization tools require that you assign source input data, parameters, and information to these categories.

Resilience benefits or avoided physical losses or damages are linked to the physical assets that will be protected by the action alternatives (i.e., investments and policy actions/decisions taken over time) that will protect and enhance resiliency to climate change events and sea level rise. Resilience benefits or values (a term used by the U.S. Department of Housing and Urban Development (HUD), the Federal

Emergency Management Agency (FEMA), and other practitioners) are monetized benefits generally consisting of the following categories:

- **Resilience benefits.** Resilience benefits include the value of avoided damages to :
  - Structures (buildings)
  - Building contents (e.g., furnishings, equipment, raw materials, etc.)
  - Roads and streets, bridges, utility lines, substations, transformers/plants/systems, waterfront facilities, water supply, water and waste-water systems
  - Service functions (e.g., security protection, firefighter, or school, hospital downtimes, power outages, road closures)
  - Vehicles
  - Cleanup costs (e.g., avoided cost of removing sediment from facilities or navigation channels)
  - Emergency/first response costs
  - Displacement or relocation costs
  - Avoided casualties/injuries and avoided mortality and morbidity associated with more frequent extreme weather events and sea level rise

Resilience benefits are those avoided damages that are directly tied to the extent of or potential impact attributable to the event. When you complete **Worksheet III.3**, these benefits should be recorded in column titled "1. Resilience Benefit Values."

The other main categories of benefits that you will see in this specialized area consist of:

- **Economic benefits.** Economic benefits can consist of avoided interruptions to businesses (both asset destruction and lost income flows), and avoided lost productivity. In addition, some action alternatives may contribute to reducing the chilling effect related to attracting future investments to the area. Economic benefits can consist of avoided disruptions to jobs, incomes, and tax revenues both directly and indirectly linked through supply chains. The term economic revitalization is also used to show how some action alternatives provide resiliency benefits that can restore and enhance an economy that would otherwise be disrupted, and increase its tolerance, adaptability, and ability to withstand future adverse events. You will record economic benefits in column "II. Economic Revitalization Benefit Values" in Worksheet III.3.

- **Installation benefits.** At the Navy installation level, you may also consider avoided mission interruptions, lost productivity, and associated costs. These avoided installation losses can be both tangible and intangible but are traceable in terms of their ultimate impacts. Interruptions to training schedules, certification processes, and deployment timelines can hurt mission capabilities and readiness. Rescheduling and finding new supply sources can add to sustainment costs if existing backup contingency plans are not set up to mitigate these costs. Ultimately, large climate-related shocks and interruptions to defense supply chains can compromise mission readiness, integrity, and warfighter efforts thereby exposing personnel in combat theatres to additional risks. You will record installation benefits in column "III. Installation/Community Benefit Values" in **Worksheet III.3**.

- **Community/Installation-Related benefits.** These often called "social" benefits may arise from action alternatives that reinforce and strengthen social cohesion and identity that defines the character of a place. Action alternatives may protect or preserve cultural assets important to Navy resident personnel, to the wider community, and the nation. For example, the USS Constitution mooring in Boston Harbor, or an installation's historic structure (e.g., a fort) of significance, may contribute to both installation/service pride and to the regional cultural signature as well as generate recreation and tourism benefits that add value to the community. It is possible that some action alternatives may generate additional unforeseen amenities for personnel that improve installation morale. For example, some alternatives may include **green infrastructure** that provides opportunities for wildlife viewing recreation, or setbacks/buffer areas that can be used for sports activities by installation personnel. Some communities have added bike trails and paths on top of levee systems. You will record community/installation-related benefits in column "III. Installation/Community Benefit Values" in **Worksheet III.3**.

- **Environmental and Ecosystem benefits.** Some action alternatives may create new land uses that will result in additional annual benefits not related to potential averted losses or avoided damages to land-based or marine structures and assets. Environmental benefits from an action alternative may arise when land is converted by an action to one that provides natural environmental benefits, or "ecosystem services" benefits. Ecosystem services have been classified according to the following widely adopted four main classes of ecosystem services (NRC 2005):
    - Provisioning (example: food, fresh water, etc.)
    - Regulating (example: use of green infrastructure and coastal wetlands for dissipating storm and tidal energy and for buffering and absorbing impacts from more frequent and severe climate events and hazards)
    - Supporting (example: providing habitat)
    - Cultural (example: recreational and ecotourism)

  You will record environmental and ecosystem benefits in column "IV. Environmental/Ecosystem Benefit Values" in Worksheet III.3

  To account for these benefits in monetary terms, the ecosystem services valuation approach was established and formally integrated into some agency processes. For example, FEMA has a vetted process for incorporating ecosystem services values (on a per acre basis) obtained from peer-reviewed studies for use in **benefits transfer** applications. **Fact Sheet 5: Ecosystem Services and Valuation** in **Appendix E** provides more details on these benefits, valuation methods, and additional resources for planners to access.

Within **Worksheet III.3 - Benefits** we have included a placeholder column, titled V. Other Benefits / Intangibles Values, for the other benefits for which you have identified dollar values but do not fit neatly into the other benefit categories. It is important to realize that, in constructing your project resource statement, you should attempt to account for all forms of benefits.

Risk and Expected Annual Damages

To estimate future annual damages (i.e., the resilience benefits of avoiding them) for placement in project resource statements, the probabilities of future events must be considered. Coastal hazard areas can be defined by hazard zones that have associated return periods. A 100-year flood has a (1/100) or a 1% probability of being exceeded in a year. In the illustrative impact scenario depicted in Stage I (**Figure**

I.3), the 1% annual chance event elevation represents that area that would be impacted by inundation at this frequency. Over time, the risk is compounded (i.e., for a 1% annual probability of occurrence over a 30-year time horizon, the chance of experiencing a flood event of that magnitude one or more times is 26%) (**Figure III.4**).

Benefits are annual estimates because the precise number and severity of future flood/hazard or severe weather events exacerbated by sea level rise is unknown. As a result, benefits are estimated based on

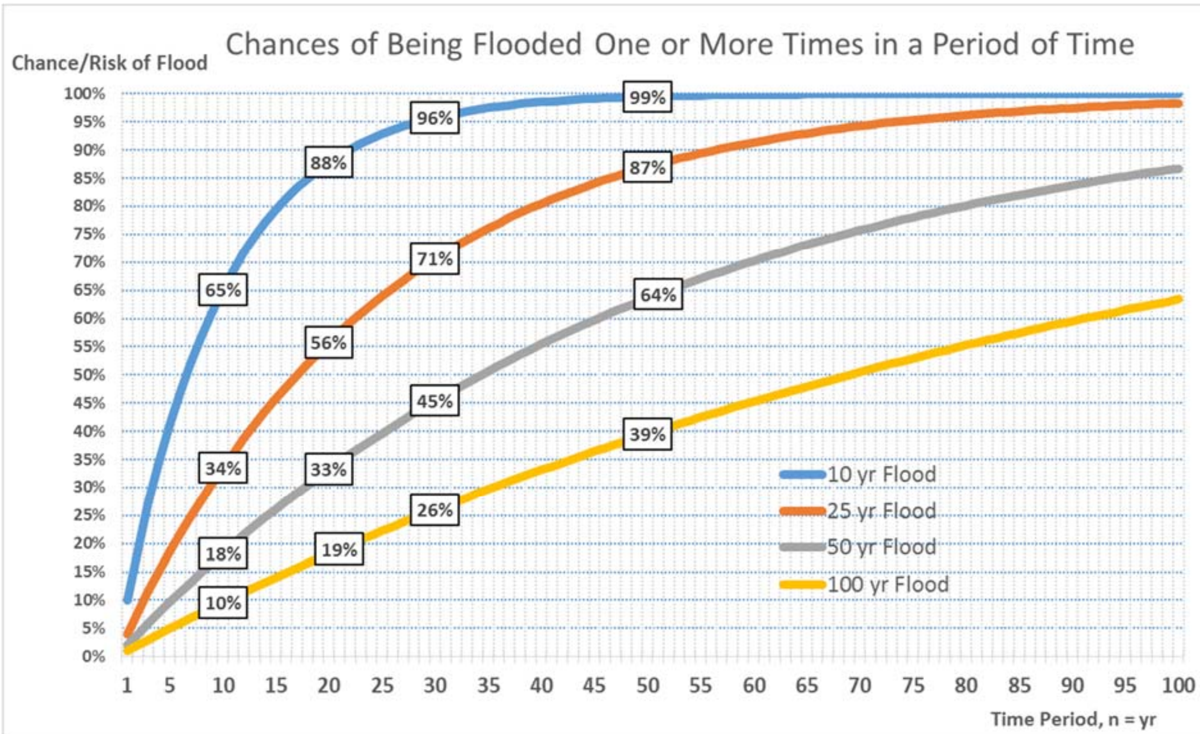


Figure III.4 Chances of Being Flooded One or More Times in a Period of Time
(Source: Adapted from Table 8, Coastal Storm Risk Management - IWR Report 2011 R-09, USACE 2011)

experienced or hypothetical flood events of various magnitudes in a probabilistic manner. Expected annual damages are the damages per year expected over the life of the protection project within the action alternative. “Expected annual” does not mean that these damages will occur every year. However in benefit cost analysis, the annualized expected damages are entered into the project resource statement benefit column to reflect the annual probability of occurrence for a mix of events.
For example, if a depth damage function that you applied from one of the benefits monetization tools indicated that a structure valued at $100,000 would be inundated by 3 feet of water above the first floor elevation, and damages to the structure were estimated at 30%, $30,000 would be entered into the project resource statement at $300 per year ($30,000 x 1/100) to reflect annual probability of occurrence of this 100-year storm event. For a mix of events, the cumulative probability for a year would be used to adjust the multiple event benefits (avoided damages) determined from the application of the depth damage function. (See **Fact Sheet 3: Application and Use of Depth Damage Functions** in **Appendix E** for a description of the application of depth damage functions.) The cumulative sum of these weighted damages, reflecting events of various magnitudes, represents the expected annual damages. It is important to express the expected annual damages as the net damages (with and without

the action alternative protection). There may be residual damages that can be expected to continue over time even with the action alternative. These latter "without adaptation" action alternative damages need to be reflected in the analysis to avoid overstating benefits. Many of the referenced benefit monetization tools calculate these damages automatically.

☐ Select appropriate benefits monetization tools based upon the information and referenced Fact Sheets in **Appendix E**.

Action Alternatives Costing Tools

The costing of alternative actions and tools that will help you develop life cycle costs are covered in detail in **Fact Sheet 4: Costing Tools and Resources** in **Appendix E.** The Fact Sheet contains links to some widely used software programs that will aid the planner and cost estimator in calculating life cycle costs. **Worksheet III.1 – Life Cycle Cost Analysis** for the notional installation provides examples of adding up costs for each action alternative.

☐ Select appropriate costing tools based on the information and referenced Fact Sheet in **Appendix E**.

Step ⑤: Determine Costs and Benefits to be Monetized and Perform Calculations

In this step, you will identify the main categories of costs and benefits that you can monetize and estimate in dollar terms for each action alternative. You will complete a ***Benefits*** *worksheet (****Worksheet III.3****) and one or more* ***Benefit Cost Ratio and Net Present Value*** *worksheets (****Worksheet III.4****). Before starting Step ⑤, you should have completed* ***Worksheet 1.7 - Impact Description and Characterization****,* ***Worksheet II.1 - Potential Action Alternatives, Worksheet III.1 - Life Cycle Cost Analysis,*** *and selected appropriate monetization and costing tools in Step ④.*

The monetized benefits used in this step were originally identified in Stage II. After completing Step ④, you should have a better understanding of which benefit streams are capable of being monetized with the tools you selected. Following the outcome of Step ②, the CEA, and the valuation of monetized benefits in this step, the list of action alternatives developed in **Worksheet II.1** will be further screened for BCA purposes.

Direct resiliency benefits result from the action alternatives and include avoided losses as well as other benefits that can be evaluated in detailed BCA procedures. Direct benefits or avoided losses have been termed by many climate change and resiliency evaluators as "core resiliency" benefits. These types of benefits would be related to the cost savings benefit category in NAVFAC Pub. 442 as they are resource savings (e.g., avoided damages or repairs) that the installation would not incur in the future with the climate proofing or adaptation measure(s) in place. Databases and tools for valuation of benefits are described in Step ④. **Fact Sheet 3: Application and Use of Depth Damage Functions** in **Appendix E** describes how depth damage functions can be applied to calculate the avoided loss (provided by the action alternative) using the replacement value of assets within the impacted area found in iNFADs property records.

☐ Use **Worksheet III.3 - Benefits** to record and transfer the monetary values for the direct, indirect, and **cumulative benefits** of each action alternative under consideration. This may require you to complete more than one Worksheet III.3 so that you can back up your detailed analyses with more specific input worksheets or dependent data and information (see notional installation below for example). You will transfer the monetized benefits for each year from the output from one of the monetization tools you have applied.

- As noted above, you may not be able to monetize all benefits at this point. The worksheet contains placeholders for intangible benefit streams that may be quantified or monetized in the future. You should flag the benefits from Worksheet II.1 that cannot be monetized for consideration during development of W**orksheet IV.1**.

*For the notional installation, **Worksheet III.3** represents data for the grouping strategy of multiple lines of defense. It contains examples of Resilience Benefit Values for benefits of avoided damages to structures, building contents, vehicles, and critical infrastructure that may arise in future years that are then discounted to present value. For illustrative purposes, we include an additional "e. other avoided damages" column which could potentially contain values for displacement costs, emergency costs, injuries, etc. Other Benefit Value columns are shown for illustration, although only the IV. Environmental/Ecosystem Benefit Values column contains data as we considered the benefits and co-benefits of reef habitat, restored marsh habitat, and any measured improvements in water quality (e.g., denitrification, etc.) The values in the IV. Environmental/Ecosystem Benefit Values column are derived from the calculations in the Notional Installation Hypothetical Data box to the right of the main worksheet. This type of data box is an example of documenting dependent data.*

*Note: the cumulative present value of benefits will be compared to the cumulative present value of life cycle costs over the portfolio time horizon to calculate the BCR in **Worksheet III.4**. Cumulative discounted benefits less cumulative discounted life cycle costs represent the cumulative net present value of the action alternative.*

☐ Use **Worksheet III.4 - Benefit Cost Ratio and Net Present Value** to perform the mechanics of BCA.

- **Worksheet III.4** represents the integrated project resource statement. This worksheet brings together all monetized life cycle costs and benefits by year and shows where they will arise over the planning time horizon. You can enter your data in this project resource statement, or alternatively, link to the dependent worksheets.
- Using an Excel-based worksheet will enable you to apply the Excel functions that are used in time value of money calculations. These functions are applied to calculate the cumulative present values for all cost and benefit streams. From these cumulative present value streams you can then construct the cost benefit ratios and net present value summary measures of adaptation merit. See **Figure III.5** for a list of the various measures of adaptation merit.
- The worksheets in Stage III can also be subjected to sensitivity analysis conducted in Stage IV because they contain parameter/assumption templates that can be easily manipulated and altered to test how the measures of adaptation intervention merit may change if some of the assumptions/parameters are modified.

We determined earlier that the notional installation was interested in combining several of these alternatives into a multiple lines of defense grouping. Alt 1 could be combined with Alts, 2, 4, and 6 to provide additional synergistic and backup protection, at a combined cost that is still less than the cost of either Alt 7 or Alt 8. Despite Alt 1's relatively high costs, we brought it over into Step ⑤ in order to assess whether the combined monetized benefits and cumulative net present value may be *worth this larger investment, either as a stand-alone alternative, and/or in combination with the other alternatives that could form the grouping.*

Thus, there are five ***Worksheets III.4 - Benefit Cost Ratio and Net Present Value*** *for the notional installation – one for the combination of Alternatives 1, 2, 4, and 6 (****Worksheet III.4.1****), and four individual worksheets (****Worksheets III.4.2 – 4.5****) for each action alternative as a stand-alone alternative. While five Benefit Value columns were shown for illustrative purposes in Worksheet III.3, only the two columns with data - I. Resilience Benefit Values and IV. Environmental/Ecosystem Benefit Values - are shown in these worksheets.* ***Worksheet III.4.1*** *shows how a multiple lines of defense strategy would be evaluated and appraised by applying BCA. BCA can aid the decision-making process but is not the end of the analytic exercise however, as other considerations are assessed in Stage IV.*

TERMINOLOGY

Evaluating the Value of Action Alternatives with Different Measures of Adaptation Intervention Merit

Benefit Cost Ratio (BCR)
Ratio of the cumulative present value of benefits to the cumulative present value of costs. A ratio greater than one means the action is economically feasible (i.e., more benefits than costs)

Internal Rate of Return (IRR)
The rate that renders the present value of the cost stream (future annual costs) equal to the present value of the benefits stream (future annual benefits). The internal rate of return is compared to the project discount rate and must exceed it for the alternative to be economically feasible.

Discount rate
The interest rate that is applied in calculating the present value of expected yearly costs and benefits, and represents the opportunity cost of funds. The discount rate is sometimes referred to as the project "hurdle rate".

Net Present Value (NPV)
The absolute difference between the cumulative present value of benefits and the cumulative present value of costs. (i.e., benefits minus costs)

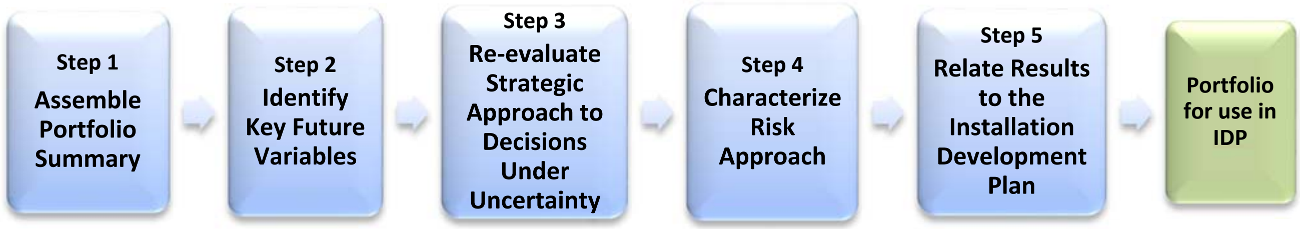
Payback Periods
Time required to recoup the costs of initial investment through costs savings attributable to the action alternative.

Figure III.5 Measures of Adaptation Merit

Stage III Output

At the completion of Stage III, you should now have completed a preliminary portfolio of action alternatives and calculated values for measures of adaptation intervention merit (BCR, cumulative discounted benefits, costs, and NPV), with associated documentation. This material augments the information generated from Stages I and II. You will also have flagged any intangible non-quantified or non-monetized benefits or limitations from Worksheet II.1 that will be given further evaluation in the portfolio assessment for Stage IV.

STAGE IV – ASSEMBLE PORTFOLIO OF ACTION ALTERNATIVES



Introduction

In Stage IV you will assemble information generated in the previous stages into a concise summary that presents the results of the analyses conducted using this Handbook. The summary will be in a format that can be used by planners and decision makers to evaluate a range of options or to inform the development of alternative courses of action during the IDP process. You will also conduct a more nuanced evaluation of each alternative in terms of future variables that may change. You will also provide a brief statement about how each alternative addresses risk. Depending on the outcome of your analyses, you may develop a concise description of how several action alternatives may be combined to achieve a particular strategic aim.

Before starting this section, you should have:

- List of adaptation action alternatives with measures of adaptation merit

Resources, skills, and tools you may need:

- Understanding of the long-range plans within the communities outside your installation for infrastructure improvements, changes in land use, and other potentially relevant changes

Key concepts you will encounter:

- **Sensitivity analysis**
- **Decision trajectory**
- **Pivot point**

At the end of this stage, the planner will be able to:

- Understand how future events and trends can influence decision making,
- Understand finance and funding options,
- Identify **climate change "signals"** that may help inform when action should be taken
- Identify potential timeframes for implementation and key decision points,
- Prepare a summary that includes the problem statement and describes the potential range of solutions. The summary will describe how these solutions would address the problem statement and describe their performance, costs and benefits, and their interrelationships, and
- Identify when data gaps and analysis merit revising or updating the problem statement, action alternatives, or benefit cost analysis.

Output: Portfolio of action alternatives. The portfolio of viable action alternatives, with background information on costs and benefits and other relevant factors, can be fed into the IDP process. This portfolio may grow or shrink over time, as new information about adaptation technologies becomes available, new climate projections are provided, or planning priorities of an installation change.

Step ①: Assemble Portfolio Summary

In this step, you will compile and summarize relevant information about the action alternatives in ***Worksheet IV.1 - Portfolio Summary*** *so that they can be readily understood for consideration in the IDP process. Before starting* Step ①*, you should have completed* ***Worksheet III.4 - Benefit Cost Ratio and Net Present Value****. You will also refer to the information recorded in* ***Worksheet II.1 - Potential Action Alternatives****.*

Planners and decision makers need to have transparent access to all outputs from Stages II and III so that they can understand the various dimensions of the analysis that has been completed using this Handbook.

Identifying the Action Alternatives included in the Summary Portfolio

☐ Use Column A in **Worksheet IV.1** to record the identification number, description, and a summary of the key benefits for each action alternative listed in **Worksheet II.1, Column B**.

- To complete this worksheet, you will transfer information from previous worksheets to build a concise description of each action alternative. Only alternatives that were evaluated in Stage III will be summarized in this stage. Alternatives that were identified as infeasible or inappropriate under current conditions during Stage II and not evaluated in Stage III can be reconsidered in future analysis. The Portfolio Summary will provide an overview of multiple relevant aspects of each action alternative that is currently viable, enabling an overview of all action alternatives.

An excerpt from the notional installation ***Worksheet IV.1*** *is below.*

Excerpt from Worksheet IV.1 for Notional Installation

	Column A - Action Alternative Description & Key Benefits	
Alt ID #	**Action Alternative Description**	**Key Benefits**
1	*Build a seawall*	*• Protects 2,000,000 sq ft of landward shore from the impacts of erosion and flooding* *• Protects 30 buildings, major shoreline road, historic officer's quarters and associated landscape (protects 1,200,000 sq ft of buildings)*

Summarizing the Results of the Economic Analysis

The Portfolio Summary should also include all of the measures of adaptation merit for each action alternative. These measures were established in Stage III and include the benefit cost ratio (BCR), the Cumulative Present Value of costs and monetized benefits, and the Net Present Value (NPV) or monetized benefits less costs. These measures are useful in comparing alternatives from multiple points of view, depending on the priorities of the user. These measures are more easily compared when presented side by side.

In economic analysis the BCR is one of several ways of expressing the merit of an adaptation intervention. However, the BCR alone does not reveal the relative "scale" of the anticipated investments in each action alternative included within the portfolio. Therefore cumulative present value costs and benefits, and the NPV (benefits less costs) are also provided. Some evaluators favor the present value for each of these measures because it shows concretely (in dollar terms) which portfolio maximizes wealth, or in this case the value of installation resilience. This is not to say that the other measures of merit are not important, it is to highlight how the planner should provide the full array of dollar-based measures behind the BCR. Some evaluators may want to immediately compare the cumulative present value of costs to anticipated budget appropriations that may be available over the next several fiscal cycles. Therefore, **Column B** in **Worksheet IV.1 - Portfolio Summary** carries over all of these summary evaluation measures, and shows them side by side for ease of comparison. The following text and tables (containing the same hypothetical data) illustrate how evaluations can be different based upon whether using BCR, NPV, or Cost.

The BCR may be used as an initial indicator of whether an alternative is considered favorable. In the case of BCR, >1 is economically feasible, <1 is not feasible. As shown in the table below (hypothetical data - different from the notional installation - is used for illustrative purposes only) a higher BCR indicates more benefit per dollars spent on action alternative 1.

ID #	Cost	Benefits	NPV	BCR	Evaluation based on BCR
X	$10	$15	$5	1.5	*Better – more benefit per $ spent*
Y	$50	$60	$10	1.2	

However, an action alternative with a lower BCR may have a higher NPV of benefits. The NPV of benefits represents the remaining benefits after costs are subtracted. In some cases an alternative with a lower BCR may be more favorable because of the absolute level of resilience benefits it would create compared to an alternative with a higher BCR. In the example below, action alternative 2 is preferable.

ID #	Cost	Benefits	NPV	BCR	Evaluation based on NPV
X	$10	$15	$5	1.5	
Y	$50	$60	$10	1.2	*Better – more absolute value*

The same may be the case for costs. For example a decision maker may want to focus on minimizing the present value of costs (rather than benefits) because she is constrained by budget appropriations that limit the available capital to specific levels on an annual basis. Thus, action alternative 1 is preferable in the table below.

ID #	Cost	Benefits	NPV	BCR	Evaluation based on cost
X	$10	$15	$5	1.5	*Better – feasible funding*
Y	$50	$60	$10	1.2	

☐ Use Column B in **Worksheet IV.1** to record the measures of adaptation merit for each action alternative. Locate the Cumulative Present Values for Total Costs, Total Monetized Benefits, and Total Monetized Benefits Less Costs (NPV) at the bottom of **Worksheet III.4 - Benefit Cost Ratio and Net Present Value** and transfer these values and the benefit cost ratio to the appropriate space in Column B.

*An excerpt from the notional installation **Worksheet IV.1** is below.*

Excerpt from Worksheet IV.1 for Notional Installation

Column B - Key Metrics				
Alt ID #	**Total Life Cycle Costs**	**Total Monetized Benefits**	**Total Monetized Benefits Less Costs (NPV)**	**Benefit Cost Ratio (BCR)**
1	*$5,776,874*	*$9,716,220*	*$3,939,346*	*1.68*
Source: Data transferred from **Worksheet III.4.2** - BCR NPV, Seawall Alt, Cumulative Present Values row				

Summarizing Non-monetized Benefits and Limitations

Alternatives may also differ in their non-monetized benefits and disbenefits (or limitations). Presenting these together with other parameters provides a more informed comparison especially if such non-monetized benefits are relatively more important for the evaluator and can support a decision for selecting an alternative with a lower BCR, but with greater non-monetized additional benefits; or for not selecting an alternative that has a high BCR, but has greater disbenefits or limitations.

☐ Use Column C in **Worksheet IV.1** to provide a description of the benefits and disbenefits (or limitations) that were not monetized and evaluated as part of the BCR. This may include benefits that can be monetized but that were not, for whatever reason, in the BCR analysis. This information can be summarized from the information in **Column B, Worksheet II.1 - Potential Action Alternatives**.

An excerpt from the notional installation ***Worksheet IV.1*** *is below.*

Excerpt from Worksheet IV.1 for Notional Installation

	Column C - Non-Monetized Benefits & Limitations (Disbenefits)	
Alt ID #	**Non-monetized Benefits**	**Non-monetized Limitations (Disbenefits)**
1	• *Protects historic landscape* • *Modern equipment can be integrated into new structure, improving efficiency*	• *Visual impacts* • *Reduced/impaired waterfront access* • *Hardened shoreline increases wave height and number of exceedance events, increases erosion on the seaward side potentially exacerbating loss of near shore ecosystem* • *Extensive environmental review process*
Source: Data transferred from **Worksheet II.1**, Action Alternative #1, Column B		

Step ②: Identify Key Future Variables

In this step, you will build on the description of the alternatives by highlighting issues and strategic approaches relevant to the decision-making process. Before starting Step ②, you should have completed Columns A, B, and C in ***Worksheet IV.1 - Portfolio Summary****.*

Each action alternative may be affected by future variables that could influence when investment would be most effective. Identifying how future variables may influence investment decisions is essential to avoid overinvestment of scarce resources, minimize disbenefits, and maintain flexibility in response to changing conditions, especially in light of climate projections that have associated uncertainties. Several concepts described below are useful to understand as you consider future variables.

Sensitivity Analysis

If external variables lead to a substantial change in the adaptation intervention merit of an alternative, this is an indication of the high sensitivity of an alternative (or portfolio) to external factors that cannot yet be defined with certainty. In such cases it is also important to understand which aspect is most sensitive to the external variable. For example, these could be cost, monetary or monetized benefits, or qualitative benefits. The extent to which the merit changes can be determined through a sensitivity analysis, by re-running the merit with different assumptions for the external factor. This can be binary or probability based. An example of a binary assumption could be whether a new roadway that may serve as an alternative flood-resilient access route to the installation is or is not constructed (by others) by the time the flood-resilient access is needed. An example of a probability assumption for an external factor could be a projected 50% increase in the probability of regional growth projections that would create new development in an area where the installation was planning to relocate some of its operations for resilience purposes. These assumptions are not unique to climate change adaptation and may be considered as part of other planning processes as well, such as Joint Land Use Studies (JLUS).

Decision Trajectory

Each action alternative typically has a timeframe over which it needs to be implemented (a decision trajectory), including a planning stage, funding/financing stage, and construction and operation stage. These stages translate into certain capital and O&M expenditures over the course of many years.

Pivot Point

A pivot point exists when an external variable has the potential to affect the cost effectiveness of an action alternative, potentially changing the choice of or timing of an action alternative. Understanding when a pivot point may occur is important in mapping out a trajectory of investment. The timing of these external variables can be compared to the timing of the significant expenditures associated with the action alternative, and a different action alternative can be explored in case the risk of early "over-investment" is substantial.

In Stage III, you identified costs and benefits, and identified which year implementation was expected and the benefits and costs associated with those years. In this stage, you will identify external events that could influence an investment decision such as, internal funding constraints, and pivot points or data gaps and would prompt a decision-maker to choose one path over another (Column D in **Worksheet IV.1 - Portfolio Summary**).

The next three sections relate to the three column headings under Column D - Key Future Variables in Worksheet IV.1 - Portfolio Summary: External Events, Funding Constraints, and Pivot Points and Data Gaps.

What type of external events could impact action alternatives?

In order to identify the future events that might influence an investment decision, you should consider several types of future variables, each of which is described further below:

- Climate Projections
- Technology
- Community Context and Land Use Patterns
- Infrastructure
- Finance and Funding Options

Climate projections

While climate projections agree on global trends, projections (including sea level change and frequency and intensity of extreme weather events) are subject to uncertainty at regional levels. As the installation planner gains access to better data or more refined projections, the basis of adaptation action selection may change and require re-evaluation. For example, the analysis conducted as part of this Handbook may be based on a projection of sea level rise that has not been down-scaled for regional conditions because that was the best data available at the time. The data limitations noted in **Worksheet I.4 - Climate Information Requirements and Attributes** may be resolved with additional or better data sources and the plausible future conditions documented in **Worksheet I.5 - Current and Plausible Future Conditions** may change. This may affect the nature and effectiveness of identified action alternatives as well as implementation timing.

Identifying climate change "signals" (such as frequency of high-tide flooding, increase in flood damage or functional impacts) can help to map decision points, regardless of the quality or "fidelity" of the data used. Climate variability is inherently uncertain but trends and "tipping points" can signal the need to implement an adaptive measure or to re-evaluate adaptation measures. Knowing what those signals are is part of the "Observational Method" of infrastructure design (ASCE 2015, see **Factsheet 6 - Modification of Existing Structures** in **Appendix D**). It is also referred to as "benchmarking" in planning and adaptive management practice. For example, the frequency and depth of tidal flooding may be underestimated in the data source used to develop the portfolio. Identifying a critical threshold for the frequency and depth of tidal flooding will allow the installation planners and engineers to use observation of actual conditions to support decision making or to repeat the analysis using data with higher fidelity. Assumptions about climate change are a key factor in the analysis and an indicator of the need to perform the analysis of this Handbook in an iterative way.

Technology

The evaluation of action alternatives includes assessment of the *feasibility* of potential action alternatives. Technological innovations may occur that would render an option feasible that previously was not considered feasible. For example, developing an off-the-grid energy supply for an installation using biodiesel generators may have been rejected as infeasible because current generator technology does not meet Clean Air Act requirements for nitrogen emissions. Development of a suitable generator filter would be a technological "game changer" that would render the adaptation action feasible. Advances in efficiency in solar technologies, such as new higher-efficiency photovoltaic materials, may reduce the area required for solar energy and thereby enable solar energy to become feasible where less area is available. A similar case may be made for energy storage, where batteries increase in efficiency.

Community Context and Land Use Patterns

Communities, especially those that are either fast growing or currently exposed to flood risk, may be developing expansion plans or experiencing expansion trends that could interfere with the installation's ability to respond to climate change. Communities may also be responding themselves to near-term, medium-term, or long-term climate change risks in ways that may influence the installation's planning.

Infrastructure

Future changes in infrastructure may require re-evaluation and may affect both the benefit cost analysis and the qualitative factors considered in the evaluation of alternatives. Infrastructure changes may be independent from or associated with the installation. It is important to identify potential changes and the extent to which they could affect the timing or nature of the alternatives.

Examples include, but are not limited to, potential construction of regional resiliency projects, transportation infrastructure near the facility, and upgrades to the power grid.

- If local communities are partnering to install a surge barrier, the decision to install a more localized seawall at the installation may become redundant. If the funding for this partnership project is not established, however, implementation of the community surge barrier may be uncertain.

- If a new highway is proposed near the installation, the installation may take advantage of such a change in regional infrastructure to relocate the installation entrance and re-orient some of the installation's internal roads. It may be advisable to either postpone the investment in the alternative until the new highway is guaranteed or to revise the alternative to keep options open.
- It is also possible that USACE may be considering plans for infrastructure and partnering with a state/regional "non-federal sponsor" that would provide some level of protection to the Navy's installation as well. The anticipated completion of such major infrastructure then needs to be related to the timeline for implementation of the alternative, and potentially represents a pivot point.

What finance and funding options could impact action alternatives?

In addition to mapping out when expenditures need to occur, it is important to include considerations of financing early in the process, even when the alternatives have not yet been developed. A distinction should be made between "cost" and "financing." Whereas cost is associated with the expenditure, financing is associated with the "how" to get the financial resources to pay for the alternative. Conventional resources such as federal funding may be available through the established funding process.

You may also want to explore alternative financing to reduce the total cost to the government. Options include cost-share programs such as DoD's Readiness and Environmental Protection Integration (REPI), or private co-investment in resilience measures especially where they involve improvements located outside the installation's boundary, where they can be shared with other stakeholders. Examples include the redevelopment of natural systems along the shoreline that mitigate the effects of sea level change and storm surge, thereby reducing the cost for onsite flood management measures. You may also be able to identify opportunities for wetland mitigation banking in conjunction with such solutions, providing both ecological value and financial resources.

What pivot points and data gaps could impact action alternatives?

Pivot points may be reached when new data are made available. This may be the outcome of a performance study on an existing defensive feature or a feasibility study of a new proposed measure. It is also important that you identify data gaps, as the development of climate change adaptation is a continuous process. Such data may include monitoring data or new analyses that take advantage of new data or technologies. Identify data needed to reach greater analysis and decision resolution (granularity) and reduce uncertainty; for each of the action alternatives, identify data gaps or further analysis or monitoring requirements.

Pivot points can also be created by external drivers such as changes in land use or development, as well as internal drivers such as asset life cycle changes. For example when evaluating short-term and long-term support services for aircraft carrier piers (e.g., water, power), different life cycles (30-50 years) should be evaluated. These considerations may affect decisions to repair or replace assets and create decision points. This is especially relevant when large capital expenditures are associated with extended life cycles. It is also relevant in the case of major external infrastructure such as the surge barrier in the example above, potentially representing a pivot point. In such cases you may want to recommend postponement of the investment in the alternative until there is certainty about the status of the new surge barrier or the alternative may be revised to keep options open.

While pivot points may not be identified with certainty in the initial planning process, it may be useful for planners to consider "what if" scenarios such as those described above. For example, the decision to invest in a higher or lower flood barrier (with associated higher or lower costs) is partially influenced by the assets to be protected. The presence and importance of such protected assets may change over time and thereby change the outcome of the BCA. Furthermore, additional and non-monetized benefits may grow in importance over time. Replacements for assets that approach the end of their life cycles may be gradually shifted to low-risk or risk-free locations. Once established in such locations they can also serve a contingency or redundancy function for assets that remain at risk, thereby creating near-term resilience while contributing to a long-term adaptation strategy. The distribution of expenditures over time can also influence whether a large investment upfront or a gradual investment initially with a decision on a bigger investment in the future is the most appropriate.

☐ Use Column D in **Worksheet IV.1 - Portfolio Summary** to identify your key future variables. Note when key investment decisions need to be made or when externalities could occur that could generate a pivot point.

An excerpt from the notional installation ***Worksheet IV.1*** *is below.*

Excerpt from Worksheet IV.1 for Notional Installation

	Column D – Key Future Variables		
Alt ID #	**External Events**	**Funding Constraints**	**Pivot Points and Data Gaps**
1	• *Third-party protective measures (e.g., surge barrier protecting larger region) can render investment redundant* • *Incremental asset protection (flood proofing, elevation) can reduce cost effectiveness of the action alternative*	*None, funding is allocated through established procedures*	• *Status change in County plans for surge barrier* • *Data on performance of marsh in limiting surge height* • *BCA if implemented with other adaptation measures in a hybrid solution* • *Data on loss of marsh area, effect on seawall performance*

Step ③: Re-evaluate Strategic Approach to Decisions under Uncertainty

In this step, you will re-evaluate the assessment performed in Stage II, Step ⑤, regarding the type of strategic approach to decisions under uncertainty each action alternative represented. Before starting Step ③, you should have completed Columns A through D in ***Worksheet IV.1 - Portfolio Summary****.*

In Stage II you identified the strategic approach to decisions under uncertainty that each action alternative represented. Based on the results of your examination of future variables, you should re-evaluate your assessment of the following strategies (review Stage II, Step ⑤ for further information):

- No-regrets strategies
- Reversible and flexible strategies
- Safety margin strategies
- Reduced time-horizon strategies

☐ Use Column E in **Worksheet IV.1** to record the approach to uncertainty that each action alternative represents. You may transfer the evaluation that you made in Stage II but you may also update this evaluation based on consideration of future variables. A safety margin strategy such as building a seawall may become a no-regrets strategy if the results of a feasibility study indicate that current O&M funding for routine upgrades to an existing seawall would allow a retrofit that meets the new design height.

*An excerpt from the notional installation **Worksheet IV.1** is below.*

Excerpt from Worksheet IV.1 for Notional Installation

Alt ID #	Column E - Strategic Approach to Decision under Uncertainty
1	***No regrets**. Shore facilities modernization already planned for 2045. Incorporating seawall adds minor cost* ***Reversible/Flexible**. Seawall can be designed to allow future increase in height as sea level rise increases*

Step ④: Characterize Risk Approach

In this step, you will characterize the approach to risk response that each action alternative represents. Before starting Step ④ *you should have the completed Columns A through E in **Worksheet IV.1 - Portfolio Summary**. You will refer to **Worksheet I.7 - Impact Description and Characterization** to determine the impact magnitude to be addressed.*

Approaches to risk response include four general strategies that reflect different levels and approaches to risk management (adapted from Sheehan 2010):

- Assume Risk
- Transfer or Share Risk
- Control Risk
- Avoid Risk

Assume risk

If the impact magnitude identified in Stage I is expected to be insignificant or minor (with either no infrastructure damage or localized infrastructure service disruption with no permanent damage), it may be reasonable to assume the risk and continue with current work-arounds (e.g., sandbagging and door dams), rather than implementing adaptation actions. Current land use patterns may already restrict development within hazard-prone areas. The existing flood hazard area or current land use restrictions detailed in the IDP in response to executive orders or other mandates restricting development within flood plains may identify this type of land use restriction. Current design standards may already have sufficient safety margins to account for climate change impacts. Natural buffers may already exist that have the capability to keep pace with climate change effects over time. Monitoring and research to confirm the conditions and provide confidence in the assumption of risk may be the only actions required. This is the "wait and see" or no action approach.

Transfer or share risk

If the impact magnitude is expected to be moderate (with widespread infrastructure damage and loss of service) and there are other stakeholders with an interest in addressing the risk, it may be possible to either rely on another entity to address the risk or to share responsibility for the adapation action with other stakeholders. For example, USACE may have a coastal defense project in the pipeline that will address the risk. Local communities may share an interest in undertaking adapation projects and can share the cost and implementation responsibilities for some types of adapation actions. It may be possible to make policy changes or implement other programmatic actions (e.g., JLUS, or Partnering) that would spread the responsibility for adaptation action among several interested stakeholders.

Control risk

If the impact magnitude is expected to be major (with extensive infrastructure damage requiring extensive repair), it may be prudent to control the exposure of the installation to the hazard. It may be necessary to revise development plans and land use designations to limit development in hazard prone areas. It may be necessary to secure additional land or easements to permit existing natural coastal defense systems sufficient space for migration into upland areas as sea level rises. Physical modifications to structures may be required to reduce the impact of climate change. The natural and nature-based infrastructure features may require increased maintenance to ensure that existing, adequate elevations or heights are maintained.

Avoid risk

If the impact magnitude is expected to be catastrophic (with permanent damage and loss of infrastructure service), it may be necessary to avoid the risk entirely by implementing adapation actions that eliminate exposure to the hazard or minimize the severity of the impact from the hazard. Avoidance of risk may require relocation of exposed infrastructure or operations.

☐ Use Column F in **Worksheet IV.1 - Portfolio Summary** to record the risk approach and the rationale for the risk approach for each action in the Portfolio.

*An excerpt from the notional installation **Worksheet IV.1** is below.*

Excerpt from Worksheet IV.1 for Notional Installation

	Column F - Risk Approach Type
Alt ID #	**Risk Approach Type**
1	***Control Risk.*** *Increases physical flood barrier protection level to reduce risk*

Step ⑤: Relate Results to the Installation Development Plan

In this step, you will relate the Portfolio of Action Alternatives you have developed using this Handbook to the IDP. Before starting Step ⑤ *you should have the completed **Worksheet IV.1**.*

The analysis conducted as part of this Handbook can be carried out independently of the IDP process or in concert with it. The output and considerations of this Handbook can be used during the Analysis stage of the IDP process. Courses of action that are identified in the Portfolio Summary can also be considered during alternatives evaluation process. **Figure IV.1** depicts the use of the output from this Handbook as an input to the IDP.

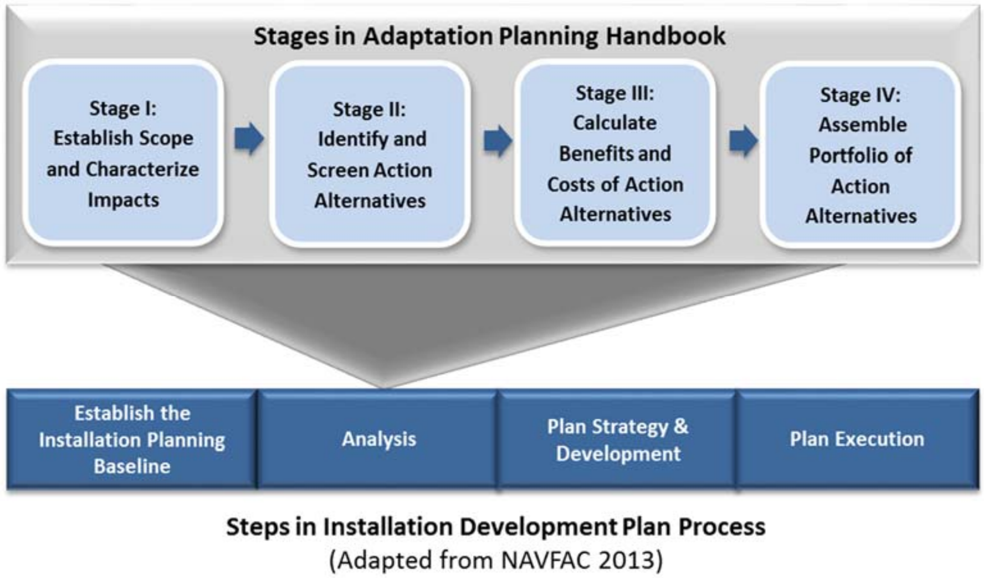


Figure IV.1 IDP Process Integration

At this stage, you have described considerations that planners and decision makers will use to develop alternative courses of action:

- BCR, NPV, and other methods for evaluating action alternatives and portfolios, as evaluated in Step ①
- Future climate projections, technology, community context, and infrastructure variables, as evaluated in Step ②
- Finance and funding variables as evaluated in Step ②
- Approaches to uncertainty as re-evaluated in Step ③
- Risk approaches characterized in Step ④

This Handbook also allows for an iterative process in which planners can return to previous stages after completing Stage IV as more information becomes available, assumptions or climate science changes the problem statement, more robust analysis becomes possible, or additional considerations are identified during the IDP process that were not considered previously.

Additional portfolios may also be developed - or an existing portfolio refined - as more information becomes available or strategic objectives change. For example, updated cost information may prompt you to modify the BCA for an action alternative in your portfolio. Alternatively, a decision could shift your strategic objective which could impact your assessment scope and problem statement, requiring development of a new portfolio of action alternatives.

Additional Considerations for Planners to Use in the IDP Process

The portfolio of action alternatives summarized in **Worksheet IV.1 - Portfolio Summary** for the notional installation provides planners with a list of viable action alternatives that were evaluated in Stages II and III and refined in Stage IV. Planners may integrate these into the IDP as individual actions or several action alternatives may be combined as one grouping to be considered in the IDP process to achieve a particular strategy.

A strategy may be based on synergies or interdependencies related to timing, improved effectiveness, cost, financing or funding, or other considerations. A group of action alternatives that reflect a particular strategy may be considered as a subset of viable action alternatives that are particularly effective, by themselves or collectively, in carrying out a strategy. Examples of strategies include a multiple lines of defense strategy in which several complementary actions are implemented as a group to take advantage of synergies. **Figure IV.2** illustrates such an approach, in this case using “gray infrastructure” (built structures such as seawalls) and “green infrastructure” (nature-based solutions such as enhanced salt marshes and oyster beds) to protect shoreline assets. Other types of strategy include selecting actions for implementation in the short term that are flexible and reversible, least cost, or shared. The actual decision to deploy a particular strategy would be made during the IDP process based on the installation leadership’s priorities and approach to uncertainty and risk.

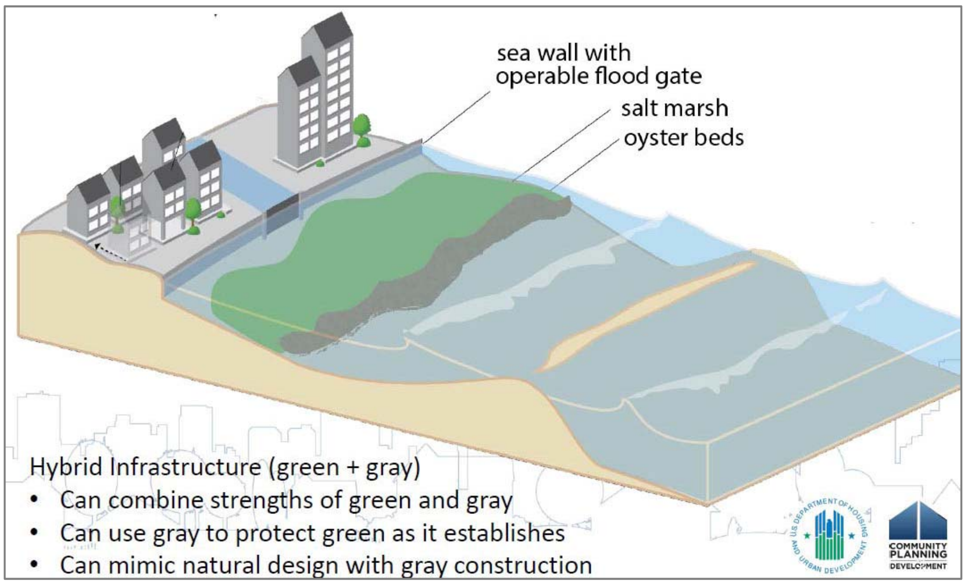


Figure IV.2 Example of Grouping Strategy: Multiple Lines of Defense
(Source: NOAA 2015)

Benefit cost analysis that is conducted for individual action alternatives can also be conducted for a grouping approach. The example **Worksheet III.4.1 - Benefit Cost Ratio and Net Present Value (Strategy Grouping: Multiple Lines of Defense)** for the notional installation illustrates how such a strategy may be evaluated using economic analysis techniques to account for the benefits that result from combining several action alternatives. This can demonstrate how the cost/benefit of a group of action alternatives can be more favorable than the sum of the separate cost benefit results of each action alternative.

The planner completing the analysis in this Handbook should maintain a record of the various strategic combinations of actions considered. In the example, a strategy of Multiple Lines of Defense would include a grouping of action alternatives that work in concert and can be implemented over time, offering flexibility for the decision-making process.

Using the notional installation as an example, we combined four action alternatives:

1 - Build a seawall

2 - Partner with County to install flood gate at mouth of river

4 - Restore and expand fresh water marsh ecosystem

6 - Install oyster reef breakwater at mouth of river

The combined benefits of this multiple lines of defense strategy are described as follows.

Restoration and expansion of the marsh ecosystem may be constructed to manage near-term flood risk involving nuisance flooding and smaller storms. In the longer term, flood risk that increases due to sea level rise and more extreme storm surge conditions will create a pivot point when a decision would have to be made whether to invest in construction of a seawall to manage the increase in risk. The height and density (and thus the cost) of the seawall in such case could be influenced by the extent to which the marsh could absorb the wave energy during surge conditions and thus reduce construction and maintenance costs of the seawall. A benefit cost analysis would be conducted to optimize the design and timing of the seawall.

Over time flood risk could continue to increase as a result of sea level rise and more intense weather, which would reduce the capacity of the seawall to prevent flooding and would also shrink the marsh area due to persistent flooding and increased storm surge frequency and intensity. This situation at some point in the future would create a second pivot point at which a decision would have to be made how to respond to the increase in risk.

An offshore breakwater could be installed to attenuate wave intensity to extend the life cycle of the combined seawall and marsh system and extend the risk reduction associated with them. A benefit cost analysis would be conducted at that time to evaluate this option or pathway relative to other pathways.

As sea level increases further, the impact of back river flooding may have reached a point that benefit cost analysis in adjacent communities also considering adaptation actions may favor a storm surge barrier at the mouth of the river, creating another pivot point for installation planners and decision-makers. A benefit cost analysis would be conducted at that time to evaluate the benefit of sharing the cost of the storm surge barrier with the adjacent community.

Stage IV Output

At the completion of Stage IV, you should have a portfolio of action alternatives that are feasible and adequately address the impacts identified for your installation. You should also have identified strategic approaches that address decisions under uncertainty and reflect your installation leadership's risk management priorities. You may also have created recommendations for combining action alternatives with a specific strategy in mind. Completion of the accompanying worksheets provides a record the analyses performed. The results of these analyses are available for consideration and integration into your IDP.

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Appendix A – Acronyms and Glossary

*This appendix contains a list of acronyms followed by a glossary with the definitions for the words bolded in **red** throughout the Handbook*

Acronyms

ACE - annual chance event

BCA - benefit cost analysis

BCR - benefit cost ratio

BFE - base flood elevation

CAC - Common Access Card

CEA - cost effectiveness analysis

CMIP - Coupled Model Intercomparison Project

CO2 - carbon dioxide

CPLO - Community Planning Liaison Officer

DSL - dynamic sea level

DoD - U.S. Department of Defense

DoDD - Department of Defense Directive

DoDI - Department of Defense Instruction

ERDC - Engineer Research and Development Center

EO - Executive Order

EWL - extreme water level

FOUO - For Official Use Only

FFRMS - Federal Flood Risk Management Standard

GCM - general circulation models

GIS - geographic information system

GHG - greenhouse gases

GRC - GeoReadiness Center

IDP - Installation Development Plan

INRMP - Integrated Natural Resources Management Plan

IPCC - Intergovernmental Panel on Climate Change iNFADS - internet Navy Facilities Asset Data Store

IRR - internal rate of return

JLUS - Joint Land Use Study

LCCA - life cycle cost analysis

MHHW - mean higher high water

NAVFAC - Naval Facilities Engineering Command

NNBF - Natural and Nature-Based Features

NOAA - National Oceanic and Atmospheric Administration

NPV - net present values

O&M - operations and maintenance

RCPs - Representative Concentration Pathways

REPI - Readiness and Environmental Protection Integration

SLC - sea level change

SLR - sea level rise

UFC - Unified Facilities Criteria

SRES - Special Report on Emissions Scenarios

USACE - U.S. Army Corps of Engineers

VLM - vertical land movement

Glossary

Terminology	Definition
100-year storm event	Storm designation based on statistical changes of occurrence. A 100-year storm has a 1 in a 100 chance of occurring in a particular year. It is also referred to as 1% annual chance event.
Action alternative	A method for adapting to the potential impacts of climate change. One of many measures that could be taken to address climate change impacts. In economic analysis, adaptation actions are also called adaptation interventions.
Adaptation	Adjustment in natural or human systems in anticipation of or response to a changing environment in a way that effectively uses beneficial opportunities or reduces negative efforts.
Adaptation intervention merit (or measures of adaptation merit)	The adaptation intervention measure of merit is the metric applied to determine the economic feasibility of the action alternative. This measure can be the Benefit Cost Ratio, Net Present Value, Internal Rate of Return, or the Payback Period.
Adaptive management	Adaptive management is an iterative, informed learning technique that adjusts management interventions in the face of uncertain outcomes.
Ancillary benefit	Secondary or supplementary benefit that accompanies a prime benefit.
Annual chance event (ACE)	See 100-year storm event.
Avoided loss	Avoided loss represents the extent of property and assets that are protected by the action alternative that can be easily given a direct monetary value (or monetized) from an economic point of view. See also “direct benefit.”
Benefit cost analysis	A benefit cost analysis is a systematic, quantitative technique that compares the present values of all benefits to the present value of related costs, (where benefits can be valued in dollars the same way as costs) in order to identify the alternatives that maximize the present value of the net benefit of the program, and to select the best combination of alternatives using the cost/benefit ratio.
Benefit cost ratio (BCR)	The benefit cost ratio is the ratio of the cumulative present value of benefits divided by the cumulative present value of costs. Where the ratio is greater than one, the action is considered economically feasible or viable.
Benefit streams	Benefit streams are annual benefits over the life of a given action item alternative.
Benefits transfer	Benefits transfer is a technique that applies or adapts the monetary values estimated from an existing empirical primary study to a subject study site or area. The method is applied where resources (time, money, technical expertise) may not be available to carry out a primary empirical study at the subject study site.
Built infrastructure	Built Infrastructure is referred to as capital improvements to land ("Class 2" property) in DoD. Class 2 property can include improvements such as buildings, structures, ground improvement structures, and utilities systems. Class 2 property also includes installed or "built-in" equipment. This built-in equipment is accessory equipment and furnishings that are: engineered and

	built into the facility as an integral part of the final design, required for operation, and are permanently affixed as part of the real property facility.
Climate	Mean and variability of relevant quantities of the climate system over a period of at least a month. These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state of the climate system, often characterized through statistics that may include the mean, standard deviation, and statistics of extremes, etc. A typical period of time over which to characterize the state of the climate system is 30 years, as defined by the World Meteorological Organization.
Climate change	Variations in average weather conditions that persist over multiple decades or longer that encompass increases and decreases in temperature, shifts in precipitation, and changing risk of certain types of severe weather events. This term and its definition are proposed for inclusion in the next edition of Joint Publication 1-02.
Climate change 'signals'	Trends or tipping points that may point to the need to implement or reevaluate adaptation measures. See the Handbook text on page IV-5 for more context.
Climate phenomenon	Factors or components of climate, including first order phenomena such as precipitation, temperature, and wind, and second order phenomena such as sea level and extreme temperatures.
Climate projection	Potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Projections involve assumptions or scenarios concerning, for example, future socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial uncertainty.
Climate scenario	Plausible and often simplified representation of future climate, based on an internally consistent set of climatological relationships and assumptions of GHG levels, typically constructed for explicit use as input to climate change impact models. A "climate change scenario" is the difference between a future climate scenario and the current climate.
Climate variability	Variations of climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system, or due to variations in natural or anthropogenic external forcing.
Co-benefits	Added (or multiple) benefits or synergies that may result from adaptation action. They do not include direct benefits.
Collateral benefit	A collateral benefit is a type of benefit that may arise as an incidental outcome of the alternative action that is generating the primary benefit of the management action's focus.
Confidence level	The confidence level is the statistical likelihood (probability) that a random variable lies within the confidence interval of an estimate.
Cost Effectiveness Analysis (CEA)	Cost effectiveness analysis (CEA) seeks to find the best alternative activity, process or intervention that minimizes resource use to achieve a desired result. Alternatively, when resources are constrained, analysis that seeks to identify the best alternative that maximizes results for a given application of resources. CEA is applied when project effects can be identified and

	quantified (through physical metrics) but not adequately valued in monetary terms.
Critical threshold	For infrastructure, structural or operational limit, beyond which function will be impaired or lost. For example, the height of a levee intended to provide protection against flooding is considered a critical threshold.
Cumulative benefits	Cumulative benefits are the sum total of all direct, indirect and collateral benefits generated from an action alternative.
Decision trajectory	A timeframe over which an action alternative needs to be implemented during which decisions about if and when to implement the alternative must be made. This includes a planning stage, funding/financing stage, and construction and operation stage that translate into certain capital and operation and maintenance expenditures over the course of many years.
Depth damage function (DDF)	Depth damage functions are standardized analytical tools that show the relationship in damages to a structure/asset (on the Y axis) versus depth of flooding inundation (on the X axis). The functions are developed empirically using data from actual flood events, and therefore represent average relationships between damages and flood depths.
Direct benefit	This represents the primary benefit of each action from an economic point of view. This type of benefit can be easily given a direct monetary value (or monetized) as an avoided loss based on the extent of property and assets that are protected by the action. In order to permit economic analysis, it is essential to identify the direct benefit of each action alternative using a metric such as square feet of buildings, acres, or linear feet of shoreline protected. See also "avoided loss."
Disbenefit	A negative effect of an action. A limitation or drawback.
Downscaling	Method that derives local- to regional-scale (typically 10 to 100 kilometers) information from larger-scale models or data analyses. For climate information, downscaling can be accomplished by either statistical or dynamical (regional climate model) means.
Dynamic sea level	Long-term changes in winds, air pressure, air-sea heat and freshwater fluxes, and ocean currents due to climate change that produce persistent trends in regional variations of global sea level.
Economic efficiency	Economic efficiency is a criterion for assessing an investment or intervention in an economy. An intervention is said to be economically efficient when it maximizes the value of output from the available resources.
Ecosystem services	Some alternative actions can provide natural environmental benefits, or "ecosystem services" benefits. There are four main classes of ecosystem services: Provisioning, Regulating, Supporting and Cultural. Monetizing the total economic value of ecosystem services is a means of accounting for the importance of ecosystems and the services they provide for human well-being, and can be used to demonstrate the value of a natural or restored ecosystem. As benefits that are valued by humans, ecosystem services can be broadly defined as socially valued aspects or outputs of ecosystems that depend on self-regulating or managed ecosystem structures and processes. Ecosystem services can directly and indirectly affect human wellbeing and ecosystem services themselves are interconnected. The economic value that individuals receive from ecosystem services can be described in a total

	economic value (TEV) framework, where TEV is comprised of both use value and non-use, or passive use, value (NRC, 2005; Freeman, 2003).
Emissions scenario	Emissions scenarios are greenhouse gas emissions (global carbon dioxide equivalents) projected trajectories, and are the product of complex dynamic systems. Emission scenarios are based on the interactions induced by forces such as global economic growth and production, demographic and socio-economic development, and technological change.
Ensemble	Grouping of models or model runs, often done to increase confidence in model run results.
Externality	Externalities as outputs involuntarily received or imposed on a person or group as a result of an action by another person or group and the recipient has no control of the output. Externalities (also referred to as external effects or spillovers) are an important class of outputs that may be classified as a benefit or disbenefit.
Extreme event (or extreme weather event)	Event that is rare within its statistical reference distribution at a particular place. Definitions of "rare" differ, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile. By definition, the characteristics of what is called "extreme weather" may differ from place to place. Extreme weather events may typically include floods and droughts.
Extreme water level (EWL)	Elevation of the sea surface defined with an exceedance probability curve as a function of the return period, which is the average length of time between exceedances of a given elevation. These are presented as mean distributions, as well as at specified confidence levels.
Facilities approaches (or facilities adaptation approaches)	Includes construction solutions such as building to a new standard that accounts for changing flood risk, constructing smaller scale built structures designed to protect an asset, such as a berm or flood wall, and making physical alterations to an existing asset to reduce flood damage. Retrofit techniques include flood proofing, retrofitting with flood-resistant materials, and physically relocating an asset or its vulnerable components out of the flood plain. Four examples are described in the **Appendix D - Adaptation Action Alternatives Fact Sheets**. See also "non-facilities approaches."
Flooding	Flow of water, especially over land not typically submerged. Flooding can be caused by precipitation on land not able to absorb the volume, a river or stream overflowing its banks, or coastal storms that push water beyond normal daily tidal limits.
Glacial isostatic adjustment	Rebound of the Earth's crust causing changes in relative sea level, caused by a change in the local radius of the solid Earth.
Global sea level	The average height of all the Earth's oceans.
Global sea level rise	The increase currently observed in the average Global Sea Level Trend, which is primarily attributed to changes in ocean volume due to two factors: mass addition through ice melt and thermal expansion.
Green infrastructure	An approach to managing stormwater by mimicking natural processes. It replaces conventional piped drainage and water treatment systems, or "gray infrastructure," with vegetation, soils, and other elements of the landscape to manage stormwater at its source and integrates parks and open spaces, riparian corridors, wetlands, significant bodies of water, and other natural

	areas to create a system that provides habitat, flood protection, cleaner air, and cleaner water.
Greenhouse Gases (GHG)	Any of various gaseous compounds (such as carbon dioxide) that absorb infrared radiation, trap heat in the atmosphere, and contribute to the greenhouse effect. Water vapor, carbon dioxide, nitrous oxide, methane, and ozone are the primary GHGs in the Earth's atmosphere.
Hazard	Hazards are natural events that threaten lives, property, and other assets. Typical hazards are floods, droughts, wildfires, earthquakes, hurricanes, tornadoes, windstorms, and tsunamis.
Hazard assessment	A hazard assessment is the process of evaluating your susceptibility and vulnerability to risks posed from multiple hazards. The hazard identification and risk assessment provides the factual basis for planning and remedial actions that may be formed into risk reduction strategies contained within a hazard mitigation plan. An effective risk assessment informs proposed actions by focusing attention and resources on the greatest risks. The four basic components of a risk assessment are: 1) hazard identification, 2) profiling of hazard events, 3) inventory of assets, and 4) estimation of potential human and economic losses based on the exposure and vulnerability of people, buildings, and infrastructure.
Ice melt effects	Gravitational and other changes to sea level due to the redistribution of land-based ice mass. As ice from glacier, ice caps, and ice sheets melts, gravitational pull on the ocean in the immediate area decreases, resulting in lowering of sea level in the vicinity of mass loss.
Impact	The positive or negative effect on the natural or built environment caused by exposure to a climate hazard. Climate hazards can have multiple impacts on people and communities, infrastructure and the services it provides, and ecosystems and natural resources.
Impact assessment	Practice of identifying and evaluating, in monetary and/or non-monetary terms, the effects of climate variability or change on natural and human systems. It is often a quantitative assessment, in which some degree of specificity is provided for the associated climate, environmental (biophysical) process, and impact models.
Indirect benefit	An indirect benefit is a type of benefit that arises from the direct benefit or is linked to it, but is not the primary focus of the management action.
Internal rate of return (IRR)	The rate that renders the present value of the cost stream (future annual costs) equal to the present value of the benefits stream (future annual benefits). The internal rate of return is compared to the project discount rate and must exceed it for the alternative to be economically feasible.
Life Cycle Cost Analysis (LCCA)	Technique applied to account for all anticipated costs of an action alternative during its various phases, including preliminary planning, construction, operations, and decommissioning activities.
Maladaptation	Maladaptation or maladaptive actions are actions that may lead to increased risk of adverse climate-related outcomes, increased vulnerability to climate change, or diminished welfare, now or in the future. Maladaptation can be actions taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups (IPCC 2014).

Mean higher high water (MHHW)	The average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
Mean sea level (MSL)	Mean sea level as a tidal datum is computed as a mean of hourly water level heights observed over 19 years. Mean sea level also can be defined as an average sea level over a specified time, such as annual or monthly mean sea level.
Mitigation	Intervention to reduce the causes of changes in climate, such as through reducing emissions of greenhouse gases to the atmosphere and enhancing greenhouse gas sinks. A human intervention to reduce the sources or enhance the sinks of greenhouse gases.
National Climate Assessment	A report that collects, integrates, and assesses climate-related observations and research from around the United States, helping to understand changes in climate and what they mean. The report includes analyses of impacts on sectors and regions of the United States.
Natural infrastructure	Features of the land and water environments, including their biota and associated ecological processes that directly or indirectly support society.
Natural/Nature-based approaches	Natural features that can enhance resilience to climate change and includes such features as: dunes and beaches, vegetated features (i.e., salt marshes, wetlands, submerged aquatic vegetation), oyster and coral reefs, barrier islands, and maritime forests/shrub communities. Approaches can incorporate features that occur from a natural process or are the result of human engineering and construction.
Net present value (NPV)	The net present value is the absolute difference between the cumulative *present* value of benefits and the cumulative *present* value of costs.
Non-facilities approaches	Range of techniques that rely on changes in siting, management, or maintenance of infrastructure to reduce flood damage.
North American vertical datum	For North America, the surface of zero elevation to which heights of various points are referred in order that those heights be in a consistent system. More broadly, a vertical datum is the entire system of the zero elevation surface and methods of determining heights relative to that surface. The North American Vertical Datum of 1988 (NAVD88) is the vertical control datum established in 1991 by the minimum-constraint adjustment of the Canadian-Mexican-United States leveling observations. It held fixed the height of the primary tidal bench mark, referenced to the new International Great Lakes Datum of 1985 local mean sea level height value, at Father Point/Rimouski, Quebec, Canada. This allows for relationships between past and current geodetic vertical datums, as well as various water level/tidal datums (e.g., Mean High Water).
Nuisance flooding	Recurrent flooding that takes place at high tide.
Performance metric	A physical (as opposed to monetized) measure of a benefit resulting from an adaptation alternative. For example, such a measurement could be square feet of building structures protected or linear feet of shoreline protected, etc.
Pivot point	An external variable that has the potential to affect the cost effectiveness of an action alternative, potentially changing the choice of or timing of an action alternative.

Probabilistic projection	Estimates of future climate conditions that assign a probability level, or likelihood, to different climate outcomes. For example, a researcher might assert "there is a 90% probability that the annual average global temperature in 2100 will be 2° C higher than the temperature in 1900."
Problem statement	Characterizes the type and magnitude of potential impacts to infrastructure in order to guide and bound the identification and evaluation of possible responses to potential impacts. The problem statement sets the goal of the adaptation strategy.
Project resource statement	A project resource statement is a summary statement of annual costs and benefits arrayed by year over time for a given action alternative. The project resource statement is used to calculate the adaptation intervention measures of merit.
Radiative forcing	Measure of the influence a factor has in altering the balance of incoming and outgoing energy in the earth-atmosphere system. Presence of GHG in the atmosphere changes the capacity of a square meter to retain or release radiative heat. It is also an index of the importance of the factor as a potential climate change mechanism. Thus, RCP 6.0 indicates that a square meter is now retaining 6.0 more watts per square meter than the 1750 baseline year used by the IPCC.
Reference datum	A geodetic datum or geodetic system is a coordinate system, and a set of reference points, used to locate places on the Earth.
Representative Concentration Pathway (RCP)	A set of four GHG concentration pathways (RCP 8.5, RCP 6.0 RCP 4.5 and RCP 2.6) intended to cover the range of climate scenarios reflected in scientific literature. The word "representative" signifies that each RCP provides only one of many possible scenarios that would lead to the specific **radiative forcing** (i.e., capacity to add warming) characteristics. The term "pathway" emphasizes that not only the long-term concentration levels are of interest, but also the trajectory taken over time to reach that outcome. Thus, RCP 8.5 represents a pathway for which radiative forcing reaches >8.5 watt per square meter (W/m^2) by 2100.
Residual damages	Residual damages are unavoidable damages to a land area, structure, or asset that may be experienced even after climate proofing action alternatives offering a given level of protection (i.e., to withstand a 100 year event) have been implemented.
Resilience benefits	Resilience benefits is a collective term to describe the avoided damages (benefits) to structures, contents, and tangible assets that are usually measured by a depth damage function.
Resiliency	Ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions.
Risk	Combination of the magnitude of the potential consequence(s) of climate change impact(s) and the likelihood that the consequence(s) will occur.
Scenario	A situation that details future plausible conditions in a manner that supports decision making under conditions of uncertainty, but does not predict future change that has an associated likelihood of occurrence.
Sea level change (SLC)	Change in sea level elevation, either rising or lowering, in relation to a specific point on land. Although sea levels are rising globally, some isolated areas are

	experiencing falling sea levels. Alaska is an example where, due to tectonic uplift, sea level is actually falling in relation to the land surface.
Sensitivity analysis	The analysis of possible or potential effects of adverse changes on a project. Values for variables and parameters used in the benefit cost analysis can be changed one at a time, or in combination, to assess how the alternative's net present value or benefit cost ratio would be affected. The exercise can reveal the most important assumptions upon which the analysis is based and reveal those to which the outcome is most sensitive.
Special Report on Emissions Scenarios (SRES)	Report by the IPCC, published in 2000, containing GHG emissions scenarios used to make projections of possible future climate change in support of the 3rd and 4th IPCC Assessment Reports. SRES scenarios are labeled in families called A1, A2, B1, and B2 that reflect storylines or assumptions about future worldwide population, land use, economy, technology, and policy choices.
Storm surge	The rise of water generated by a storm, over and above the predicted astronomical tides. Typically, wind associated with a storm pushes water toward the shore, resulting in higher levels of water than experienced under normal tidal changes.
Structural approach	A type of adaptation action that employs a built structure such as a levee or storm surge barrier to alter the flow of floodwater to protect a large area from inundation.
Tidal epoch	Specific 19-year periods of time used to describe the 18.6-year lunar cycle. The United States currently uses the 1983 to 2001 National Tidal Datum Epoch (NTDE) for referencing all tidal datums and local mean sea level. The center year of the NTDE – 1992 – is the reference year from which inundation estimates from sea level rise are developed.
Total water level	Water level resulting from complex interactions between multiple oceanographic, hydrologic, geologic, and meteorological forcings that act over a wide range of scales. Important components include astronomical tide, wave set-up, wind set-up, large-scale storm surge, precipitation, fluvial discharges, monthly mean sea level anomalies, and land subsidence or uplift.
Vertical land movement (VLM)	Measured trends in vertical land motion due to a variety of factors, including response of the earth's surface to the last ice age (modeled by Glacial Isostatic Adjustment [GIA] models), local uplift from isostatic rebound in glacial fjords, post-earthquake deformations, volcanism, and slow tectonic movement. Locally, land subsidence also can be due to withdrawal of hydrocarbons (oil and gas) and groundwater and local sediment compaction.
Vulnerability assessment	The process of measuring susceptibility to harm by evaluating the exposure, sensitivity and adaptive capacity of systems to climate change and related stressors.
Weather phenomenon	Weather is the day-to-day conditions of a particular place, usually described in terms of temperature, atmospheric pressure, wind, and moisture. A weather phenomenon is a short-term event, such as a snowfall or rainfall event. Other examples include storm surge, thunderstorms, tornado, and heat or cold waves.

Appendix B - Federal, DoD, and Navy Requirements Relating to Climate Change

This appendix provides planners with the primary federal, DoD, and Navy requirements relating to climate change. As issuances are updated, others may also include reference to these documents and/or inclusion of climate considerations.

Policy	Description
Executive Order 13653 6 November 2013 *Preparing the United States for the Impacts of Climate Change*	Section 5 required that federal agencies plan for climate change related risk: - Identify and assess climate change related impacts on and risks to missions, operations, and programs - Describe actions taken to manage climate risks in the near term and build resilience in short and long term - Identify climate risks that significantly impair an agency's mission - Describe needs to improve climate adaptation and resilience and associated costs and impacts to suppliers, supply chain, real property investments, relocation and construction of new facilities - Prepare climate adaptation plan and update annually
Executive Order 13677 23 September 2014 *Climate-Resilient International Development*	Requires that federal agencies with international development programs incorporate climate resilience into strategies, planning, programming, investments, and management of overseas facilities.
Executive Order 13690 30 January 2015 *Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input*	Establishes Federal Flood Risk Management Standard (FFRMS) for federally-funded projects. It is a flexible framework that allows federal agencies to define "flood plain" following one of three methods: - Elevation and flood hazard area that result from using a climate-informed science approach - Elevation and flood hazard area that result from using the freeboard value, reached by adding 2 feet to the base flood elevation for non-critical actions and 3 feet for critical actions - Other method identified in updates to the FFRMS
Executive Order 13693 19 March 2015 *Planning for Federal Sustainability in the Next Decade*	Establishes federal sustainability goals (building on EOs 13423 and 13514 goals), including the incorporation of climate-resilient design and management elements into the operation, repair, and renovation of existing agency buildings and the design of new agency buildings. Reinforces EO 13653 requirements to address impacts of climate change and increase preparedness for impacts.

Policy	Description
Executive Order 13728 18 May 2016 *Wildland-Urban Interface Federal Risk Mitigation*	Directs federal agencies to enhance the resilience of federal buildings and lands to wildfire in order to promote public safety, economic strength, and national security.
Department of Defense Instruction (DoDI) **4715.03** 18 March 2011 *Natural Resources Conservation Program*	"All DoD Components shall, in a regionally consistent manner, and to the extent practicable and using the best science available, utilize existing tools to assess the potential impacts of climate change to natural resources on DoD installations, identify significant natural resources that are likely to remain on DoD lands or that may in the future occur on DoD lands and, when not in conflict with mission objectives, take steps to implement adaptive management to ensure the long-term sustainability of those resources."
Department of Defense Manual 4715.03 25 November 2013 *Integrated Natural Resources Management Plan (INRMP) Implementation*	Implementation Manual for DoDI 4715.03. Enclosure 8, Planning for Climate Change Impacts to Natural Resources, provides DoD Components with tools and resources, and guidance for updating an INRMP to include climate change considerations.
Department of Defense Directive (DoDD) **4715.21** 14 January 2016 *Climate Change Adaptation and Resilience*	Calls for implementation of the 2014 DoD Climate Change Adaptation Roadmap. Directs the Office of the Secretary of Defense, Military Departments, Office of Chairman of Joint Chiefs of Staff, Combatant Commands, and all other entities within DoD to - Identify and assess effects of climate change on the mission, - Take climate change effects into consideration when developing plans and implementing procedures, and - Anticipate and manage climate change risks to build resilience.
UFC 2-100-01 15 May 2012 *Installation Master Planning*	Section 3-5.6.2.3 (Environmental Conditions) directs master planners to understand, monitor, and adapt to changes in external conditions that impact planning decisions, including climate conditions.
Navy Arctic Roadmap 2014-2030 February 2014 *Chief of Naval Operations*	Appendix 3 – Arctic Roadmap Implementation Plan, Section 2.6 Installations and Facilities, requires Naval Facilities Engineering Command (NAVFAC) participation in: - Identifying requirement to establish Aerial and Sea Port of Debarkation - Ensuring Arctic infrastructure requirements reflected in Sponsor Program Proposals in alignment with Navy Strategic Plan and Classified Annex to CS-21R; relating to Arctic installations, airfields, and hanger

Policy	Description
	requirements. Also conducting environmental impact assessments to assure environmental compliance.
Presidential Memorandum 21 March 2016 *Building National Capabilities for Long-Term Drought Resilience*	Addresses the Nation's need to sustain and expand efforts to reduce the vulnerability of communities to the impacts of drought. Establishes National Drought Resilience Partnership; DoD is a member. All members are to support drought resilience through better communication, coordination, and development of tools, guidance, and relevant resources to be shared with all levels of stakeholders.
Presidential Memorandum 21 September 2016 *Climate Change and National Security*	Establishes a framework for coordination and directs federal agencies to take actions to ensure that climate change-related impacts are fully considered in the development of national security doctrine, policies, and plans.

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Appendix C - Climate Science, Data, and Projections

This appendix provides planners with background on basic concepts related to climate science, climate models, and climate projections. It also lists information sources for climate data relevant to planners and provides example output from one of the referenced tools in Section 2 – the U.S. Department of Defense (DoD) Regional Sea Level Change and Extreme Water Level Scenarios For Official Use Only (FOUO) Database, and a discussion on how to align climate projection values to your site reference datum.

The science behind climate systems and climate change is complex, with many interacting factors and processes. It is no surprise that *projecting* climate conditions for the future is even more complex, as uncertainties about the future must be considered. It is important to know that our understanding of weather and climate systems has expanded significantly in the past 40 years or so. Research by individuals and organizations using continuously refined tools and increasing amounts of observational data adds to the worldwide body of knowledge on climate science and climate change.

Navy planners preparing for the impacts of future climate change need a basic, working knowledge of climate science and the modeling that produces projections about possible conditions in the future. This appendix is divided into three sections:

Section 1 provides some rudimentary information about several basic climate science concepts that will aid planners, particularly with regard to understanding and using climate projections data.

Section 2 provides online resources that may be helpful in enhancing knowledge about climate science, models, and climate data.

Section 3 provides example output from one of the referenced tools in Stage II – the DoD Regional Sea Level Change and Extreme Water Level Scenarios FOUO Database, and a discussion on how to align climate projection values to your site reference datum.

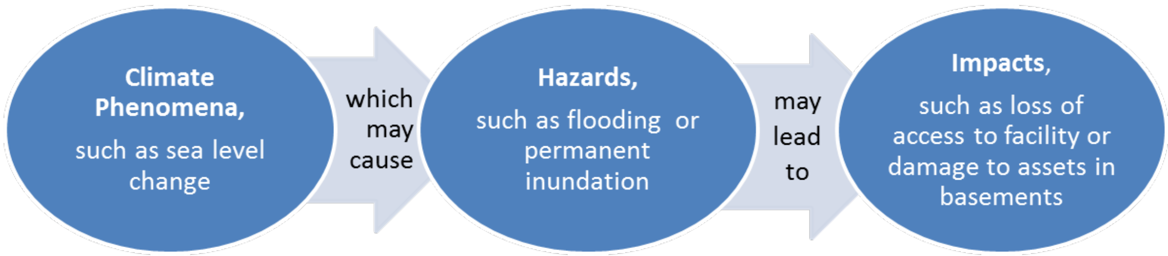
Appendix A – Acronyms and Glossary contains the terms often used in climate reports and discussions that you should become familiar with.

Section 1 – Basic Climate Science Concepts to Understand

This section provides some rudimentary information about several basic climate science concepts that will aid master planners, particularly with regard to understanding and using climate projections data.

Terminology to Connect the Pieces

It is helpful to distinguish between climate phenomena, the hazards resulting from those phenomena, and the impacts at installations from exposure to those hazards. The illustration below shows the relationships between these terms. **Table I.1** in the main body of this report provides a longer list of phenomena, hazards, and associated impacts.



Climate Phenomena

Physical phenomena affecting climate are a complex set of interacting forces and conditions, overlain by cycles of natural variabilities that may play out over two to three decades.

Understanding climate science is challenging, but deciphering impacts of climate change to any specific region or location is even more so. It may be helpful to think in terms of impacts from *gradual changes* and from **extreme weather events**. Gradual changes include sea level change, changing patterns of precipitation, and gradually rising average temperatures. Extreme weather events include changes in timing and patterns of downpours, storm surge, and heatwaves. The worksheets included in this Handbook guide planners to consider the impacts from both gradual changes and extreme events, and their change over the coming century. The two types of impacts cannot always be considered separately—a rising sea level will exacerbate impacts of storm surge. And inland flooding from extreme precipitation events may also contribute to flooding of coastal installations facing sea level rise and storm surge impacts.

> **AN EXAMPLE OF CLIMATE COMPLEXITY: NOTES ON REGIONAL PROJECTIONS FOR SEA LEVEL RISE**
>
> *Because many Navy installations are located on land subject to impacts from sea level rise (SLR) and storm surge, regional or even local climate data may be necessary for adaptation planning.*
>
> The ocean is not a bathtub; water does not rise evenly over the globe as it does in a bathtub. Many factors affect the actual sea level rise (or drop) experienced in a particular area. Likewise, location on the globe and bathymetry affect storm surge and wave impacts.
>
> Projections of *global* sea level rise may need to be adjusted to account for the following *regional or local* factors: **vertical land movement** (VLM), **dynamic sea level** (DSL), and **ice melt effects**.
>
> *Global SLR + VLM + DSL + ice melt effects = regional/local SLR*

Global Climate Models and Projections

Global climate models, often referred to a General Circulation Models (GCM), are used to mathematically describe the behavior and interactions of earth, ocean, and atmosphere parameters, such as the motion of the air, heat transfer, radiation, moisture content, and surface hydrology (i.e., precipitation, evaporation, snow melt, and runoff) (NYPCC 2010). As additional data are gathered and research conducted into the interactions of climate factors, climate models are refined to more accurately simulate climate phenomena. Once researchers are confident that a climate model accurately reproduces current and historic climate, and even paleoclimate conditions from thousands of years ago, the models can be used to project future climate conditions, using assumptions about process changes that will occur as global temperatures gradually increase.

Climate scientists are using over 25 models in their research and analysis (Gettelman and Rood 2016). Projections of future climate factors are usually made by averaging outputs from multiple models (i.e., an ***ensemble*** of models) to increase the confidence levels in reported figures. Nevertheless, uncertainties are associated with projections from climate models. Models are just that – *models* of very complex systems. No model can perfectly simulate a natural system with this range of parameters. Also, the *sensitivity* of the climate system to future changes is not perfectly understood. In addition, any projection of future events or trends inherently carries uncertainties. Adding to the complexity is the factor of “stationarity,” the assumption that actions in the future will be similar to actions in the past such that we can use the past as a guide for the future. To quote the title of a research paper on this topic, “Stationarity is dead” (Milly et al. 2008). In the new reality of non-stationarity, projections about climate must assume a constantly evolving basis.

All climate models must include a mechanism for describing future greenhouse gas (GHG) emissions and levels, or concentrations, of GHGs in the atmosphere. Carbon dioxide, or CO2, is the most plentiful GHG in the atmosphere. Climate scientists speak in terms of GHG or “CO2 equivalents” to describe emissions. The term “**emissions scenarios**” is used to describe possible variations in the trajectory of GHG emissions in the future. The approach for including assumptions about GHG emissions and levels has evolved over the past 20 years. The World Climate Research Programme established the Coupled Model Intercomparison Project (CMIP) in 1995 as a standard protocol for studying the output from atmosphere-ocean general circulation models. Since that time, several CMIP initiatives have provided projections analysis to support Intergovernmental Panel on Climate Change (IPCC) updates. As an example of the change in model assumptions on GHG emissions, the model results analysis (CMIP3) supporting the IPCC 4th Assessment Report (2007) used emissions scenarios A2, A1B, and B1. These are from the Special Report on Emissions Scenarios (SRES), and thus are referred to as “SRES” scenarios or “climate futures” (Nakićenović et al. 2000).

The A2, A1B, and B1 SRES scenarios link to “storylines” describing the relationships between the driving forces that affect GHG emissions over the 21st century. Elements of the storylines include differing assumptions about population growth, economy, technology, energy, land use, and agricultural practices. For example, the A2 storyline assumes a future of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies. On the other hand, the B1 storyline has similar population trends as those in A2, but assumes the economy rapidly changes toward a service and information economy and includes clean, resource-efficient technologies. Thus the B1 emissions scenario shows a slower increase of atmospheric CO2 levels than the A2 emissions scenario. All storylines are assumed to be equally valid with no assigned probabilities of occurrence (http://sedac.ciesin.columbia.edu/ddc/sres/).

Fast-forward to the IPCC 5th Assessment Report (2013 and 2014), which used climate data from CMIP5. A new set of scenarios, called Representative Concentration Pathways (RCPs), were developed to describe a range of possible emissions futures. The RCPs have designations like 2.6, 4.5, 6.0, and 8.5 and also include assumptions about the trajectory of GHG emissions over the next century. Please note that RCP 8.5 is considered the “business as usual” trajectory; it is the most conservative RCP as it assumes GHG mitigation efforts are slow and CO2 levels are steadily climbing throughout the century.

Regardless of the *type* of emissions scenarios used to drive climate models – SRES or RCPs – climate models using emissions scenarios with higher levels of CO2 concentrations will yield higher projections for sea level rise and annual average temperatures than climate models using emissions scenarios with lower levels of CO2.

Finally, regional models or other statistical methods can be used to “downscale” output from global models. Resolution of model outputs is often expressed in “grid size,” that describes the geographic area over which the data apply.

Climate models are used to project changes in average annual temperature, sea level rise, annual precipitation, number and duration of heat waves, and seasonal patterns in precipitation and temperature. Some projections may be *quantitative* in nature; others are more *qualitative*, depending on confidence in modeling and resolution of the modeling effort.

Scientists are surer about projections for some climate change phenomena than others. As demonstrated in **Figure C.1** below, scientists have more confidence in projections about heat waves and less confidence in projections about the occurrence of tornadoes and hurricanes. Also note the depiction of secondary and tertiary impacts from changes in climate factors. For example, heatwaves and droughts together increase the likelihood of wildfires (secondary impact). Increased wildfires render an area more vulnerable to erosion impacts from extreme precipitation events (tertiary impact). A specific branch of science, called attribution science, evaluates the relative contributions of multiple causal factors to a change or event. For example climate attribution scientists try to determine when specific extreme weather events can be attributed to human-caused climate change and when they are due to natural variability (National Academies of Sciences 2016). They may look at several factors to determine what part climate change played in affecting the magnitude and/or probability of the extreme event. Planners need to appreciate the interplay of multiple climate impacts on Navy infrastructure, as well as the natural variabilities in climate and weather.

Projections for climate conditions are often given for ranges of decades, or time slices, in the future, such as 2030s, 2050s, 2080s. Other sources for climate projections may indicate discrete years, such as 2035, 2065, and 2100.

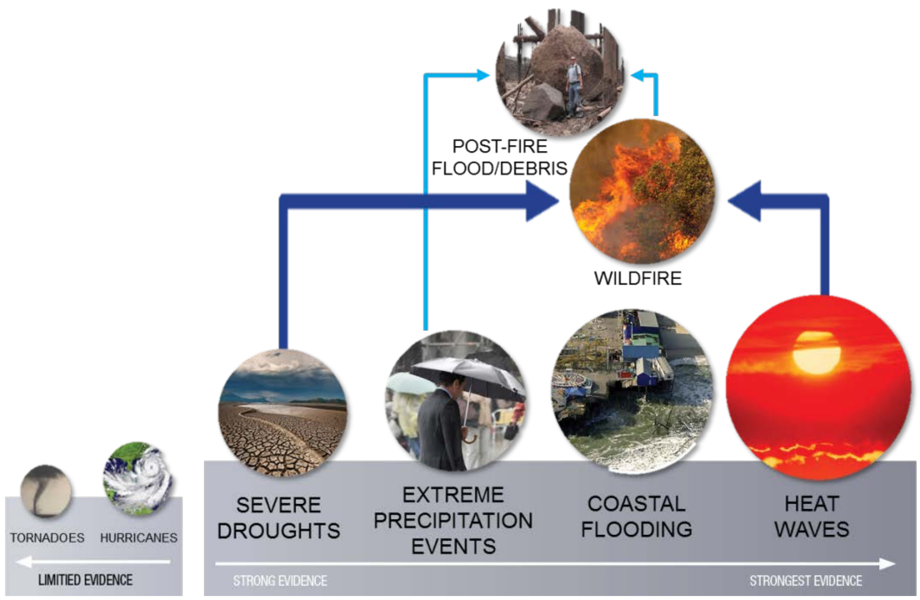


Figure C.1 Climate Changes in the Context of the Supporting Evidence
(Courtesy of Kate White, Ph.D., P.E., U.S. Army Corps of Engineers)

Questions to ask yourself regarding Climate Data:

- Is the climate projection *qualitative* or *quantitative*? Depending on the level of assessment, qualitative results may be sufficient to guide a planner's efforts. For example, that an installation is "very likely to have increased chances of erosion from inland flooding and storm surge" may be sufficient to plan adaptation strategies that guard against erosion impacts at important facilities. In other situations, such as the siting (or re-siting) of very valuable coastal assets, planners may need to access more localized and quantitative data on sea level change (SLC) and storm surge projections.

- How many models were used in the *model ensemble* to develop the projections? In general, a larger number of models will increase the confidence in the results produced.

- What type of ***emissions scenarios*** were used to develop the climate projections – the **Special Report on Emissions Scenarios (SRES)** or **Representative Concentration Pathways** (RCPs)? Emission scenarios are based on assumptions about future worldwide changes in demographic development, socio-economic development, and technological change that result in different greenhouse gas concentrations in the atmosphere. SRES was developed in 2000 in support of the 3rd and 4th Intergovernmental Panel on Climate Change (IPCC) Assessment Reports and SRES scenarios are labeled in families called A1, A2, B1, and B2. RCPs were developed in 2010 for use in the IPCC 5th Assessment Report and are representative of four GHG concentration pathways, rather than GHG emissions scenarios. RCP scenarios are numeric, RCP 8.5, RCP 6.0 RCP 4.5 and RCP 2.6. In addition, take note of which specific emission scenarios were used (e.g., SRES B1, RCP 8.5, etc.)? You should have an understanding of the assumptions behind the emission scenarios so that you can determine what type of outlook it represents (e.g., a more conservative or more optimistic outlook) and how that might affect your scenario selection.

- What is the spatial *resolution* of the climate projection? Climate model input may cover a very large area (e.g., a single sea level value for the entire American East Coast) or it could be more granular (e.g., sea level value for Miami). Modelers refer to "grid size," such as 50 kilometers (km) x 50 km, when describing the granularity of data. The larger the grid size, the more "generic" the modeling results. Will a global projection suffice for your assessment or do you need down-scaled regional, or even local, information?

- Take note of the reported values for projections. Model results are often distributed across a range of values. In some cases, a median value is reported. In some cases, low values, middle values, and high values are provided. For example, if 60 different model runs are made using different assumptions in the model runs, 60 results may be generated. If these 60 results are arranged from low to high, the lowest 10% and the highest 90% may be reported as the "low" and "high" ranges respectively, with the rest of the results between those two values as the "middle" range. If you want a very conservative estimate (or a plausible worst-case figure), you may choose to use the "high" estimate.

- Be aware of differences in *confidence* for different types of projections; for example researchers are confident about evidence for, and projections of, changes in the number of heatwaves in the future, but much less confident about projected changes in the occurrence of typhoons. Our understanding of the climate science behind different components of the climate system is not necessarily equal.

Use of Climate Change Scenarios in Adaptation Planning

The text above referenced the use of emissions scenarios to develop projections about future climate conditions. These climate projections are accompanied by a probabilistic measure of the condition happening. For example, the IPCC projected in its Fifth Assessment report that global sea level rise would "likely" rise between 0.45 and 0.82 meters in the 2081–2100 timeframe, using the 8.5 RCP. The term "likely" means there is a 66–100% probability that sea level rise will be within the reported range. A "very likely" projection has a 90–100% probability. Probabilistic measures such as this have a measure of uncertainty.

DoD, and other organizations, are recommending a shift from use of probabilistic projections to non-probabilistic scenarios as a way of managing the uncertainty associated with projections. In this use, climate "scenarios" are plausible and scientifically credible future conditions that reflect possible changes due to climate change. According to the DoD definition from DoD Directive 4715.21 - Climate

Change Adaptation and Resilience, a scenario "details future potential conditions in a manner that supports decision-making under conditions of uncertainty, but does not predict future change that has an associated likelihood of occurrence." This approach allows a planner to pose plausible "what-if" scenarios and plan accordingly. For example, a planner may choose to look at options for two different possible outcomes: "What if sea level rises between 1 and 2 meters by 2100? What should our strategies look like?" and "What if sea level rises between 2 and 3 meters by 2100? What should our strategies look like?" While the two scenarios have their basis in probabilistic climate projections that are based on specific emissions scenarios with assumptions about future GHG levels, the climate scenarios themselves allow for conducting planning activities that *manage* uncertainty. In other words, by considering a range of plausible futures, rather than planning to a specific projection with an associated probability of occurrence, planners do not hinge their plans on a specific projected condition actually occurring in the future For more reading about this risk-based planning approach, see Hallegatte et al. 2012, Hinkel et al. 2015, and Davis 2012.

In addition to those references, "Regional Sea Level Scenarios for Coastal Risk Management" (Hall et al. 2016) provides background on the selection of scenarios in accordance with a user's specific situation. In particular, the following sections of the document referenced above may be helpful in selecting scenarios to use in assessing hazards to infrastructure of concern:

- Section 2.5 Decision Framing: A Brief Description (1 page)
- Section 3.3 Global Scenarios (8 pages)
- Section 5.3 Scenario Application and Decision-Making under Uncertainty (17 pages, especially 5.3.3)

In general, the selection of scenarios appropriate for your situation depends on the time horizon of interest, the expected lifespan of the infrastructure of concern, the value of the infrastructure, and its mission criticality. These factors inform your "tolerance for risk." For example, the tolerance for risk for a very valuable, and perhaps unique, asset that is critical to your installation's function will be low; you will want to protect that asset against possible climate impacts. You will therefore choose higher scenarios to reflect higher sea level rise, more temperature rise, and higher extreme water levels than lower scenarios. On the other hand, you may be less interested in investing adaptation resources on a low-lying sports field that can accommodate occasional flooding. In this instance, you have a high tolerance of risk for the sports field compared to more valuable assets.

Section 2 – Online Resources

This section provides online resources that may be helpful in enhancing knowledge about climate science, models, and climate data. This section is not intended to be exhaustive.

The following three websites may be a helpful place to start your exploration of online resources.

https://toolkit.climate.gov/

The National Oceanic and Atmospheric Administration (NOAA) maintains the U.S. Climate Resilience Toolkit, which is specifically aimed at providing resources and tools to support adaptation planning efforts at multiple scales (national, regional, and local). The site provides case studies, resource lists, training courses, and climate data (current and projected). The information includes resources from multiple federal agencies. Two tools in particular provide visualization data for climate projections for locations in the United States. The Explorer tool (Legacy version) includes flooding and inundation impacts from sea level rise (1–6 foot scenarios) and Category 3 hurricanes; the new version 1.5 Explorer tool provides graphs and maps of observed and projected temperature, precipitation, and related climate variables for every county in the United States. A tool in the "Coastal" topic folder allows users to explore inundation impacts of 1–6 foot sea level rise.

https://www.climate.gov/

NOAA also maintains the climate.gov website, which is designed to provide information helpful in promoting public understanding of climate science and climate-related events. The site is organized into three major sections that serve different audiences: News and Features, Maps and Data, and Teaching Climate. The Dataset Gallery, under the Maps and Data tab, may provide usual maps and data charts for current weather and climate conditions. Most resources are at the Global or National level.

http://www.adaptationclearinghouse.org/

The Georgetown Climate Center, with other partners, maintains this clearinghouse on reports and other resources specific to climate adaptation. A Sector tab provides information organized according to sectors, such as Coastal, Ecosystems, Emergency Preparedness, Energy, Land Use, and Transportation. The search function may help to narrow down research for a range of topics relating to adaptation. A customized e-mail alert system can be used to automatically send e-mails relevant to topics specified by the user.

Basics of Climate Change and Climate Science

All of these websites provide introductory material accessible to general audiences. Many sites contain links to more specific information suitable for intermediate audiences.

U.S. Global Change Research Program link to description of how the climate is changing and why. This website includes videos illustrating projected changes in temperature and precipitation by 2100 under two different scenarios (CO_2 concentration) in the United States.	http://www.globalchange.gov/climate-change/whats-happening-why
NASA website on global climate change contains sections on evidence, causes, effects, scientific consensus, vital signs, and Frequently Asked Questions (FAQs).	http://climate.nasa.gov/evidence/
U.S. Forest Service website, with sections on current climate change, climate mechanisms, natural climate cycles, and effects in the United States.	http://www.fs.usda.gov/ccrc/climate-basics/climate-primer
Center for Climate and Energy Solutions website contains basics about climate change and FAQs.	http://www.c2es.org/science-impacts/basics
Skeptical Science. While not a government-funded website, this source provides differing levels of complexity in exploring climate change concepts. Technical discussions are easily searchable; the format is geared for laymen audience, with cartoon images and videos to explain concepts.	http://www.skepticalscience.com/ http://www.skepticalscience.com/rcp.php?t=3#emissionsconcentrations; this is an example from the website, a Beginner's Guide to Representative Concentration Pathways, arranged in three parts.

United Nations Climate Change Learning Partnership website, with links to e-courses of varying levels on climate change topics. The site also has links for advanced learning topics.	http://www.uncclearn.org/learning-resources

Impacts of Climate Change

U.S. Army Corps of Engineers website contains links to many climate impacts references, including the U.S. Global Climate Research Program's Third National Climate Assessment Report and the Intergovernmental Panel on Climate Change.	http://www.corpsclimate.us/impacts.cfm
Home page for the **U.S. Global Change Research Program**, which is responsible for preparing the National Climate Assessment and regular updates. This site provides links to resources, data, and multimedia. Much of the Third National Climate Assessment is about the impacts of climate change.	http://www.globalchange.gov/climate-change
MetEd is a free collection of hundreds of training resources intended for the geoscience community. This URL is for a half-hour online training course on climate change impacts in different regions of the United States. Also discusses the use of modeling to project changes in the future.	https://www.meted.ucar.edu/training_module.php?id=972#.VzDN_eleT18

Climate Modeling

NOAA's Modeling, Analysis, Predictions, and Projections (MAPP) program's mission is to better understand and predict natural variability and changes in the earth's climate system. This site lists NOAA research projects on climate modeling.	http://cpo.noaa.gov/ClimatePrograms/ModelingAnalysisPredictionsandProjections.aspx
Gavin Schmidt, climate scientist at NASA's Goddard Institute for Space Studies, provides a 12-minute TED talk on the scale and complexity of climate models and how disruptions affect climate patterns.	https://www.ted.com/talks/gavin_schmidt_the_emergent_patterns_of_climate_change?language=en
The National Academies of Sciences website contains brief introductions to different aspects of weather and climate modeling, including constructing a climate model, validating models, and using climate models.	http://nas-sites.org/climate-change/climatemodeling/index.php

About Climate Data

NOAA collects and maintains a large amount of data about weather and climate. This portion of the website includes sections on measuring, predicting, visualizing, and using climate data.	https://www.climate.gov/maps-data/primer/climate-data-primer
The **U.S. Forest Service** compiled a 41-page document that includes FAQs about the use of climate data for management decisions, research applications, and other information about climate models.	http://www.fs.fed.us/rm/pubs/rmrs_gtr277.pdf Note: this URL opens a PDF document
NOAA maintains a drought portal that includes tabs for Data, Maps, and Tools; Regions; Research; and Resources. The Regions tab is organized according to eight U.S. regions and individual states. The regional Quarterly Outlooks provide summary information on precipitation and drought, fires, and other relevant information, such as the hurricane season for east coast states.	https://www.drought.gov/drought/resources/reports

Information Sources for Climate Data

Governmental organizations worldwide have made substantial investments in research aimed at better understanding 1) climate science and 2) the impacts of climate change. Starting in 1990, the IPCC has periodically published a series of climate studies to review the current state of scientific knowledge relevant to climate change. The most recent series, the Fifth Assessment Report (AR5), was issued in 2013 and 2014 and includes three reports from working groups and a synthesis report (IPCC 2013, 2014).

In the United States, the U.S. Global Change Research Program released its Third National Climate Assessment (NCA) report in 2014 (Melillo et al. 2014). The NCA report provided results according to eight U.S. geographic regions—the Northwest, Southeast and Caribbean, Midwest, Great Plains, Southwest, Northwest, Alaska, and Hawaii and U.S. Affiliated Pacific Islands. At this coarse scale, planners may gain a better understanding of current and anticipated impacts for their region, but not necessarily for their specific installation. Stage I of the Handbook takes the planner through a series of questions to define data quality and resolution needs with regard to current and future climate information.

Several resources on climate data for international locations are available. Please note that the assumptions and technical foundations for international data may not be the same as those for U.S.-only data.

Table C.1 provides some example sources for national and international climate data.

Table C.1 Examples of Sources for Climate Data

Description: climate factors included, qualitative / quantitative, coverage, basis (SRES, RCPs, Planning Scenarios)	**Notes:** limitations of application, public access or Common Access Card (CAC)-enabled
Intergovernmental Panel on Climate Change; link to access Fifth Assessment Report and link to Data Distribution Centre http://www.ipcc.ch/index.htm; http://www.ipcc-data.org/	
The authoritative international study for climate change. All climate factors included; 4 RCPs (2.6, 4.5, 6.0, 8.5). Provides climate estimates from observations, global climate model data, socio-economic data and scenarios, data and scenarios for other environmental changes, and links to other reviewed datasets.	Multiple reports accessible to public. Tabs on the Data Distribution Centre describe guidance on the use of data and how to discover, view, and download data.
National Climate Assessment; link to Third National Climate Assessment reports and resources http://nca2014.globalchange.gov/; http://www.globalchange.gov/browse/datasets http://www.globalchange.gov/browse/federal-adaptation-resources/regional-climate-information-modeling	
All climate factors included; 3 RCPs (2.6, 6.0, 8.5); 4 scenarios for SLR (0.2, 0.5, 1.2, 2.0 meter rise by 2100). Most useful for assessing regional impacts for 10 regions in the United States.	Available to public. Common reference used in the United States, resolution may limit site-specific decisions.
DoD Regional Sea Level Change and Extreme Water Level Scenarios Database (FOUO) https://sealevelscenarios.serdp-estcp.org Accompanying report – Regional Sea Level Scenarios for Coastal Risk Management – is posted on: DENIX Sustainability site: http://www.denix.osd.mil/sustainability/ SERDP-ESTCP page: https://www.serdp-estcp.org/Program-Areas/Resource-Conservation-and-Climate-Change/Climate-Change	
Site-specific SLC and Extreme Water Level scenario values for about 1,800 military sites worldwide. Based on 5 scenarios for SLR (0.2, 0.5, 1.0, 1.5, 2.0 meter rise) by 2100. Provides annual percent chance event information (e.g., 1% or 100-year storm elevation on top of SLC elevation.)	CAC-enabled only, coastal and tidally influenced locations only. • Secure log-in requires that a CAC certificate is already installed on the user's machine • Users also need to request an account by clicking on "Contact Us" when first visiting the site • Once granted an account, click on the "Secure Log In" button. From there, users can access the database and the instructions via the User Manual
U.S. Army Corps of Engineers (USACE) Sea Level Change Calculator http://www.corpsclimate.us/ccaceslcurves.cfm	
Produces table and graph of projected SLC based on tide gauge selected by user. Also allows user to estimate Extreme Water Levels using NOAA tide gauge data. Users calculate Low, Medium, High scenarios for planning purposes.	Available to public. Intended to support screening level vulnerability assessments; results alone do not support engineering designs where consequences are high.

Table C.1 Examples of Sources for Climate Data

Description: climate factors included, qualitative / quantitative, coverage, basis (SRES, RCPs, Planning Scenarios)	**Notes:** limitations of application, public access or Common Access Card (CAC)-enabled
NOAA Climate Data Online http://www.ncdc.noaa.gov/cdo-web/	
URL reflects former name - NOAA National Climatic Data Center (now called National Center for Environmental Information). Includes links to datasets, a search tool, mapping tool, and other specialized data tool. (The link below can be used to review model output data, such as the CMIP 5 data used to support the IPCC Fifth Assessment Report. These data are useful primarily for climate researchers. http://www.ncdc.noaa.gov/data-access/model-data/model-datasets)	Available to the public.
NOAA National Center for Environmental Information https://www.ncei.noaa.gov/	
Another pathway to NOAA home page for current and archived global weather and climate data; contains atmospheric, coastal, oceanic, and geophysical data, such as bathymetry and paleoclimatology data.	Available to the public. Information is organized to facilitate searches for specific climate datasets.
Climate Central's Surging Seas Risk Finder http://riskfinder.climatecentral.org/about	
Interactive toolkit with mapping capabilities and local sea level and flood risk projections for U.S. and international coastal cities.	Available to public. Background research supporting the toolkit is published in a Proceedings of the National Academies of Science paper. The user is able to select information by country, state, or zip code. The user selects SLR scenario to describe/map potential extent of flooding. These maps may be used to gain a rough understanding of possible flooding impacts, but are not intended to be used for detailed planning or design processes.
United Kingdom Met Office Website http://www.metoffice.gov.uk/climate-guide/science/uk/obs-projections-impacts	
Compilation of reports for more than 20 countries, providing information on the physical impacts of climate change. Each report contains description of national weather and climate, analysis of extreme events, data on changes in temperature extremes, projections from IPCC's Fourth Assessment Report, and impact information from the United Kingdom's Avoiding Dangerous Climate Change programme.	Available to the public. These are static reports, not an interactive website. Reports provide helpful summaries on other related impacts, such as crop yields, food security, water stress and drought, etc.

Description: climate factors included, qualitative / quantitative, coverage, basis (SRES, RCPs, Planning Scenarios)	**Notes:** limitations of application, public access or CAC-enabled
Bureau of Reclamation Website and Other Organizations http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html	
Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections.	This site is best viewed with Chrome (recommended) or Firefox. Some features are unavailable when using Internet Explorer. Requires JavaScript to be enabled.
LOCA Statistical Downscaling (Localized Constructed Analogs) http://loca.ucsd.edu/	
Data from statistically downscaling 32 global climate models from the CMIP5 archive at a 1/16th degree spatial resolution, covering North America from central Mexico through Southern Canada. The historical period is 1950-2005. Two future scenarios are available: RCP 4.5 and RCP 8.5 over the period 2006–2100.	Data are publically available through several links provided on the LOCA home page. This dataset was released in 2015 and is the next generation of downscaled CMIP5 data.
NOAA Sea Level Rise and Coastal Flooding Impacts Viewer https://coast.noaa.gov/digitalcoast/tools/slr	
Viewer tool, data, and map services are available for almost all U.S. coastal states and territories. Tool enables user to specify inundation scenarios from 0 to 6 feet above current Mean Higher High Water, and view mapped inundation results.	Maps not currently available for Alaska.
NOAA U.S. Climate Resilience Toolkit https://toolkit.climate.gov/climate-explorer (Legacy version) https://toolkit.climate.gov/climate-explorer2/	
Visualization tool to depict historic climate and weather data; allows investigation of impacts of 1 foot, 2 feet, and 3 feet SLR. Base maps are from the ESRI Web services. Data are from http://climate.data.gov. Climate Explorer updated in 2016 provides observed and projected data for temperature, precipitation, and related climate phenomena, including days over 95 degrees Fahrenheit (°F), days of heavy precipitation, and Heating and Cooling Degree Days. Uses RCP 4.5 and 8.5.	Available to public. Data by county for contiguous United States only.
USAID Climate Links Website https://www.climatelinks.org/	
Provides links to Resources and Tools, which may contain reports or tools with climate data for international locations.	Not a source of climate data for specific international locations, but may provide relevant information, especially relating to agriculture and forest impacts.

Section 3 – Sample Output

This section provides sample outputs for the notional installation adapted from the DoD Regional Sea Level Change and Extreme Water Level Scenarios FOUO Database and a discussion on how to align climate projection values to your site reference datum.

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Reference Datum NAVD88
Mean Sea Level is 0.092 feet below NAVD88
Mean Higher High Water is 0.623 feet above NAVD88

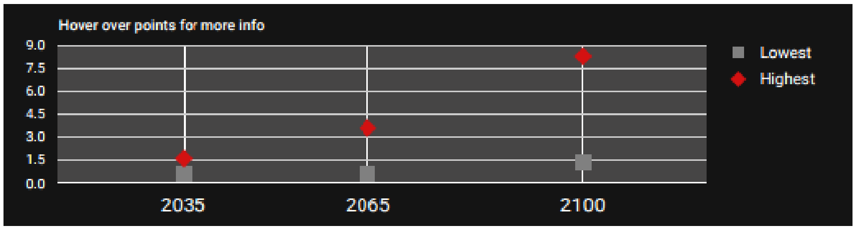
Regionalized Sea Level Change Scenarios

Scenarios are non-probabilistic but plausible depictions of future conditions that can enable decision-makers to bound their risk based on the best available science. The scenarios provided as part of this tool take into account physical processes, local setting, and data availability to provide a basis for the values provided.

Adjustments relative to global mean sea level (reference to 1992, the 1983-2001 **tidal epoch**)

User choices include selection of the appropriate time horizon, global sea level scenarios, and unit (meters or feet).

Global Scenario	2035	2065	2100
Lowest	0.6	0.6	1.4
Highest	1.6	3.6	8.3
Base Unit > Feet			



2035 Scenarios

Global Scenario	Global SLR	Site-Specific Adjustments			Total Site-Specific Adjustments	Global SLR + Site-Specific Adjustments
		Vertical Land Movement	Ocean Circulation	Ice Melt Effects		
Lowest (0.7)	0.3	0.3	0	0	0.3	0.6
Low (1.6)	0.3	0.3	0	0	0.3	0.6
Medium (3.3)	0.7	0.3	0.3	0	0.6	1.3
High (4.9)	0.7	0.3	0.3	0	0.6	1.3
Highest (6.6)	1.0	0.3	0.3	0	0.6	1.6
Base Unit > Feet						

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2065 Scenarios

Global Scenario	Global SLR	Site-Specific Adjustments			Total Site-Specific Adjustments	Global SLR + Site-Specific Adjustments
		Vertical Land Movement	Ocean Circulation	Ice Melt Effects		
Lowest (0.7)	0.3	0.3	0	0	0.3	0.6
Low (1.6)	0.7	0.3	0.3	0	0.6	1.3
Medium (3.3)	1.3	0.3	0.3	0	0.6	1.9
High (4.9)	2.0	0.3	0.3	0	0.6	2.6
Highest (6.6)	2.6	0.3	0.7	0	1.0	3.6
Base Unit > Feet						

2100 Scenarios

Global Scenario	Global SLR	Site-Specific Adjustments			Total Site-Specific Adjustments	Global SLR + Site-Specific Adjustments
		Vertical Land Movement	Ocean Circulation	Ice Melt Effects		
Lowest (0.7)	0.7	0.7	0	0	0.7	1.4
Low (1.6)	1.6	0.7	0.3	-0.3	0.7	2.3
Medium (3.3)	3.3	0.7	0.7	-0.3	1.1	4.4
High (4.9)	4.9	0.7	0.7	-0.3	1.1	6.0
Highest (6.6)	6.6	0.7	1.0	0	1.7	8.3
Base Unit > Feet						

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Regionalized Extreme Water Level Statistics

Values in the table(s) below are heights above mean higher high water

Extreme Water Levels include the effects of the astronomical tide and storm surge. Given that both of these are time varying, their combined effect can be expressed in terms of annual exceedance probability. The probabilities chosen here reflect different return periods for combined storm and tide elevations of different magnitudes of interest to planners and managers. Tide gauge information is a common method to estimate extreme water level statistics. The proximity of gauges to a site, and their length of records, dictate the category to which a site belongs and the type of analyses that may be conducted - single gauge or multiple gauge. Values in the table(s) below are heights above mean higher high water. Note: these water levels do not include the effects of waves.

The site belongs to Category 1 – Site has a local tide gauge within 50 km and with at least 30 years of record.

Multiple Gauges - Regional Frequency Analysis

A Regional Frequency Analysis (RFA) is a statistical method that provides estimates for extreme event probabilities with the assumption that coastal environments with similar attributes will experience a similar flood frequency. To conduct an RFA, three to five tide gauges of sufficient length of record and proximity to the site of interest are needed. An RFA assists in placing tide gauges with short records into a regional context, enlarging the sampling for rare events both in space and time, and transferring Extreme Water Level information to un-gauged sites. Note: the RFA analysis includes data from the single gauge below.

20% Annual Chance Event ["5 Year Event"]	5% Annual Chance Event ["20 Year Event"]	2% Annual Chance Event ["50 Year Event']	1% Annual Chance Event ['100 Year Event"]
2.6	3.0	3.3	3.6
Base Unit > Feet			

Single Gauge

In contrast to the RFA analysis in which multiple tide gauges are used, a single gauge analysis is possible when a representative tide gauge of sufficient proximity (within 50 km) and length of record (at least 30 years) can be used. Depending on the situation, a single gauge analysis vs a multiple gauge analysis will sometimes give similar or different results especially with respect to rare events and their statistics. Differences could exist between a single and multiple gauge analysis, most likely in the rarer events (1% and 2% annual chance events) and their statistics. The choice of analysis depends on the user's emphasis on the type of information needed and risk tolerance.

20% Annual Chance Event ["5 Year Event"]	5% Annual Chance Event ["20 Year Event"]	2% Annual Chance Event ["50 Year Event']	1% Annual Chance Event ['100 Year Event"]
2.6	3.0	3.3	3.3
Base Unit > Feet			

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Combined Sea Level Change & Extreme Water Level Scenarios

Scenarios are non-probabilistic but plausible depictions of future conditions that can enable decision-makers to bound their risk based on the best available science. The scenarios provided as part of this tool take into account physical processes, local setting, and data availability to provide a basis for the values provided.

Adjustments relative to global mean sea level (reference to 1992, the 1983-2001 tidal epoch)

Combined Scenario Value =
Global Mean Sea Level Scenario (t) + Total of Local Adjustments (t) + Mean Higher High Water Offset + Extreme Water Levels (ace)

where (t) is time and (ace) is % annual chance event

1% Annual Chance Event
["100 Year Event"]

% chance in any given year that there will be an extreme water level event of at least this magnitude

Values in the tables below represent elevations above the reference datum for the combination of sea level change scenario and the selected annual chance event.

Based on Multiple Gauge Analysis

Global Scenario	2035	2065	2100
0.7 - Lowest	4.8	4.8	5.6
1.6 - Low	4.8	5.5	6.5
3.3 - Medium	5.5	6.1	8.6
4.9 - High	5.5	6.8	10.2
6.6 - Highest	5.8	7.8	12.5
Base Unit > Feet			

Based on Single Gauge Analysis

Global Scenario	2035	2065	2100
0.7 - Lowest	4.5	4.5	5.3
1.6 - Low	4.5	5.2	6.2
3.3 - Medium	5.2	5.8	8.3
4.9 - High	5.2	6.5	9.9
6.6 - Highest	5.5	7.5	12.2
Base Unit > Feet			

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How to align climate projection values to your site reference datum

Proper application of sea level change and extreme water level projections for risk management requires anchoring these inundation heights to a common vertical datum. To map inundation from projected changes in sea level and storm surge, this common vertical datum must also match that used to anchor the site's available geospatial data (e.g., geographic information system). Depending upon the information sources used for each elevation value, this may require an alignment of disparate datums through a conversion process.

Converting from one datum to another requires the addition or subtraction of a datum "offset." A datum offset represents the magnitude of the difference in vertical height (in meters or feet) between two datums. When values in a source dataset are anchored to a datum below the target datum (the chosen common vertical datum), the offset must be subtracted from the source values to anchor them to the target datum; conversely, when a source dataset is anchored to a datum above the target datum, the offset must be added. The example below helps illustrate this process for a specific site.

Notional Installation Example:

Notional Installation
Reference Datum NAVD88
Mean Sea Level is 0.092 feet below NAVD88
Mean Higher High Water is 0.623 feet above NAVD88

The notional installation choses to anchor all their geospatial data to NAVD88, so this is the site's target datum. Projections of sea level change (SLC) and extreme water level (EWL), however, are available anchored to two differing datums.

In this case the DoD Scenarios Database anchors **SLC projections** to the mean sea level (MSL) datum and provides the MSL offset for the notional installation as 0.092 feet *below* NAVD88. Since MSL in this case is *below* NAVD88, one must *subtract* 0.092 feet (the NAVD88-MSL offset) from the SLC projections to anchor them to NAVD88. Thus 8.3 feet from the database converts to 8.2 feet (8.3 – 0.092). See **Figure C.2**.

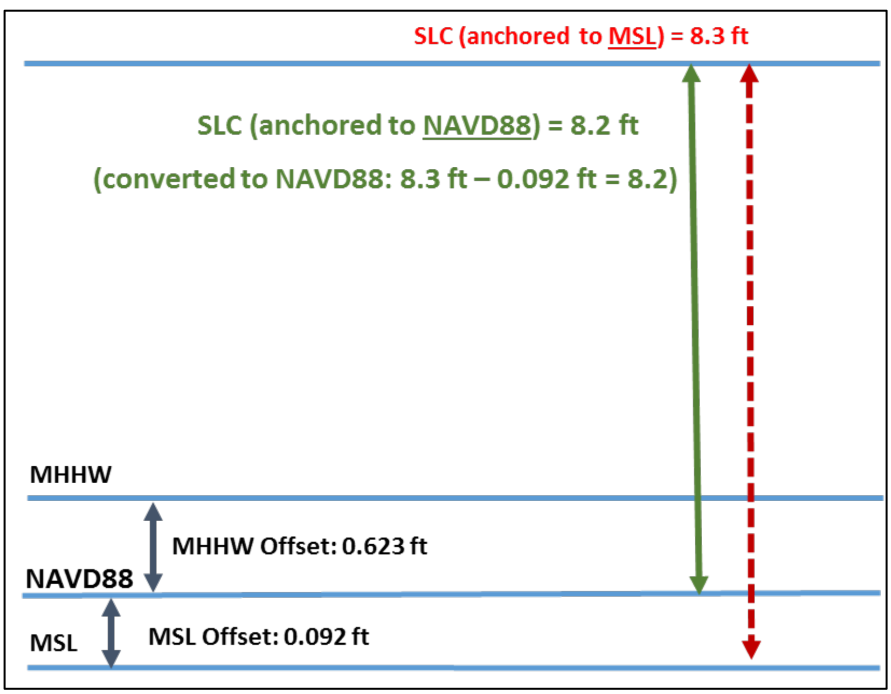


Figure C.2 Converting Sea Level Change anchored to MSL to Sea Level Change anchored to NAVD88

Conversely, **EWL projections** from the DoD Scenarios Database anchor to the Mean Higher High Water (MHHW) datum and provides the MHHW offset for the notional installation as 0.623 feet *above* NAVD88. Since MHHW in this case is *above* NAVD88, one must then *add* 0.623 feet to the EWL projections to anchor the additional vertical inundation height to NAVD88. For the notional installation, the Single Gauge 1% Annual Chance Event is 3.3 feet. When the MHHW offset of 0.623 feet is added, the value is 3.9 feet. See **Figure C.3**.

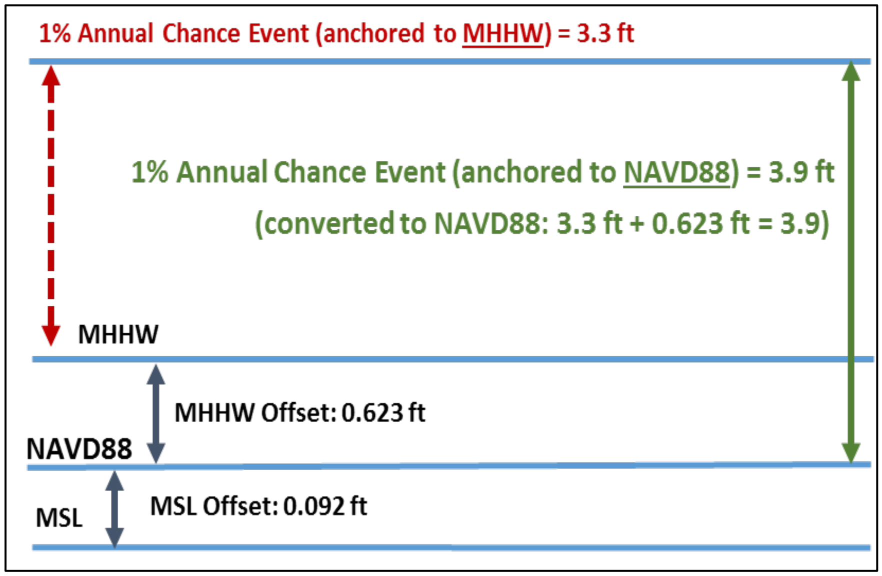


Figure C.3 Converting 1% Annual Chance Event anchored to MHHW to 1% Annual Chance Event anchored to NAVD88

The DoD Scenarios Database also anchors the **combined SLC and EWL scenarios** to mean sea level, so the same type of calculation is required as in **Figure C.2**. For the notional installation, the combined SLC and EWL scenario value for the 2100 highest scenario is 12.2 feet. Since MSL is *below* NAVD88, one must *subtract* 0.092 feet (the NAVD88-MSL offset) from the SLC projections to anchor them to NAVD88. Thus 12.2 feet from the database converts to 12.1 feet (12.2 – 0.092). See **Figure C.4**.

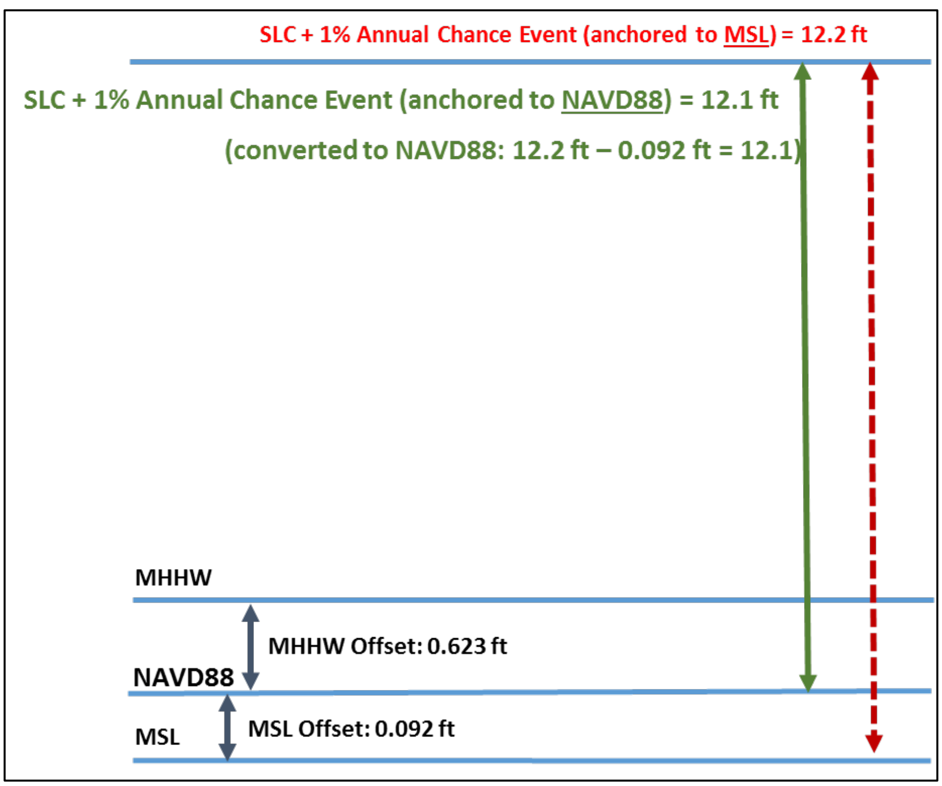


Figure C.4 Converting Combined Scenarios anchored to MSL to Combined Scenarios anchored to NAVD88

Appendix D – Adaptation Action Alternatives Fact Sheets

This appendix contains Fact Sheets that address four broad categories of adaptation approaches:

***Structural** – employs a built structure to alter the flow of floodwater to protect a large area from damage (e.g., levee, storm surge barrier).*

***Natural and Nature-based** – employs natural features to enhance resiliency (e.g., dunes, beaches, salt marshes, oyster and coral reefs, barrier islands, forests, shade trees).*

***Facilities** – employs construction techniques to reduce flood damage to a specific asset (e.g., flood-proofing, building to a more resilient standard, small-scale structures such as a berm).*

***Non-facilities** – employs non-construction techniques such as infrastructure siting, management, or maintenance to reduce flood damage (e.g., land use modifications, real estate actions, community coordination, operational changes, modified maintenance routines).*

Structural Adaptation Approaches

1. Levees
2. Storm Surge Barrier Gates
3. Seawalls
4. Revetments
5. Off-shore Breakwaters
6. Modification of Existing Structures

Natural and Nature-based Adaptation Approaches

7. Preserve and Restore Natural Coastal Defenses
8. Beach Nourishment
9. Barrier Island Restoration
10. Vegetated Dunes
11. Living Shorelines (Edging and Sills)
12. Living Breakwaters (Oyster and Coral Reefs)

Facilities Adaptation Approaches

13. Flood Proofing
14. Materials Replacement
15. Relocation of Vulnerable Components
16. Protection with Small Scale Structures

Non-facilities Adaptation Approaches

17. Land Use Modifications
18. Real Estate Actions
19. Community Coordination
20. Operational Changes
21. Modified Maintenance Routines

Structural Adaptation Approaches

1. Levees

Levees and dikes are embankments constructed along a waterfront to prevent flooding in relatively large areas for high levels of flood risk. If a levee or dike is located in an erosive shoreline environment, revetments may be needed on the waterfront side for more protection from erosion. Levees usually have the following characteristics. They:

- are higher than the adjacent water body and its flood plain;
- are typically an earthen berm parallel to a river or coastal shoreline and may have a channel adjacent to it that is formed by excavating earth to form the raised embankment;
- provide flood risk reduction to landward facilities without the need to alter the protected facilities;
- are designed to prevent overtopping during flood events;
- are typically large civil works with significant cost; and
- are scaled to protect large inland areas.

Levees may also require flood gates if there is a navigable waterway requiring access.

Limitations

The design height of the levee is established by standard engineering risk factors, which assume that unusual storms will exceed the design height. As sea level rises, storm events are anticipated to increase in number and the exceedance of the design height is more likely. The appropriate safety margin for a levee cannot be determined with certainty. Overtopping of the levee or breaching of a portion of the levee can release large floods into the protected flood plain and floodwaters may be impounded following an overtopping or breaching event. Levees are less effective at attenuating or dissipating wave energy as they are prone to erosion. Levees require reinforcements such as erosion control planting or structural reinforcements along the water edge.

Levees may be set back from the water body a significant distance to provide a flood plain for lesser flooding events, making their overall footprint extensive. Because of their height and extent, levees separate inland areas from the water body, complicating or preventing access and eliminating visual and ecological connections.

Appropriate Uses

Levees are appropriate as part of a coordinated flood plain management program. Levees are intended primarily to reduce flooding.

Information Resources

- U.S. Army Corps of Engineers. 2013. *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*. CWTS 2013-3. Washington, DC: USACE.
- U.S. Army Corps of Engineers North Atlantic Division. 2015. *North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk*. USACE.

Structural Adaptation Approaches

2. Storm Surge Barrier Gates

Storm surge barrier gates are a specific type of flood gate. Storm surge barriers are movable gates that stay open normally and are closed when storm surge or spring tide is expected to exceed a certain level. Storm surge barrier gates are constructed at a range of scales, including miles-long structures that protect major estuaries and smaller, local gates that moderate the inundation of smaller inlets and estuaries. Storm surge barriers are frequently used with a levee system to prevent surge from traveling up a waterway.

Storm surge barrier gates limit the water level in tidal inlets, estuaries, and river flood plains and thus reduce the height and strength required of protective measures in the upriver flood plain. Upriver flooding from storm and tidal inundation is a significant source of flood damage that is sometimes left unaddressed. Storm surge barriers also reduce salt water intrusion into freshwater ecosystems.

Storm surge barriers can provide collateral water quality and recreational benefits by controlling or eliminating tidal influence, either creating additional flushing of pollutants by opening and closing or by creating reservoirs of fresh water when left closed or installed as permanent closures with features allowing river discharge.

Limitations

Storm surge barriers require extensive engineering and environmental planning as well as the concurrent development of a forecast, monitoring, and operation system to ensure that the barrier can be activated before the storm or tidal surge arrives. More frequent deployment of the barrier with anticipated increases in storm and tidal flooding will require a significant management and operation effort. Significant investment in construction, maintenance, and operation is required.

Storm surge barriers can result in landward flooding when the water level is elevated from river discharge. Changes in inflow and outflow caused by storm surge barriers can alter the ecology of the protected water body by increasing salinity, temperature, sediments, and nutrients.

Appropriate Uses

Storm surge barrier gates are appropriate at narrow tidal inlets where the required length of the defense is limited. Storm surge barriers are appropriate when the cost is justified by the avoidance of increasing upriver defenses. On larger water bodies, storm surge barriers are appropriate as a regional rather than local investment due to the extent of the protected flood plain and the cost.

Information Resources

- U.S. Army Corps of Engineers. 2013. *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*. CWTS 2013-3. Washington, DC: USACE.
- U.S. Army Corps of Engineers North Atlantic Division. 2015. *North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk*. USACE.

Structural Adaptation Approaches

3. Seawalls

Seawalls are typically massive structures whose primary purpose is interception of waves and reduction of wave-induced overtopping and flooding. Note that under this definition seawalls do not include structures with the principal function of reducing flood risk to low-lying coastal areas. In those cases a high, impermeable, armored structure known as a sea dike is typically required to prevent coastal flooding. The purpose of a seawall is to dissipate wave energy to prevent wave damage to structures and erosion. Seawalls are typically large civil works with significant cost.

Limitations

Seawalls are designed to prevent overtopping during storm events. The design height of these structures is established by standard engineering risk factors, which assume that unusual storms will exceed the design height. As sea level rises, storm events are anticipated to increase in number and the exceedance of the design height is more likely. The appropriate safety margin for a levee or seawall cannot be determined with certainty.

Hardened shoreline structures isolate the seaward ecosystem from the upland ecosystem, which limits the capacity of the shoreline to adapt naturally to changing sea levels by migrating inland. If there is no landward ecosystem behind the hardened shoreline structure, this should not be a significant limitation.

Hardened shorelines can increase erosion on the seaward side by deflecting wave energy to the seabed and by cutting off the near shore from the inland sediment source, resulting in deeper water offshore and increased wave height and wave damage.

Appropriate Uses

Seawalls are appropriate in conditions in which a hardened shoreline is required for functional adequacy, such as a wharf. Seawalls are not appropriate as part of a natural or constructed living shoreline system in which the system is intended to adapt to sea level rise by migrating inland.

Information Resources

- U.S. Army Corps of Engineers. 2013. *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*. CWTS 2013-3. Washington, DC: USACE.
- U.S. Army Corps of Engineers North Atlantic Division. 2015. *North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk*. USACE.

Structural Adaptation Approaches

4. Revetments

Revetments are hardened or armored shoreline structures intended to dissipate wave energy and prevent erosion. They are typically sloped structures located on a natural embankment or cliff and are constructed using a wide variety of materials and techniques including wooden planks, rip-rap or rock armoring, interlocking concrete units such as tetrapods, concrete mats, or geotextiles. Revetments are used on both ocean and river shorelines. On low energy river banks natural revetments can be constructed using live willow stakes and woven strips. They are typically placed on the outside banks of river bends where erosive currents are strongest or along navigation channels to stabilize the channel alignment.

Revetments are used frequently with a seawall, berm, roadway, or rail embankment.

Limitations

Hardened shoreline structures isolate the seaward ecosystem from the upland ecosystem, which limits the capacity of the shoreline to adapt naturally to changing sea levels by migrating inland. If there is no landward ecosystem behind the hardened shoreline structure, this should not be a significant limitation.

Hardened shorelines can increase erosion on the seaward side by deflecting wave energy to the seabed and by cutting off the near shore from the inland sediment source, resulting in deeper water offshore and increased wave height and wave damage.

Appropriate Uses

Revetments are appropriate in locations where natural ecosystem function is not a priority.

Information Resources

- U.S. Army Corps of Engineers. 2013. *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*. CWTS 2013-3. Washington, DC: USACE.
- U.S. Army Corps of Engineers North Atlantic Division. 2015. *North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk*. USACE.

Structural Adaptation Approaches

5. Off-shore Breakwaters

Offshore breakwaters are low-crested structures built in nearshore waters parallel to the shore in shallow water depths. They protect shorelines from erosion by reducing wave heights and by promoting even distribution of sediment along the shoreline. Off-shore breakwaters may be submerged or may extend above the water surface.

Limitations

Offshore breakwaters can interrupt sediment migration and alter nearshore ecosystems. While they are effective at managing erosion and deposition along the shore they parallel, the area downdrift of the breakwater may be more susceptible to erosion. Offshore breakwaters can also pose a danger to navigation if they are submerged.

Appropriate Uses

Offshore breakwaters are appropriate where wave energy is magnified by a long fetch such as open ocean or a wide bay.

Information Resources

- U.S. Army Corps of Engineers. 2013. *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*. CWTS 2013-3. Washington, DC: USACE.
- U.S. Army Corps of Engineers North Atlantic Division. 2015. *North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk*. USACE.

Structural Adaptation Approaches

6. Modification of Existing Structures

Modification of existing structures involves observation of the performance of the existing structure and adaptation with predefined solutions as required to meet new design criteria as the uncertainty surrounding those criteria is reduced. This approach can be applied to extend the useful life of a structure without risk of over investment in a replacement structure before design criteria have been established. Predefined solutions range from lower cost measures such as adding sandbags to the top of a seawall to limit overtopping from tidal and storm surge to more durable modifications such as adding a higher concrete parapet. This approach is often referred to as the "observational method." Modification of existing structures using the observational method is a "no regrets" strategy for addressing uncertainty about design parameters that are appropriate for future climate states.

All structures are designed based on a reasonable forecast of the most common conditions that they will face, not the most unfavorable since building to the rare worst case scenario is usually not cost effective. All structures are built with the assumption that rare conditions will exceed their safety margin and acceptance of this risk is based on past observation of the frequency of these exceedance events and the consequences of exceedance. Existing structural defenses are built to design criteria that underestimate the risk posed by sea level rise. Exceedance events are anticipated to increase but at uncertain frequency making appropriate safety margins difficult to establish.

The observational method can be incorporated into the design of new structures where the new structure is designed to meet relatively certain future conditions but to incorporate pre-designed modifications that can be implemented as conditions warrant (such as a bridge that will allow the deck to be raised if and when water levels reach a triggering height).

Limitations

To be effective, modification of existing structures requires a continuous monitoring process that observes relevant metrics and includes defined responses that can be implemented in a timely way.

Appropriate Uses

Modification of existing structures is appropriate for structural defenses that have a large footprint and represent a significant capital investment but where there is a wide range of uncertainty about the design height needed to ensure protection. This approach is most appropriate where it is necessary to retain an existing structure or design a more economical initial structure for cost reasons.

Information Resources

- U.S. Army Corps of Engineers. 2013. *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*. CWTS 2013-3. Washington, DC: USACE.
- U.S. Army Corps of Engineers North Atlantic Division. 2015. *North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk*. USACE.
- American Society of Civil Engineers. 2015. *Adapting Infrastructure and Civil Engineering Practice to a Changing Climate*. Ed. J. Rolf Olsen, Ph.D. Committee on Adaptation to a Changing Climate. www.ascelibrary.org.

Natural and Nature-based Adaptation Approaches

7. Preserve and Restore Natural Coastal Defenses

Natural coastal ecosystems are resilient to storm damage and can naturally adapt to climate change. The type of coastal ecosystem varies greatly by location. The species mix is highly dependent on the depth and duration of the inundation, salinity, and temperature. These habitats are adapted to periodic inundation and can store large influxes of floodwaters. Where healthy ecosystems exist, they should be considered for preservation and restoration. This approach involves setting aside land for limited or no development and may require restoration plantings and earthwork, and acquisition of upland areas to accommodate inland migration in step with sea level rise.

Coastal forests and mangroves are exceptionally effective buffers against inland storm surge impacts as they slow water and reduce waves. Mangrove forests are inundated coastal forests that are adapted to salt water and replace salt marshes as a coastal ecosystem in subtropical and tropical climates. Mangrove forests are anticipated to migrate inland and northward as sea level and temperatures rise, displacing salt marsh and temperate coastal forests.

Coastal wetlands include a wide range of habitat types in periodically inundated temperate shorelines with salt marshes dominating coastal zones and fresh water marshes occurring in upriver estuarine environments. As sea level rises, these communities will migrate into upland areas that are not currently inundated. This process requires that hardened shorelines are removed, allowing a connection between the upland and water environments conducive to natural migration.

Limitations

Fragmented ecosystems do not provide coastal protection as effectively as continuous healthy expanses of undisturbed natural coastal communities. Although remnant communities do provide habitat and scenic value, it is large, continuous natural coastal ecosystems that provide protection to upland areas. Barrier island and dune systems are significantly less effective coastal defenses where there are gaps in the system. Rolling easements (see **18. Real Estate Actions Fact Sheet**) may be required to allow the habitat to evolve naturally by moving inland as sea level rises, requiring extensive inland buffers.

Appropriate Uses

Preservation and restoration of natural areas are appropriate where shore facilities are not impaired by their presence. This approach is most appropriate as part of an ecosystem-based conservation and restoration initiative undertaken on a regional scale or at a local scale in collaboration with local communities.

Information Resources

- Cunniff, S. and A. Schwartz. 2015. *Performance of Natural Infrastructure and Nature-based Measures as Coastal Risk Reduction Features.* Environmental Defense Fund, September 2015.
- U.S. Army Corps of Engineers. 2013. *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*. CWTS 2013-3. Washington, DC: USACE.
- U.S. Army Corps of Engineers. 2015. *Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience*. Final Report. SR-15-1. Vicksburg, Mississippi: Engineer Research and Development Center (ERDC).

Natural and Nature-based Adaptation Approaches

8. Beach Nourishment

Beach nourishment is a method of counteracting beach erosion by replacing sand lost due to storm surge and wave action, natural causes of sediment migration along sandy shorelines. Sand is pumped by dredge, truck, or conveyor belt onto the eroded beach from an outside source. Replenishing lost sand reestablishes a wider beach, which can mitigate impacts on coastal development by reducing and attenuating wave impact and preventing flooding.

Limitations

Beach nourishment is a costly measure ($300-1,000 per linear foot) that must be repeated periodically. Because beach erosion is a natural process, if the sediment migration pattern that causes beach narrowing remains, periodic nourishment will be necessary. A reliable local source of suitable sand is required. Environmental permitting requirements are extensive for this measure because impacts on the ecosystem from which the sand is harvested and on the receiving ecosystem are negative, disrupting existing ecosystems and typically not providing the same habitat value as natural sediment migration would provide. Beach nourishment is minimally effective at preventing flooding due to larger flood events that overtop the beach height and provide no protection from back-bay flooding.

Appropriate Uses

This strategy is most appropriate for low-lying oceanfront areas with existing sources of sand. This technique is a highly effective means of protecting dunes and other coastal defense structures, both natural and structural by providing a buffer that absorbs the brunt of storm action. Provision of a wider beach through nourishment can result in significant flood and erosion protection for coastal development and can provide a source of sand for downdrift stretches of beach.

Information Resources

- Cunniff, S. and A. Schwartz. 2015. *Performance of Natural Infrastructure and Nature-based Measures as Coastal Risk Reduction Features.* Environmental Defense Fund, September 2015.
- U.S. Army Corps of Engineers. 2013. *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*. CWTS 2013-3. Washington, DC: USACE.
- U.S. Army Corps of Engineers North Atlantic Division. 2015. *North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk*. USACE.
- U.S. Army Corps of Engineers. 2015. *Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience*. Final Report. SR-15-1. Vicksburg, Mississippi: Engineer Research and Development Center (ERDC).

Natural and Nature-based Adaptation Approaches

9. Barrier Island Restoration

Barrier islands are naturally occurring island chains, typically composed of sand or sediment deposited as part of a natural sediment migration pattern along a coast. Barrier islands often include a seaward beach and dune system and a landward wetland system that together provide a natural coastal defense system for inland areas. Barrier islands absorb the impact of waves and storm surge, reducing wave height by a significant factor and reducing the extent of coastal flooding by diverting storm surge to low-lying areas and reducing flood volumes reaching inland areas. Barrier islands can reduce tidal water surface elevations.

Restoration of barrier islands involves a variety of techniques depending on the habitat type including depositing dredged sand to increase height and width, installing hard structures to prevent erosion, and installing sand traps to allow natural accretion of sand to build width and to stabilize sand dunes.

Limitations

Barrier island restoration is a costly measure (hundreds of thousands of dollars per acre) that must be maintained periodically using techniques similar to beach nourishment and vegetated dunes. As part of a natural sediment migration pattern along a coast, they are not stable. Erosion and sediment transport to other locations can change and diminish the height and width of the island dramatically during one storm event, requiring restoration to be repeated. Barrier islands are susceptible to breaching, which can result in damaging flooding in areas not otherwise protected. This possibility is greatly reduced where dunes of appropriate height are present.

Appropriate Uses

Barrier island restoration is appropriate in locations that have naturally-occurring barrier islands that are effective coastal defenses and where a source of sand is readily available.

Information Resources

- Cunniff, S. and A. Schwartz. 2015. *Performance of Natural Infrastructure and Nature-based Measures as Coastal Risk Reduction Features.* Environmental Defense Fund, September 2015.
- U.S. Army Corps of Engineers. 2013. *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*. CWTS 2013-3. Washington, DC: USACE.
- U.S. Army Corps of Engineers North Atlantic Division. 2015. *North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk*. USACE.
- U.S. Army Corps of Engineers. 2015. *Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience*. Final Report. SR-15-1. Vicksburg, Mississippi: Engineer Research and Development Center (ERDC).

Natural and Nature-based Adaptation Approaches

10. Vegetated Dunes

Vegetated dunes are part of the natural profile of sandy shorelines and consist of sand deposited by wind action on the landward edge of the beach. They are stabilized by vegetation such as grasses that establish extensive root systems that hold the sand in place. Dunes provide significant coastal protection by acting as a barrier to waves, currents, storm surge and wash over, reducing erosion and flooding. They also reduce wind speed. Dunes are most effective when they are continuous along a shore or barrier island chain. The height of the dune is an important factor in their effectiveness. Dunes absorb wave energy and contribute sand to natural sediment migration along a shore. Well-established and stable dune systems are among the most effective natural storm surge protections. Dunes can be established by depositing sand to create the berm at an appropriate height and planting with appropriate species to stabilize the berm. Dune berms can also be created by installing sand fences or stacking Christmas trees along the beach to catch sand and allow natural accretion of sand.

Limitations

The height and width of natural and engineered dune systems must be maintained at the appropriate elevation. Erosion and storm damage can diminish the height of the dunes and reduce their effectiveness in preventing overtopping and flooding. Maintenance of the dune height is a recurring maintenance requirement if a natural source of accretion is not in place, such as a wide beach and updrift sand sources. Dunes are fragile systems that must be protected from damage including trampling, vehicular traffic, and construction. Artificial dunes can be less effective than naturally developing dunes. Dunes may redirect overwash to adjacent low-lying areas.

Appropriate Uses

Vegetated dunes are appropriate as components of a natural coastal defense system in combination with beach renourishment and barrier island restoration. Wide beaches with natural sources of sand are most suitable for dune development, both natural and artificial.

Information Resources

- Cunniff, S. and A. Schwartz. 2015. *Performance of Natural Infrastructure and Nature-based Measures as Coastal Risk Reduction Features.* Environmental Defense Fund, September 2015.
- U.S. Army Corps of Engineers. 2013. *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*. CWTS 2013-3. Washington, DC: USACE.
- U.S. Army Corps of Engineers North Atlantic Division. 2015. *North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk*. USACE.
- U.S. Army Corps of Engineers. 2015. *Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience*. Final Report. SR-15-1. Vicksburg, Mississippi: Engineer Research and Development Center (ERDC).
- National Oceanic and Atmospheric Administration (NOAA). 2015. NOAA habitat conservation restoration center website: "Living Shoreline Planning and Implementation." http://www.habitat.noaa.gov/restoration/techniques/lsimplementation.html.

Natural and Nature-based Adaptation Approaches

11. Living Shorelines

Living shorelines are man-made systems incorporating natural sediments and plants that are used to stabilize eroding shorelines. Living shorelines can also provide storage for flood waters, mimicking natural coastal wetlands. Typical living shoreline treatments include planting riparian, marsh, and submerged aquatic vegetation and installing sediment (frequently sand fill with organic admixtures) as a growing medium with a sill or ledge to retain the sediment. Sills and ledges can be formed from a wide range of materials including rip-rap, oyster shell bags, coir logs, and coir logs seeded with mollusks (mussels or oysters). The sill acts as a natural off-shore breakwater to dissipate wave energy before it reaches the planted shore.

Limitations

Living shorelines provide little protection against storm surge due to their limited crest height. The shoreline profile that would naturally support the introduced shoreline community may be absent and restoring it may require extensive grading. Bank erosion rate and elevation, wave energy, prevailing wind and wave direction, vegetation, and soil type must be evaluated by a coastal engineer to determine if a living shoreline would be feasible and effective in a location. Living shorelines may not be an adequate defense against high energy waves such as coastal breakers or along water bodies with a long fetch. Maintenance activities include debris removal, replanting vegetation, adding additional sand fill, and ensuring that the organic and structural materials remain in place and continue to stabilize the shoreline.

Appropriate Uses

Living shorelines are an appropriate replacement for breakwaters and eroding natural shorelines since they provide wave attenuation for low energy waves and allow natural coastal defenses to provide some resilience to the shoreline. As sea level rises, shoreline communities will migrate into upland areas that are not currently inundated. This process requires that hardened shorelines are removed, allowing a connection between the upland and water environments conducive to natural migration.

Living shorelines are appropriate in conditions that would support the natural community that is being mimicked and may include riparian banks, marshes, and submerged aquatic vegetation beds.

Information Resources

- Cunniff, S. and A. Schwartz. 2015. *Performance of Natural Infrastructure and Nature-based Measures as Coastal Risk Reduction Features.* Environmental Defense Fund, September 2015.
- U.S. Army Corps of Engineers. 2013. *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*. CWTS 2013-3. Washington, DC: USACE.
- U.S. Army Corps of Engineers. 2015. *Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience*. Final Report. SR-15-1. Vicksburg, Mississippi: Engineer Research and Development Center (ERDC).
- National Oceanic and Atmospheric Administration (NOAA). 2015. NOAA habitat conservation restoration center website: "Living Shoreline Planning and Implementation." http://www.habitat.noaa.gov/restoration/techniques/lsimplementation.html.

Natural and Nature-based Adaptation Approaches

12. Living Breakwaters (Oyster and Coral Reefs)

Oyster and coral reefs are natural coastal ecosystems that provide shoreline protection from wave damage by dissipating the wave energy before it reaches the shore, lowering wave height. Where they naturally occur, they should be considered for preservation and restoration.

Creation of man-made or cultivated reef systems is feasible and is frequently incorporated into living shoreline installations. Reef creation involves establishing a man-made substrate that is suitable for the zoological elements to establish themselves.

Limitations

Establishment of artificial or cultivated oyster and coral reefs is a water quality and habitat restoration practice that has been in use for decades. A reef is a complex biological system and science-based guidance on best practices is still evolving to address issues such as the shape, material, and spacing of the man-made structure needed to promote sustainable growth of the zoological elements of the system.

Appropriate Uses

Preservation and restoration of natural areas is appropriate where shore facilities are not impaired by their presences. This approach is most appropriate where the co-benefits of habitat and water quality protection and restoration are values, such as part of an ecosystem-based conservation and restoration initiative undertaken on a regional scale or at a local scale in collaboration with local communities.

Information Resources

- Cunniff, S. and A. Schwartz. 2015. *Performance of Natural Infrastructure and Nature-based Measures as Coastal Risk Reduction Features.* Environmental Defense Fund, September 2015.
- U.S. Army Corps of Engineers. 2013. *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*. CWTS 2013-3. Washington, DC: USACE.
- U.S. Army Corps of Engineers. 2015. *Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience*. Final Report. SR-15-1. Vicksburg, Mississippi: Engineer Research and Development Center (ERDC).
- National Oceanic and Atmospheric Administration (NOAA). 2015. NOAA habitat conservation restoration center website: "Living Shoreline Planning and Implementation." http://www.habitat.noaa.gov/restoration/techniques/lsimplementation.html.

Facilities Adaptation Approaches

13. Flood Proofing

Flood proofing is a means of resisting flood damage and allowing a structure to return to normalcy after flood waters have receded. Design standards for flood proofing buildings are incorporated into building codes and distinguish treatments for dry flood proofing and wet flood proofing.

Dry flood proofing techniques include permanently locating the functional components such as habitable rooms and their structural members above the base flood elevation (BFE). This may involve elevating the structure above the BFE and for structures that are not elevated, making the building watertight below the BFE. Dry flood proofing requires walls and columns that are completely or partially impermeable to water and that are resistant to hydrostatic, hydrodynamic, and impact loads and buoyancy. Dry flood proofing below the BFE also requires sealing the walls with waterproof membranes, or sealants or a supplementary layer of masonry or concrete, or installation of watertight shields either permanently or temporarily over windows and doors, and the installation of backflow preventers.

Wet flood proofing applies to structures that will allow flood waters to enter and then leave and has structural standards for walls, slabs and other structural components, contents and interior finishes for buildings to ensure that these elements are capable of withstanding inundation and returning to service with minimal repair. Wet flood proofing includes properly anchoring the structure, using flood resistant materials below the BFE, protection of mechanical and utility equipment, and use of openings or breakaway walls. Functions such as storage can be located within the wet flood proofed space, allowing the stored material to be relocated.

Appropriate Uses

Flood proofing is most appropriate as an approach to extending the service life of existing structures that will be exposed to flooding events and applies primarily to buildings. Flood proofing is appropriate as an interim measure if a structure cannot be relocated.

Limitations

Flood proofing is not a suitable strategy for areas that will be permanently inundated or that are subject to persistent nuisance flooding or high velocity flood flow or wave action. Dry flood proofing can be challenging for existing structures and may be infeasible if the BFE is expected to exceed 6 feet. Retrofit of existing buildings with wet flood proofing may result in a significant loss of useful floor area and is not feasible for buildings without a second story. Wet flood proofing and dry flood proofing that relies on temporarily installed flood shields requires an advance warning system to allow relocation of materials from wet spaces and installation of flood shields for expected flood events.

Information Resources

- American Society of Civil Engineers. 2015*. Adapting Infrastructure and Civil Engineering Practice to a Changing Climate*. Ed. J. Rolf Olsen, Ph.D. Committee on Adaptation to a Changing Climate. www.ascelibrary.org.
- U.S. Army Corps of Engineers. 2016. Non-Structural Flood Proofing. National Non-structural Flood Proofing Committee. http://www.usace.army.mil/Missions/Civil-Works/Project-Planning/nfpc/.

Facilities Adaptation Approaches

14. Materials Replacement

Materials replacement is an approach to ensuring that structures in a floodable location are capable of being soaked by flooding and dry out without lasting damage, corrosion, or mold growth.

If resistant materials are not used, concrete structures that experience frequent inundation are more susceptible to corrosion of reinforcements and cracking from salt water exposure; likewise, building finishes in wet flood proofed buildings are not salvageable when inundated.

Remedies for degraded concrete include increases in cover thickness, improved quality of concrete, and coatings and barriers.

Interior finishes such as standard paper-faced drywall, wall-to-wall carpeting, wood and cellulosic materials, sheet materials such as wallpaper and resilient flooring that can trap moisture, and plaster finishes are not flood resistant materials. Poured concrete floors, ceramic tile, brick, and fiberglass-faced drywall are suitable replacements.

Appropriate Uses

This approach is appropriate for all structures and systems including concrete structures, parapets on shore protection facilities, water distribution pipes, culverts, pilings, columns bridge abutments, and building foundations as well as interior finishes.

Limitations

Replacement and repair of materials can significantly increase the life cycle cost of a structure.

Information Resources

- American Society of Civil Engineers. 2015*. Adapting Infrastructure and Civil Engineering Practice to a Changing Climate*. Ed. J. Rolf Olsen, Ph.D. Committee on Adaptation to a Changing Climate. www.ascelibrary.org.
- Stewart, M., X. Wang, and M. Nguyen. 2012. “Climate Change Adaptation for Corrosion Control of Concrete Infrastructure.” Structural Safety 35: 29–39. http://www.sciencedirect.com/science/article/pii/S0167473011000750.

Facilities Adaptation Approaches

15. Relocation of Vulnerable Components

Relocation of vulnerable components is a retrofit approach that can reduce flood and storm damage to existing facilities in a targeted way. Structures capable of withstanding repeated flooding and to resist structural damage under increased storm and flood stress may include systems attached to the structure that are less resilient. Reducing their exposure to flood and storm damage can extend the life of the structure.

Appropriate Uses

This approach is most appropriate for structures that have structural elements above the base flood elevation, including buildings, waterfront facilities and stormwater and sewer systems with outfalls that can be relocated. Mechanical and electrical systems are frequently housed in the ground floor or basement level or below pier decking where they are most vulnerable to impacts. Because these elements are intended to be replaced with relative frequency, compared to structural elements, they are not usually embedded in the structure, making relocation to elevations above the base flood level feasible.

Limitations

Relocating vulnerable components may require other functions to be displaced.

Information Resources

- American Society of Civil Engineers. 2015. *Adapting Infrastructure and Civil Engineering Practice to a Changing Climate*. Ed. J. Rolf Olsen, Ph.D. Committee on Adaptation to a Changing Climate. www.ascelibrary.org.
- Kirshen, P., L. Caputo, R. Vogel, P. Mathisen, A.Rosner, and T. Renaud. 2014. "Adapting Urban Infrastructure to Climate Change: A Drainage Case Study." *Journal of Water Resources Planning and Management.* Volume 141, Issue 4 (April 2015). doi: 10.1061/(ASCE)WR.1943-5452.0000443.
- U.S. Army Corps of Engineers. 2013. *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*. CWTS 2013-3. Washington, DC: USACE.

Facilities Adaptation Approaches

16. Protection with Small-scale Structures

Protection with small-scale structures prevents flood and storm impacts to an individual structure. The area surrounding a structure protected with a small-scale structure will still flood, but the structure itself will be protected from damage. This approach differs from structural approaches such as seawalls and levees in that it is intended only to protect the individual structure, not the flood zone in its entirety. While small-scale protective structures differ in scale, cost, and the number of facilities protected, the techniques are similar to large structural features and include berms and walls. Small-scale protective structures differ from retrofit approaches such as flood proofing in that the protective structure is independent of the structure being protected. Examples include an earthen berm on the seaward side of a runway that deflects floodwaters to low-lying areas away from the runway or a floodwall around a building that attenuates wave impact.

Appropriate Uses

A small-scale structure such as a floodwall is used to prevent flooding and to protect relatively small areas or areas with limited space for large flood protection measures and are most frequently used in urban and industrial areas. Protection with small-scale structures is most appropriate for existing infrastructure that has a life-expectancy that will overlap with climate impacts. Examples include an airfield that has 20 years of useful life that is subject to nuisance flooding anticipated to increase in frequency over the next two decades. Relocating the airfield may be a suitable long-term solution, but realizing the useful life of the facility can be made possible by a small-scale intervention that controls the impact to acceptable levels in the interim.

This approach is appropriate where failure of one element will have a cascading effect on other elements. Examples include mission critical facilities, structures or systems with significantly longer or more complex recovery needs than surrounding or interconnected structures or components, and the “weak link” in any interdependent system such as the electrical system on a pier.

Smaller structures require a less complex permitting and environmental evaluation process, less community coordination, and are easier to justify and fund than structural approaches, and can be evaluated through cost effectiveness analysis to identify whether multiple smaller structures provide more cost-effective protection than a single structure.

Limitations

Most infrastructure is part of an interconnected system, which makes isolating the structure to be protected challenging. Multiple combinations of approaches should be examined during benefit cost analysis to determine which Mission Critical Facilities can be protected with smaller structures.

Information Resources

- American Society of Civil Engineers. 2015. *Adapting Infrastructure and Civil Engineering Practice to a Changing Climate*. Ed. J. Rolf Olsen, Ph.D. Committee on Adaptation to a Changing Climate. www.ascelibrary.org.
- U.S. Army Corps of Engineers. 2013. *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*. CWTS 2013-3. Washington, DC: USACE.

Non-facilities Adaptation Approaches

17. Land Use Modifications

Land use modifications generally relocate development out of flood hazard areas as a means of minimizing flood damage. Land use modifications are implemented through the Installation Development Planning process. The typical Installation Development Plan has a planning horizon of approximately 20 years and includes an extensive analysis process that identifies constraints on future development and redevelopment or reinvestment. Integrating future climate impact scenarios into the constraints analysis process will reveal land areas that may be constrained in the longer term. These constraints can inform siting decisions. Shortened time horizon strategies can be considered for the near-term development of land. Examples include continuing existing land uses only for the duration of the life-expectancy of current infrastructure and identifying future relocation areas that can be implemented over the longer time horizon in which climate impacts will become definitive siting constraints. This strategy can be paired with protective measures that ensure that infrastructure is hardened against potential storm impacts if it is planned to age in place.

Limitations

Land availability, investment in existing infrastructure, and coordination with the Global Shore Infrastructure Plan and Regional Integration Plan limit the flexibility of planners to institute land use changes.

Appropriate Uses

Land use modifications are appropriate for all installation infrastructure systems and can be used as part of a risk transfer or sharing strategy with local community jurisdictions.

Information Resources

- U.S. Army Corps of Engineers. 2013. *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*. CWTS 2013-3. Washington, DC: USACE.
- Naval Facilities Engineering Command. 2013. *Installation Development Plan Consistency Guide, Version 1.0 A Framework*.

Non-facilities Adaptation Approaches

18. Real Estate Actions

Real estate actions secure access to land that is not impacted by climate change for installation activities. Real estate actions are not the same as relocation or consolidation, which is the purview of the Base Relocation and Closure program. Real estate actions addressing climate change impacts are limited to measures that change the footprint of the installation.

Tools to implement this strategy include fee simple acquisition, withdrawal from other federally-owned lands, and acquisition of permanent or rolling easements. Fee simple acquisition, land withdrawal, and permanent easements are similar in purpose: acquisition of new developable land. Rolling easements are a specialized real estate tool used to define a land area in terms of a natural characteristic that changes over time such as mean high water, vegetation line, or upper boundary of tidal wetlands. Rolling easements are usually employed to prohibit hardened shoreline structures and can be used as part of a natural or nature-based approach that requires natural shoreline migration or sediment transport to be effective. Infrastructure landward of the rolling easement is either abandoned or protected by facilities solutions such flood proofing.

Cost is a key consideration in all strategies that include acquisition of new land. Withdrawal of federal lands from other agencies such as the Bureau of Land Management (BLM) or the Federal Highway Administration may be less costly than outright purchase of similar land. Examples include withdrawal of a road right of way outside the projected impact zone from adjacent BLM land to secure access to an installation. The level of development must be considered as well as the appropriateness of the existing infrastructure for Navy purposes, as these will influence cost significantly. Easements are less costly than fee simple purchase and can also be purchased or implemented through zoning under the auspices of a Joint Land Use Program.

Limitations

Cost and the need to undertake extensive compliance activities to ensure the acquisition does not have a negative impact on adjacent communities are important limitations.

Appropriate Uses

Real estate actions are appropriate where suitable land is available, where benefit cost analysis warrants, and where long-term planning can transfer functions to the new land area through a feasible capital improvement strategy and a manageable community relations plan. Other agencies may be better suited to undertake real estate action if Navy property rights are not critical, in which case the real estate action is more appropriate as part of a risk sharing strategy with local communities.

Acquisition of easements is appropriate where an adaptation strategy such as protecting or restoring a natural coastal defense requires additional area. Permanent or rolling easements may be applicable in this circumstance.

Information Resources

- U.S. Army Corps of Engineers. 2013. *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*. CWTS 2013-3. Washington, DC: USACE.

Non-facilities Adaptation Approaches

19. Community Coordination

Climate change impacts installations as well as the communities in which they are located. Where the impact of climate change is a recognized mutual challenge, coordination of efforts with local communities is an option for installations. The host community may have ongoing adaptation planning or projects in progress that would be beneficial to the installation. Coordination or at a minimum knowledge of these efforts is an important part of installation-level planning. Identification of measures that are to be funded by other people's moneys is an important aspect of selecting appropriate adaptation actions for the installation to consider. Transfer or sharing of risk is a viable and cost-effective strategy that is reliant on maintaining adequate situational awareness of local planning and capital investment programs. As an agency providing opportunities for shared or transferred risk mitigation, U.S. Army Corps of Engineers (USACE) project planning with local jurisdictions is of special importance. Existing programs such as the Readiness, Sustainment, and Compatibility program or Joint Land Use Studies may provide opportunities to establish familiarity with measures that would benefit the installation or that would be beneficial to support.

Limitations

Joint Land Use Studies (JLUS) are founded in the identification of land use policies that host communities can adopt to limit adverse impacts on installations and address encroachment challenges through a specific process that is relevant to the local jurisdictions. Actions that are recommended through the JLUS program may not be focused on the climate adaptation requirements of the region depending on what other competing priorities are at play. The JLUS program is funded by the Office of Economic Adjustment and the studies are conducted by regional planning councils and jurisdictions. In this structure, the interests of the installation are subordinated to the interests of the larger community and may not be sufficiently represented. Similarly, the Readiness, Sustainment, and Compatibility program does not have procedures or practices in place to facilitate planning for climate change, although the program's existing strategies for community engagement require the Community Planning Liaison Officer (CPLO) to engage local jurisdictions as a stakeholder and to initiate programs or policy discussions that reflect the needs of the installation. The CPLO may not be a subject matter expert on the issues of climate change adaptation.

Appropriate Uses

Community coordination is appropriate for all installations as a means of maintaining situational awareness at a minimum and as a means of establishing cost-effective and adequately justified joint initiatives.

Information Resources

- Department of Defense, Office of Economic Adjustment. Compatible Use. http://www.oea.gov/how-we-do-it/compatible-use/compatible-use-technical-assistance.
- U.S. Army Corps of Engineers. 2013. *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*. CWTS 2013-3. Washington, DC: USACE.

Non-facilities Adaptation Approaches

20. Operational Changes

Operational changes that provide adaptation benefits vary in scale and complexity. This approach is not generally intended to change the mission-oriented operations of an installation but to modify more routine practices in such a way that the impact of climate change is minimized. In some cases, where benefit cost analysis warrants, a change in operations that increases the agility of a mission function may be appropriate if there is no impact on readiness. Examples include shifting the location of air operations to an alternative runway subject to nuisance flooding if a redundant airfield is available or locating training activities in available locations that are not subject to flooding.

Operational changes to more routine functions include enhanced preparedness routines, identification of alternative access routes or facilities, and temporary protective measures such as sand-bagging or deployment of flood proofing.

Limitations

Operational changes can be disruptive to current practices and require evaluation of the effect of one change on interconnected functions. Examples include relocation of berthing of ships from inundated docks to docks with adequate high-water infrastructure where these are available. Alternative locations for some operations are not always available, are expensive to operate, or are not as well-suited to the function.

Appropriate Uses

Operational changes are appropriate where alternative facilities are available, where there is no impact on readiness, and where benefit cost analysis warrants. Operational changes can be feasible “reduced time horizon” approaches in cases where the long-term integrity of the existing facilities is uncertain and long-term solutions have not been established.

Information Resources

- American Society of Civil Engineers. 2015. *Adapting Infrastructure and Civil Engineering Practice to a Changing Climate*. Ed. J. Rolf Olsen, Ph.D. Committee on Adaptation to a Changing Climate. www.ascelibrary.org.
- U.S. Army Corps of Engineers. 2013. *Coastal Risk Reduction and Resilience: Using the Full Array of Measures*. CWTS 2013-3. Washington, DC: USACE.

Non-facilities Adaptation Approaches

21. Modified Maintenance Routines

Maintenance is an important strategy for countering the degradation of existing structures impacted by climate change. Maintenance protocols vary significantly by sector but adaptation-focused maintenance has similar objectives across sectors. The design loads for structures in all sectors are based on assumptions about frequency and magnitude of hazards. Failure to maintain a structure can reduce its capacity to withstand the assumed loads and increase the likelihood of failure. As design loads are exceeded with greater frequency as a result of climate change, the likelihood of failure is increased. Evaluation of the performance of structures under current conditions provides an indicator of where additional or enhanced maintenance will be of benefit. Examples include determining where nuisance flooding has resulted in corrosion of materials that were specified for rare inundation, where erosion has affected building, road, or utility foundations, and where natural processes have reduced the height or integrity of protective features such as levees, dune systems, and natural coastal defenses.

More vigilant repair of damage can improve the effectiveness of existing infrastructure by ensuring that accelerated deterioration of a structure does not result in failure. In some instances, it is possible to build a "safety margin" into existing structures during the course of maintenance activities. Examples include replenishing dune systems to a higher design height as part of maintenance, replacing corroded stormwater pipes with corrosion-resistant materials that include a safety margin in the size of the pipe, or bringing pavement or road embankments to original design elevations and profiles. Increased cleaning of drains can improve the effectiveness of drainage systems.

Limitations

Existing structures are typically built to standards that have not been revised to reflect the greater design loads anticipated as a result of climate change and maintenance cannot ensure that existing structures are adequate to meet future conditions. Life cycle costs of increased maintenance may exceed replacement structures that meet new design loads.

Appropriate Uses

Modified maintenance routines are appropriate for structures and systems with long life cycles that would be cost-prohibitive to retrofit or replace to new design standards or for which new design standards have not been established. Modification of maintenance routines is a "no regrets" strategy that also permits a "reduced time horizon" approach in cases where life cycle costs favor continuing to invest in a system over replacing it.

Information Resources

- American Society of Civil Engineers. 2015. *Adapting Infrastructure and Civil Engineering Practice to a Changing Climate*. Ed. J. Rolf Olsen, Ph.D. Committee on Adaptation to a Changing Climate. www.ascelibrary.org.
- Furata, H., D. Frangopol, and M. Akiyama, eds. 2015. *Life-cycle of Structural Systems: Design, Assessment, Maintenance and Management*. Hitoshi International Association of Life-Cycle Engineering Netherlands: CRC Press/Balkema.
- U.S. Army Corps of Engineers North Atlantic Division. 2015. *North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk*. USACE. This guide provides information on all types of measures, not just structural.

Appendix E - Economic Analysis Tools and Resources Fact Sheets

This appendix includes five Fact Sheets referenced in Stage III that address the following topics:

1. Life Cycle Cost Analysis
2. Benefits Monetization Tools
3. Application and Use of Depth Damage Functions
4. Costing Tools and Resources
5. Ecosystem Services Benefits and Valuation

1. Life Cycle Cost Analysis

Overview

Life Cycle Cost Analysis (LCCA) is an **economic efficiency** tool that evaluates the full set of costs over an asset's lifespan. Life cycle cost analysis can be applied to evaluate the full array of costs associated with alternative adaptive resiliency investments being considered on an installation. The life cycle costs can include development, planning, engineering/design, ownership, operations, maintenance, renewal, rehabilitation, replacement, decommissioning, and disposal. LCCA can be applied to buildings, facilities, and infrastructure projects (across sectors) and can be applicable to any long-lived asset. The technique is particularly useful for assessing adaptive resiliency investments under uncertainty because it incorporates the timing of investment expenditures over a future horizon and can also include probabilistic considerations. Where some investments can be sequenced within an adaptive management framework, LCCA can compare the efficiency of alternative investments that are staged based on assessing and re-assessing the results of future projections and uncertain outcomes. LCCA is typically used to evaluate alternative designs that have higher initial costs but lower operating (annually recurring) costs over the project life compared to the lowest-initial-cost design. The tool is applied during the preliminary design phase of alternatives analysis before the full set of economic benefits are compared to life cycle costs during the benefit cost analysis (BCA). LCCA is a cost efficiency exercise. BCA is necessary when design alternatives will not yield equal benefits, such as when unlike projects are being compared or when a decision maker is considering whether or not to undertake a project investment.

Techniques

The steps applied in LCCA include:

1. Establish the design alternatives
2. Determine activity timing
3. Estimate costs (agency and user)
4. Compute life cycle costs / Discount to present value
5. Analyze/Compare the results

To see how the LCCA technique is applied, the following hypothetical example is provided that compares the life cycle costs for the design of two bulkheads: one constructed with concrete, and one with wood.[1] The analysis period is over a 25-year horizon. **Diagram 1** represents two alternative cash flow profiles for each

Technology and Life Cycle Costs

Advances in material science influence life cycle costs. For example, researchers at the University of Bath, Cardiff University and the University of Cambridge created a concrete blend, which is full of bacteria hidden in tiny capsules. As water permeates a crack, the bacteria are activated and quickly emerge from their cases and produce limestone, sealing the aperture before it can widen and expand into a pothole. The researchers believe the technique could increase the lifespan of concrete, remove the need for repairs, and reduce maintenance costs by up to 50%*. While using some of these materials in construction may cost more up front, LCCA can demonstrate the long-term cost savings from using such sustainable materials compared to conventional materials.

* DOT, Office of the Assistant Secretary for Research and Technology, Materials Science in Infrastructure. http://www.rita.dot.gov/publications/technology_scan/materials

[1] This hypothetical example is adapted from data contained in the Boyd presentation (See Information Resources).

design. The cash flow diagram is a standard way to depict the inflows and outflows in each projected year for each category of costs.

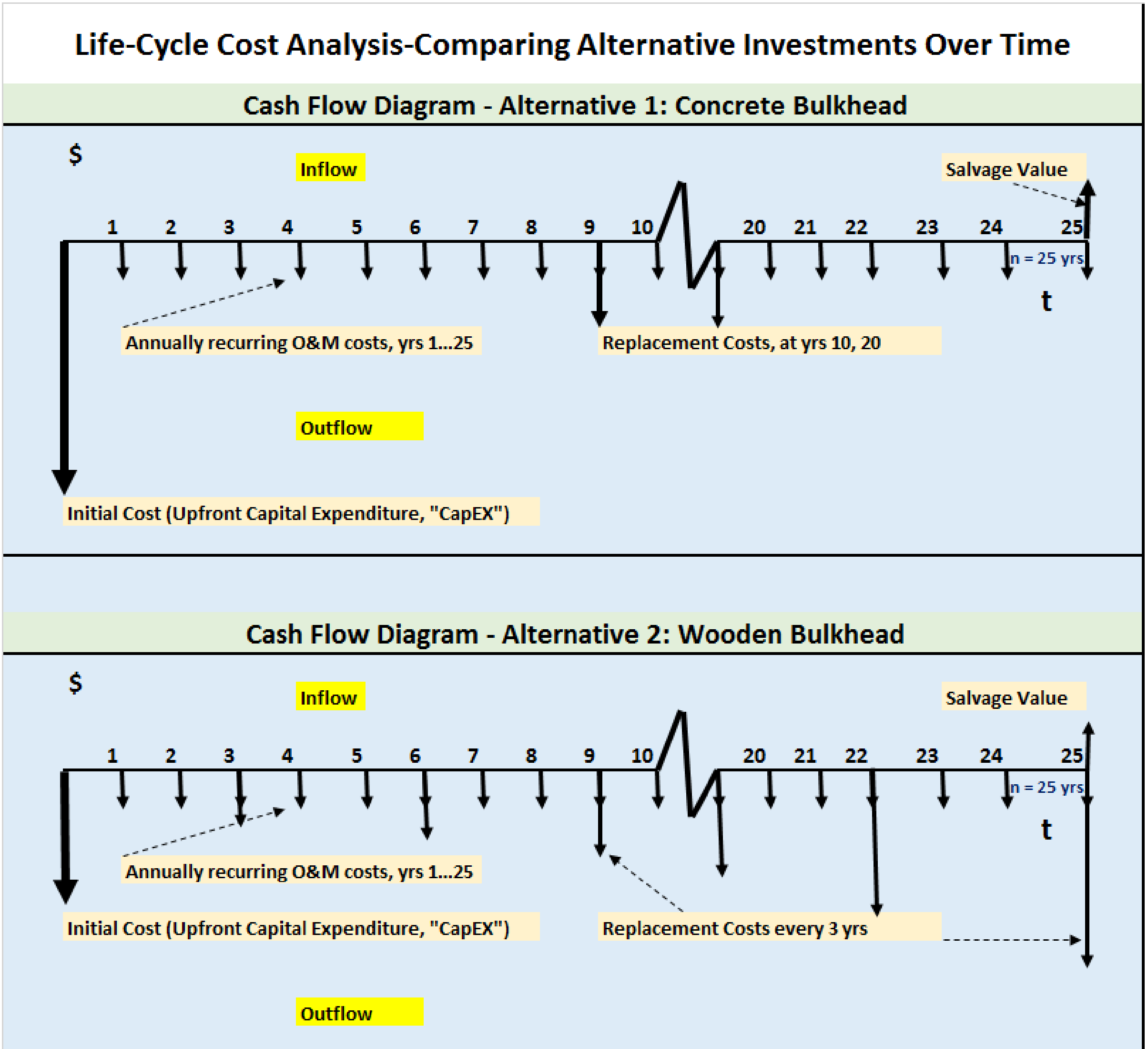


Diagram 1. Alternative Cash Flow Profiles

Diagram 1 shows the conceptual cash flow profiles for the two investment alternatives. The life cycle costs are generally comprised of upfront initial costs or capital costs (CapEX), annually recurring operation and maintenance costs (O&M), periodic replacement and renewal/rehabilitation costs (R), and any other identified cost (Oth) that can enhance resilience over the useful life. Also included is the salvage value (SV) of the depreciated asset (a positive value) that is netted from life cycle costs at the end of the asset's life. The formula for life cycle costs (LCC) is:

$$LCC_{Alt\ X} = \sum_{t=1}^{n=25} \left(\frac{CapEX + O\&M + R + Oth + -SV}{(1+i)^t} \right)$$

The top panel of **Diagram 1** shows that Alternative 1, the concrete bulkhead alternative, would require a much larger upfront initial investment cost (CapEX) compared to Alternative 2 that uses wood materials. Alternative 1 would also have lower annual O&M costs compared to Alternative 2. In addition, replacement investments for the concrete alternative would be required at 10-year intervals, compared to every 3 years for the wooden bulkhead, Alternative 2. Using hypothetical data, **Table 1** shows the costs in each year for each alternative and the cumulative net present value calculations for LCC using a 5% discount rate (*'i'* in Table 1 below) and a 2.5% annual cost escalation rate.

Table 1: Life Cycle Cost Analysis – Bulkhead Designs

	Alternative 1: Concrete Bulkhead				Alternative 2: Wooden Bulkhead			
Year	**Capital Cost-Initial Upfront Cost (CapEX)**	**Replacement Costs, R**	**Operations & Maintenance, O&M**	**Total Cost LCC**	**Capital Cost-Initial Upfront Cost (CapEX)**	**Replacement Costs, R**	**Operations & Maintenance, O&M**	**Total Cost LCC**
0	-$1,320,000	$0	$0	-$1,320,000	-$303,600	$0	$0	-$303,600
1	$0	$0	-$3,075	-$3,075	$0	$0	-$15,888	-$15,888
2	$0	$0	-$3,152	-$3,152	$0	$0	-$16,285	-$16,285
3	$0	$0	-$3,231	-$3,231	$0	-$173,644	-$16,692	-$190,336
4	$0	$0	-$3,311	-$3,311	$0	$0	-$17,109	-$17,109
5	$0	$0	-$3,394	-$3,394	$0	$0	-$17,537	-$17,537
6	$0	$0	-$3,479	-$3,479	$0	-$201,014	-$17,975	-$218,990
7	$0	$0	-$3,566	-$3,566	$0	$0	-$18,425	-$18,425
8	$0	$0	-$3,655	-$3,655	$0	$0	-$18,885	-$18,885
9	$0	$0	-$3,747	-$3,747	$0	-$232,699	-$19,357	-$252,057
10	$0	-$81,445	-$3,840	-$85,285	$0	$0	-$19,841	-$19,841
11	$0	$0	-$3,936	-$3,936	$0	$0	-$20,337	-$20,337
12	$0	$0	-$4,035	-$4,035	$0	-$269,378	-$20,846	-$290,224
13	$0	$0	-$4,136	-$4,136	$0	$0	-$21,367	-$21,367
14	$0	$0	-$4,239	-$4,239	$0	$0	-$21,901	-$21,901
15	$0	$0	-$4,345	-$4,345	$0	-$311,839	-$22,449	-$334,288
16	$0	$0	-$4,454	-$4,454	$0	$0	-$23,010	-$23,010
17	$0	$0	-$4,565	-$4,565	$0	$0	-$23,585	-$23,585
18	$0	$0	-$4,679	-$4,679	$0	-$360,993	-$24,175	-$385,168
19	$0	$0	-$4,796	-$4,796	$0	$0	-$24,779	-$24,779
20	$0	-$132,665	-$4,916	-$137,581	$0	$0	-$25,399	-$25,399
21	$0	$0	-$5,039	-$5,039	$0	-$417,894	-$26,034	-$443,928
22	$0	$0	-$5,165	-$5,165	$0	$0	-$26,684	-$26,684
23	$0	$0	-$5,294	-$5,294	$0	$0	-$27,351	-$27,351
24	$132,000	$0	-$5,426	$126,574	$30,360	-$483,765	-$28,035	-$481,440
Cumulative Present Value (NPV, *i* =5%)	-$1,279,071	-$100,000	-$54,018	**-$1,433,089**	-$294,186	-$1,200,000	-$279,094	**-$1,773,280**

The LCCA comparison shows that despite the larger initial cost associated with the concrete bulkhead design, Alternative 1 results in cost savings of $340,000 in present value terms over the 25-year period.

Barriers to Implementation (Feasibility Considerations)

In many instances LCCA is applied when a decision on a project has been made to see which design alternative is the most economically efficient. An effort to populate the LCCA with all upfront, annually recurring, and periodic costs can appear to be a barrier to its implementation. However, expending this effort up front can save time and money in the long-run and avoid maladaptation. There is often a tension between overinvesting versus underinvesting. In this example of a larger upfront investment, it actually prevented maladaptation and was the optimal investment because it was later revealed that significant annual sustainment costs were avoided and physical injuries to personnel were prevented. While some costs are uncertain, confidence in projecting this data can be overcome by applying probability distributions to these variables using risk analysis software and Monte Carlo simulations.

Some installations may lack maintenance data. However, estimates from procurement databases and invoices as well as engineering rules of thumb can be applied to overcome these barriers. The resources section below also provides links to agency software programs designed for LCCA that can assist planners.

Information Resources

- American Society of Civil Engineers. *Maximizing the Value of Investments Using Life-Cycle Cost Analysis.* http://www.asce.org/uploadedFiles/Issues_and_Advocacy/Our_Initiatives/Infrastructure/Content_Pieces/asce-eno-life-cycle-report.pdf
- Building Life Cycle Cost Programs – The National Institute of Standards and Technology (NIST) developed the Building Life Cycle Cost (BLCC) Programs to provide computational support for the analysis of capital investments in buildings. They include BLCC5, the Energy Escalation Rate Calculator, Handbook 135, and the Annual Supplement to Handbook 135, http://energy.gov/eere/femp/building-life-cycle-cost-programs
- Cost Estimates for Shoreline Erosion Products in the Northern Gulf of Mexico. Are Living Shorelines the Cheapest Alternative? By: Chris A. Boyd, Ph.D., Associate Extension Professor, Environmental Ecology, Mississippi State University, Coastal Research and Extension Center.
- Federal Highway Administration - Asset Management – Life-Cycle Cost Analysis http://www.fhwa.dot.gov/infrastructure/asstmgmt/lcca.cfm
- NIST Handbook 135, 1995 Edition, Life-cycle Costing Manual for the Federal Energy Management Program, Sieglinde K. Fuller, Stephan R. Petersen, U.S. Department of Commerce, National Institute of Standards and Technology.
- National Institute of Building Sciences – Whole Building Design Guide – Life-Cycle Cost Analysis (LCCA), https://www.wbdg.org/resources/lcca.php
- U.S. Army Corps of Engineer's website: http://www.usace.army.mil/Missions/Sustainability/ExpertiseinSustainability/LifeCycleCostAnalysisforEngineerSystems.aspx

2. Benefits Monetization Tools

Guidance Comment	Caveats and Limitations
Benefit Cost Toolkit 5.2.1 / FEMA http://www.fema.gov/media-library/assets/documents/92923	
Useful tool designed to quantify benefits associated with many hazards (e.g., floods, hurricanes, etc.). Incorporates triple bottom line/sustainability related economic research (and values) for social, economic and environmental/ecosystems benefits. Also has a Sea Level Rise feature that is added to hazard event risks associated with flood plains and risk zones. Could be useful to apply to installation's select assets to be protected or groups of functions that can be isolated. Resilience benefits are based on depth damage functions built into software that quantify damages to structures and their asset contents.	● Not GIS based. Dependent on Flood Insurance Studies to source key input parameters. While these studies may be accessible through FEMA website as downloadable "pdf" files, some may be out of date or in the process of being revised. For a life cycle annual expected damages analysis, user will need to extract annual flood damages benefits (i.e., avoided damages to building structure, contents, etc.) and bring into Project Resource Statement for further analysis. ● Planners can download and start using immediately with knowledge of key coastal information (e.g., flood plains, first floor elevations, flood risk zones, etc.).
HAZUS / FEMA https://www.fema.gov/hazus	
HAZUS is a nationally applicable standardized methodology that contains models for estimating potential losses from earthquakes, floods, and hurricanes. HAZUS uses Geographic Information Systems (GIS) technology to estimate physical, economic, and social impacts of disasters. It graphically illustrates the limits of identified high-risk locations due to earthquakes, hurricanes, and floods. Users can then visualize the spatial relationships between populations and other more permanently fixed geographic assets or resources for the specific hazard being modeled, a crucial function in the pre-disaster planning process. Could be useful for installation-wide or region-wide analyses that also consider impacts to adjacent communities.	● Requires some GIS expertise and knowledge of relevant data layer coverages. ● A user will need to supplement HAZUS with other sources to value Green Infrastructure ecosystem benefits and apply them to spatial coverages (i.e., identified habitats and communities in acres).
COAST (Coastal Adaptation to Sea Level Rise Tool) / Blue Marble Geographics / New England Environmental Finance Center, University of Southern Maine https://www.bluemarblegeo.com/products/COAST.php	
COAST is a GIS-based program developed by Blue Marble Geographics with the New England Environmental Finance Center (NEEFC) at the University of Southern Maine. COAST is a process that helps users answer questions on the costs and benefits of actions and strategies to avoid damages to assets from sea level rise and/or coastal flooding. •Should we build a sea wall? •Should we develop a proactive building ordinance? •Should we build a levee? •Should we change our zoning? •Should we relocate? For multi-decade periods, COAST produces cumulative expected damage tallies in tabular form for a given set of	● COAST uses 3D visual images that depict the relative value of assets at stake, geometrically, superimposed along the coastal area at risk from climate change events, inundation, and sea level rise. This feature is a powerful way to convey the risk of sea level rise and more severe and frequent extreme weather events to stakeholders in the coastal environment. ● Program is not free and user has to purchase software from vendor, Blue Marble Geographics. See website at left. ● Requires GIS expertise.

Guidance Comment	Caveats and Limitations
conditions and adaptation actions. This allows numeric understanding of expected damages from increased flood frequency over time, as well as identification of robust adaptation strategies that may function acceptably and save money under any climate scenario.	
Depth Damage Functions / USACE USACE – Planning Community Toolbox: https://planning.erdc.dren.mil/toolbox/index.cfm Planner's Library Containing Economic Guidance Memoranda on Depth-Damage relationships https://planning.erdc.dren.mil/toolbox/library.cfm?Option=Listing&Type=EGM&Search=Policy&Sort=Default	
Depth damage functions are built into the above-named software programs. USACE also provides guidance memorandums that contain these depth damage functions.	Users should consult recent studies and USACE Planning Community Toolbox website for updates and coverage extensions of depth damage functions. Best used with vertical infrastructure (e.g. buildings)
Beach-fx / USACE http://www.corpsriskanalysisgateway.us/lms/course.cfml?crs=14&crspg=180 http://www.erdc.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/476718/beach-fx/	
Beach fx is a comprehensive software tool developed by researchers at the USACE ERDC Coastal and Hydraulics Laboratory (CHL) and the USACE Institute for Water Resources (IWR). The tool is a Monte Carlo life cycle simulation model for estimating shore protection project evolution and cost benefit analyses. Beach-fx provides a comprehensive framework for evaluating the physical performance and economic benefits and costs of shore protection projects.	Model is best populated by users who have familiarity with hydraulics and coastal processes, working together with planners and analysts who have experience in running Monte Carlo simulations.
FEMA Benefit---Cost Analysis Re-engineering (BCAR) Development of Standard Economic Values, Version 6.0, December 2011 https://www.hudexchange.info/course-content/ndrc-nofa-benefit-cost-analysis-data-resources-and-expert-tips-webinar/FEMA-BCAR-Resource.pdf	
This FEMA resource provides standard default values applied in the FEMA BCA software tool described above. The resource also provides overview of methods for valuing damages to critical infrastructure (roads and bridges, water and wastewater treatment services, hospitals, police, EMS, fire and loss of electric/power services).	While the resource provides values that can be applied, (i.e., value of time for users impacted by road delays/road closures) the user will have to obtain additional data such as days/hours of road closure and population(s) impacted to apply the method and default values provided. Also, a planner will need to update or escalate the default values to current dollars.

3. Application and Use of Depth Damage Functions

Overview

Depth damage functions (DDFs) are standardized analytical tools (also called curves) that show the relationship in damages to a structure (on the Y axis) versus depth of flooding inundation (on the X axis). Structure is usually defined as a permanent building and everything that is permanently affixed to it. Both FEMA and the U.S. Army Corps of Engineers (USACE) have developed DDFs for many different kinds of structures, and to also show the damages to buildings' contents associated with various depths of flooding (IWR Report 92-R-3). Standardized building content DDFs have also been developed from surveys used to establish functions that portray content to structure value ratios versus flood depths. In addition to flooding, depth damage curves have also been developed to address erosion and wave height related effects. The planner will have to choose the appropriate curve to address the given situation. This task can be simplified by application of the appropriate hazard mitigation and monetization tools that are summarized in the Handbook (See Stage III).

With valuation data available related to an installation's assets and property (replacement values), DDFs can be applied to estimate the losses associated with inundation. Many of the monetization tools profiled in the Handbook have DDFs embedded within their programs to aid analysts working with hydraulic and hydrology (H&H) data and studies showing inundation reaches. **Figure 1** illustrates a depth damage curve related to flood depth. The x-axis shows flood depth relative to the First Floor Elevation (FFE) of a structure. The y-axis shows damages as percent of the structure value. The process for generating the curves uses historical impact data from coastal events creating damages and statistical analyses, as well as expert opinions.

Figure 1 illustrates a DDF that was developed as part of the USACE North Atlantic Comprehensive Study (NACCS, USACE, 2015).

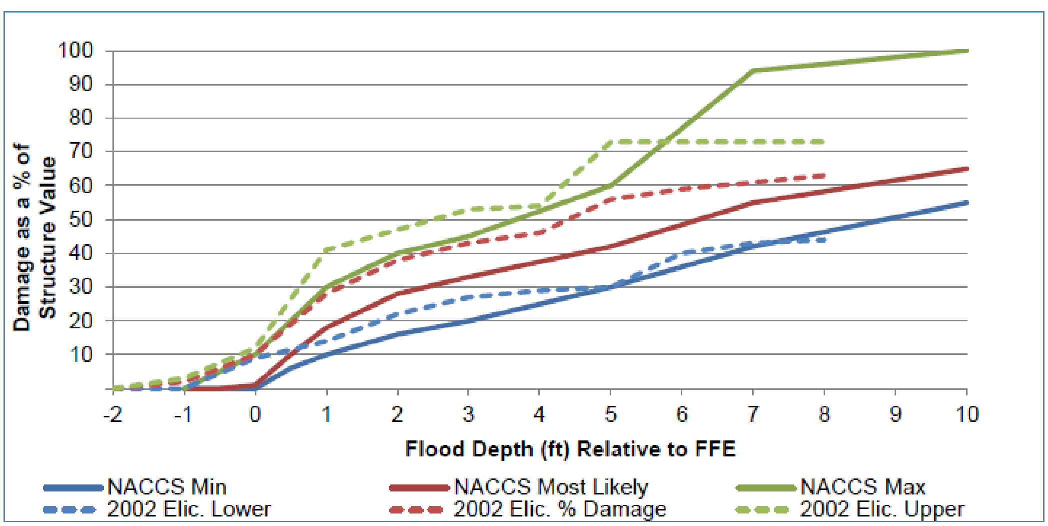


Figure 21. Comparison – Structural Damage from Inundation: NACCS Prototype 5A Single-Story, No Basement vs 2002 Elicitation Wood Frame without Piles

Figure 1. Illustration of a Depth Damage Function (Source: USACE 2015)

Figure 2 below shows a standardized or generic depth damage function for structure content damages as a percent of structure value.

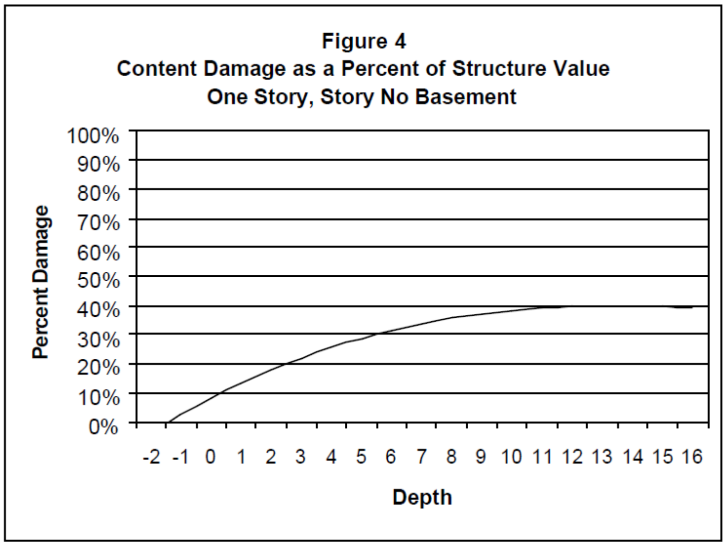


Figure 2. Generic Depth Damage Function (Source: USACE 2000)

Diagram 1 shows the base flood elevation (in 2010 and anticipated in 2060) after sea level rise. The left part of the diagram indicates how much damage a specific level of water will have (flood depth) as a percent of the building and shows the anticipated damages based on a future flood depth (2060) with sea level rise.

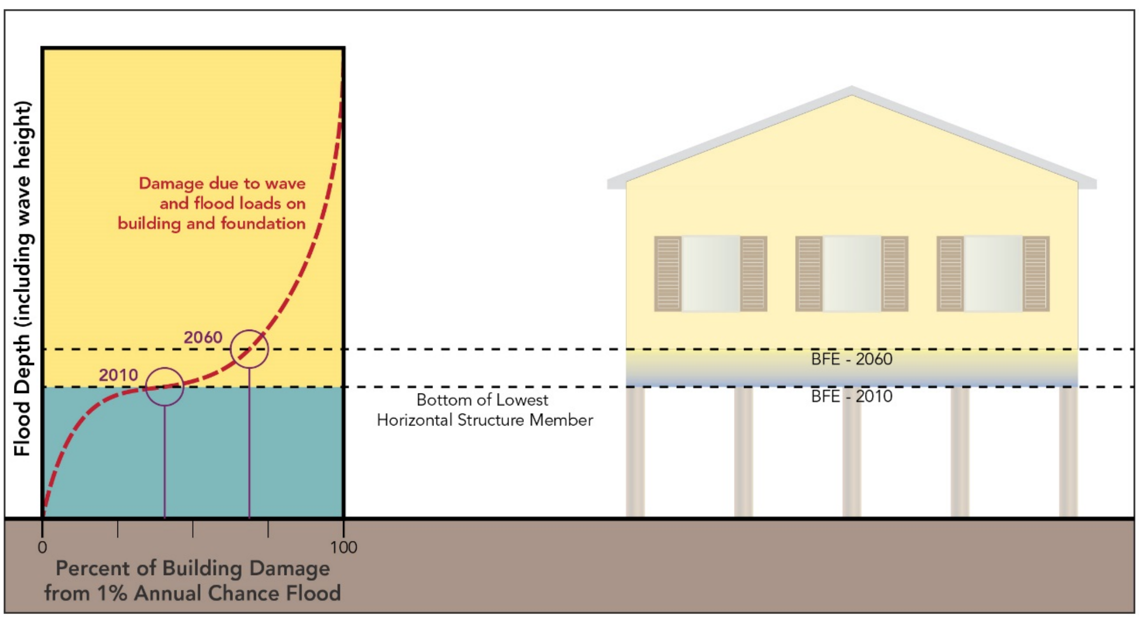


Diagram 1. Before and After Base Flood Elevation

Techniques

The general steps in applying depth damage functions to estimate damages involve the following:

1. Inventory the assets and their replacement values that would be impacted within the vulnerable zone.
2. Determine which structures would be impacted from the reach of inundation and sea level rise over time (See Handbook Notional Map).
3. Determine the impact flood depths above the first floor elevation (FFE).
4. Determine the appropriate type of Depth Damage Curve to apply (i.e., flood, erosion, wave etc.[2]), and for which type of structure (i.e., buildings, contents, or vehicles, etc.). For ease of use, apply a standard tool that has standard functions built in within the program (See Handbook's descriptions of Monetization Tools). Invoke the appropriate curve from the software's curve library (See HAZUS or FEMA BCA 5.1 software tools for example).
5. Apply the specific percentage of building value to the total replacement value of the asset or structure at the relevant depth to determine damages at that particular depth.

Barriers to Implementation (Feasibility Considerations)

Many of the specialized software tools mentioned in the Handbook include standardized depth damage functions built into the programs. Many of the original sources of these functions are provided within the Information Resources below. These functions are then applied with other hydraulic and hydrology (H&H) data and flood inundation profiles to estimate damages. You will need to determine the level of detail required or necessary for you to secure estimates of avoided flood damages on your installation. The Handbook contains many resource references that can simplify this task.

Information Resources

- IWR Report 92-R-3, May 1992, U.S. Army Corps of Engineers, Institute for Water Resources, "Catalog of Residential Depth-Damage Functions Used by the Army Corps of Engineers in Flood Damage Estimation", http://planning.usace.army.mil/toolbox/library/IWRServer/92-R-3.pdf
- IWR Publication 96-R-12, U.S. Army Corps of Engineers, Institute for Water Resources "Analysis of Non-Residential Content Value and Depth Damage Data for Flood Damage Reduction Studies," http://www.iwr.usace.army.mil/Portals/70/docs/iwrreports/92-R-3.pdf
- IWR Report 2011–R–09, November 2011, U.S. Army Corps of Engineers, Institute for Water Resources, Coastal Storm Risk Management
- Reeder, A. and E. Coughlin. "Cost-Effective Method for Determining if your Community is at Risk from Sea Level Rise and Recommendations to Modify your Flood Provisions and Building Codes." (Slide presentation, 2008). Atkins, Starr Strategic Alliance for Risk Reduction.
- U.S. Army Corps of Engineers North Atlantic Division. 2015. North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk.
- U.S. Army Corps of Engineers. 2000. Generic Depth-Damage Relationships. Economic Guidance Memorandum (EGM) 01-03. Washington, DC: USACE

[2] Tools exist that will allow you to apply multiple DDFs for combined impacts without double-counting losses associated with the union of joint impacts. See Beachfx and (2001-R-09.pdf).

4. Costing Tools and Resources

Overview

This fact sheet describes some useful costing tools and resources and provides links to these applications. The development of conceptual life cycle costs (i.e., upfront capital construction costs, periodic renewal or rehabilitation costs, and annually recurring operations and maintenance costs) will be necessary inputs to the benefit cost analysis. This fact sheet describes some widely used tools that have been applied to estimate these costs and provides more details on where the planner can access resources to develop cost estimates for alternative adaptation measures. The tools and resources described are applicable mostly to structural measures, but some of the techniques can also be applied in cost estimates for non-structural measures as well.

Techniques

The process and effort used in generating cost estimates can vary based on the given alternative's objectives and resources available to the planner. Generally, for planning purposes the term "conceptual cost" has a specific meaning that is clarified by some order of magnitude as to expected accuracy or how closely the estimate compares to final installed cost. At the concept stage, the contingency percentage (expressed in terms of range of accuracy) can vary by a relatively large percentage (plus or minus) for the given adaptation investment infrastructure based on how specifically defined the alternative is at this point in time. As more information is developed and formalized in more data intensive models, or bid tenders, the range of accuracy narrows. **Figure 1**, reproduced from the DOE, conveys this general concept according to stages, project gestation, and methods.

DOE G 413.3-21 15
5-9-2011

	Primary Characteristic	*Secondary Characteristic*		
ESTIMATE CLASS	**DEGREE OF PROJECT DEFINITION** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges [a]
Class 5	0% to 2%	Concept screening	Capacity factored, parametric models, judgment, or analogy	L: -20% to -50% H: +30% to +100%
Class 4	1% to 15%	Study or feasibility	Equipment factored or parametric models	L: -15% to -30% H: +20% to +50%
Class 3	10% to 40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	L: -10% to -20% H: +10% to +30%
Class 2	30% to 70%	Control or bid/tender	Detailed unit cost with forced detailed take-off	L: -5% to -15% H: +5% to +20%
Class 1	70% to 100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	L: -3% to -10% H: +3% to +15%

Notes: [a] The state of process technology and availability of applicable reference cost data affect the range markedly. The +/- value represents typical percentage variation of actual costs from the cost estimate after application of contingency (typically at a 50% level of confidence) for given scope.

Table 4.3 – Cost Estimate Classification for Process Industries

Figure 1. Conceptual Costs (Source: DOE 2011)

The costing techniques applied can range from initial simple "back of the envelope" estimates to more detailed full-blown parametric costing studies. For example, some planners may have access to historical databases containing costs for similar structures or facilities. These estimates may be sourced and updated or escalated to current prices and would suffice as initial concept estimates.[3] There may also be planning and engineering cost curves that have been developed from U.S. Department of Defense (DoD) databases of past projects or that could be developed by the planner working with an economist and cost engineer (see **Figure 2** for example). A cost curve relates a unit cost to some physical measure of output or capacity. The data arrayed can then be used to estimate the curve function depicting average relationships represented by the best fit algorithm. The planner should start the conceptual cost estimating research by first investigating available resources and interacting with installation engineers and cost estimators. For specific coastal adaptation infrastructure, however, this fact sheet lists some additional useful resources that have been applied within the resilience community of practice.

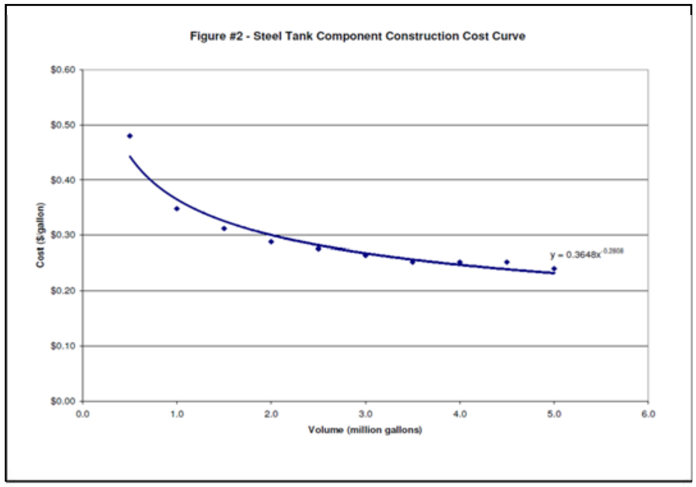


Figure 2. Example Cost Curve
(Source: CH2M HILL 2005)

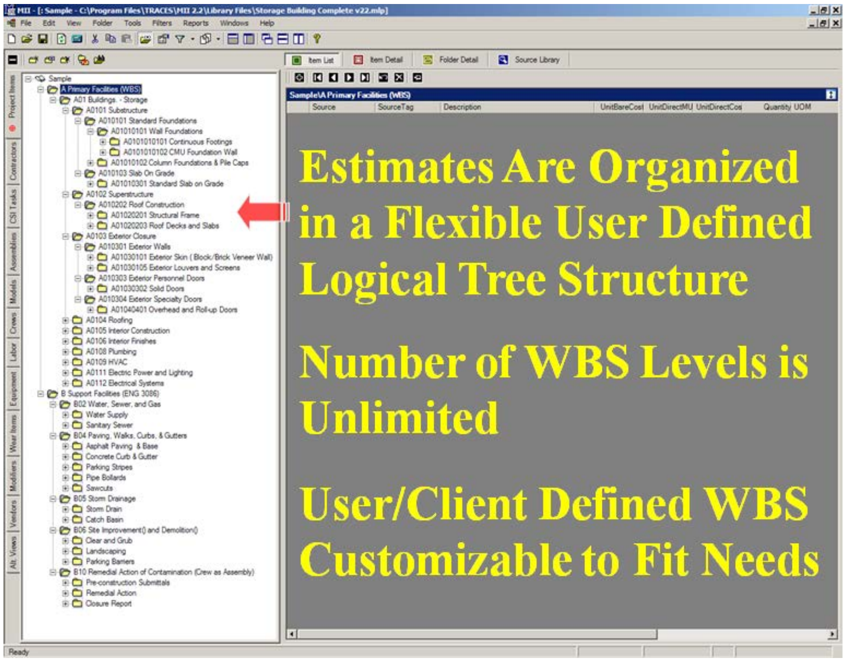
Resources and Tools:

Select available "costing" tools that have been applied in DoD installations are described on the following pages. The planner is encouraged to check with other installation professionals and cost estimating engineers for additional resources and specific tools applied in their regions.

Micro-Computer Aided Cost Estimating System (MCACES)
http://www.miisoftware.com/
MII is the second generation of the Micro-Computer Aided Cost Estimating System (MCACES). The tool was developed by Project Time & Cost, Inc. under contract with the U.S. Army Corps of Engineers (USACE) and has been widely used in USACE cost estimating and applications and by DoD architect-engineering (A-E) contractors for military, civil works, and hazardous, toxic and radioactive waste (HTRW) projects. MII provides an integrated cost estimating system (software and databases) that meets the USACE requirements for preparing cost estimates. Now being used by many of the USACE districts, it will soon be a requirement for all USACE districts to use MII, as well as all A-E firms performing design work for the USACE.

[3] A widely used construction cost index is available from the Engineering News Record (ENR) publication. This construction cost index is available by region and can be applied to generate cost escalation factors. See http://www.enr.com/economics/

Screenshot from Micro-Computer Aided Cost Estimating System (MCACES)



Parametric Cost Engineering System (PACES)

http://www.wbdg.org/tools/paces.php?a=1

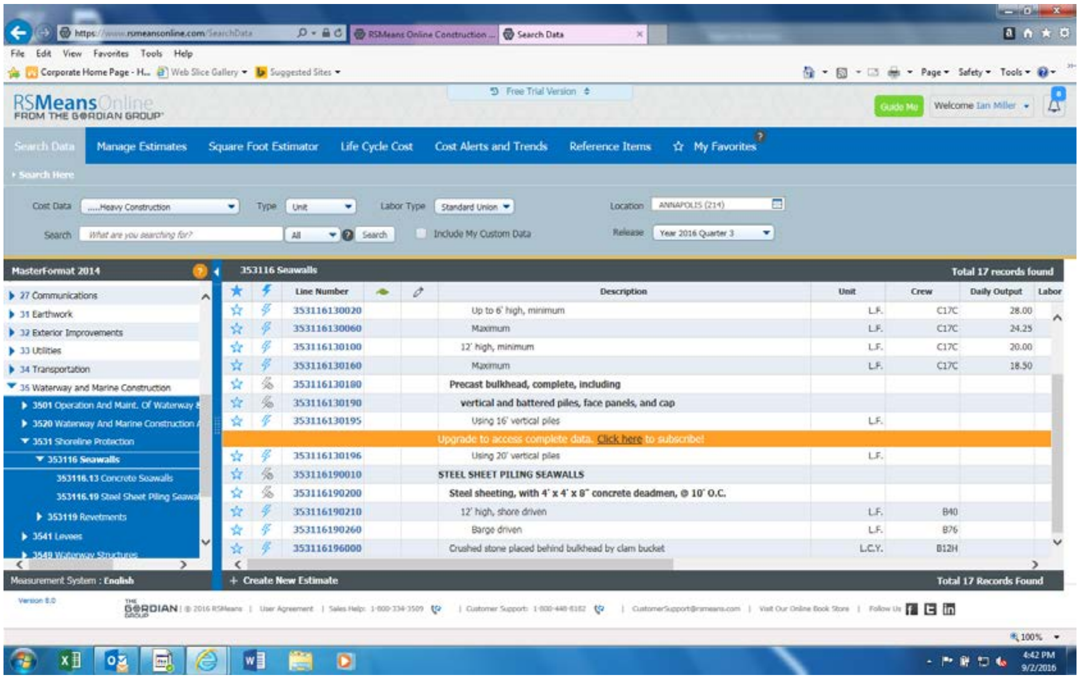
Parametric Cost Engineering System (PACES) software is a cost engineering tool used to assist with the development of planning and budgeting facility and infrastructure construction and renovation costs. PACES has been used by the Air Force Civil Engineer Center (AFCEC), the Naval Facilities Engineering Command (NAVFAC), and USACE. PACES is an integrated PC-based software system that prepares parametric cost estimates for new facility construction, renovation, and life cycle cost analysis. PACES uses pre-engineered model parameters and construction criteria to accurately predict construction costs with limited design information.

RS Means Online Services for Costing

https://www.rsmeans.com/products/online.aspx

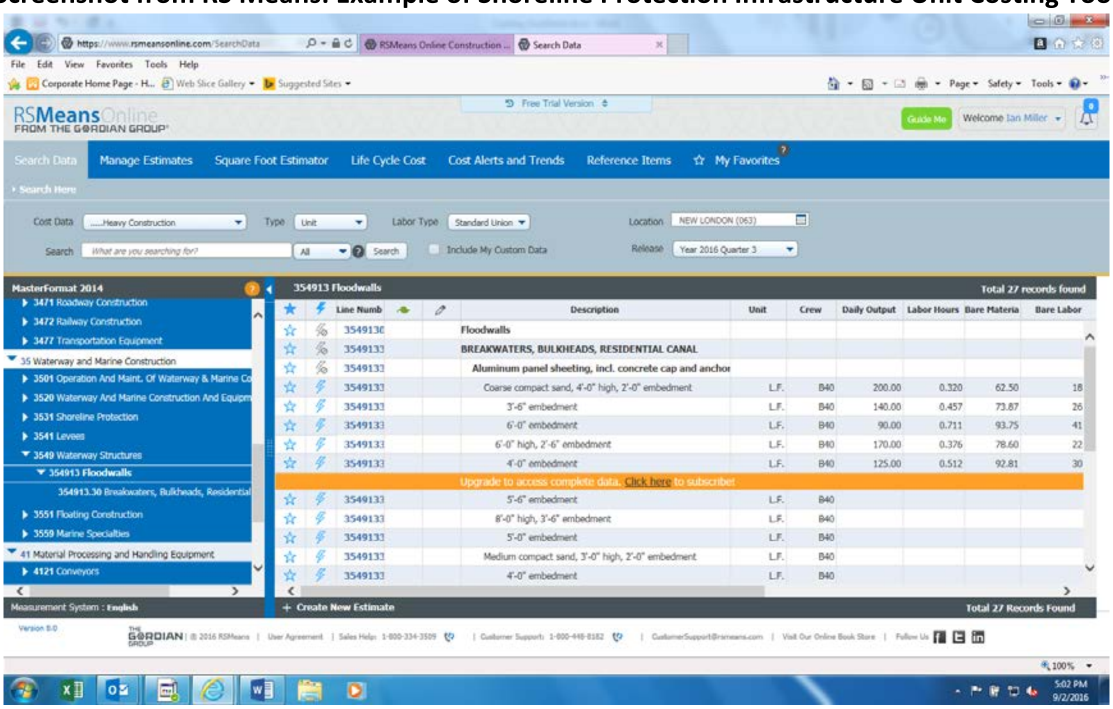
RS Means Online Services for Costing offers the planner the ability to generate cost estimates for heavy duty construction projects related to enhancing resiliency including shoreline protection features necessary to prepare for climate change. The Online software version offers unit costs tailored to regions. The following screen shot demonstrates some of the cost parameter features that can aid planners/costing engineers in developing cost estimates for structural solutions essential to climate proofing and rendering installations more resilient to sea level change. The software also has features to develop full life cycle cost estimates. The planner/engineer working with economists and financial analysts can then integrate these estimates into the benefit cost analysis.

Screenshot from RS Means: Shoreline Protection Options & Region Specific Cost Options

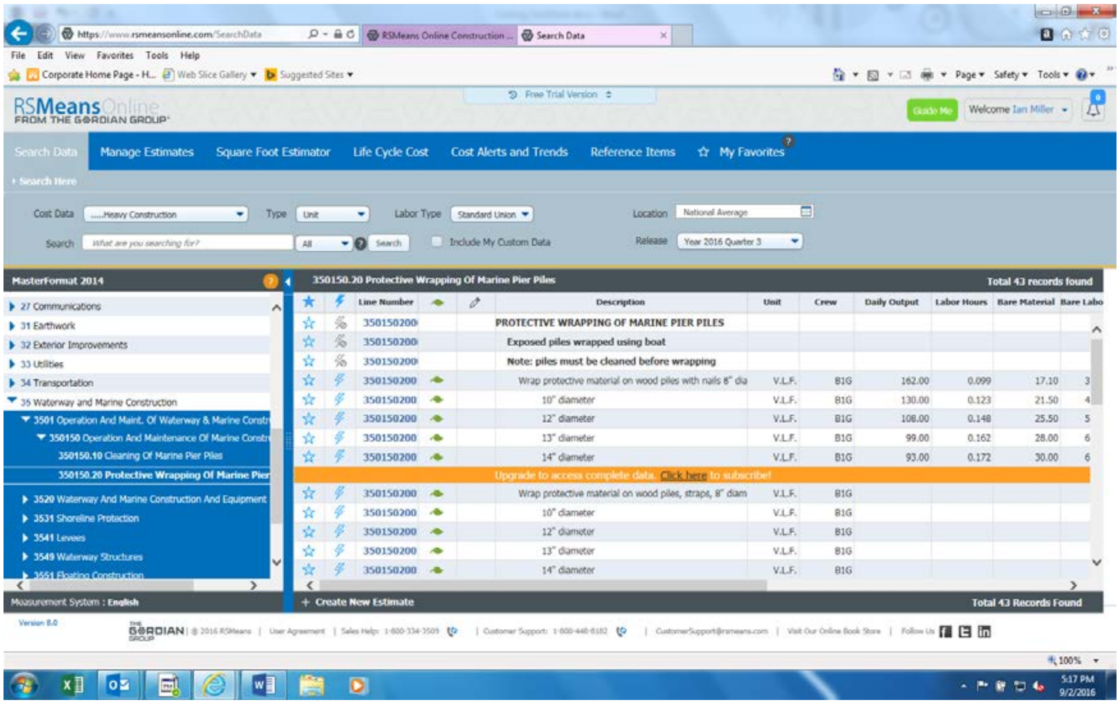


The following screenshots show some of the program's features:

Screenshot from RS Means: Example of Shoreline Protection Infrastructure Unit Costing Tool



Screenshot from RS Means: Example of Operational & Maintenance parameters available to calculate life cycle costs (Pier Protection)



NIST Building Life Cycle Cost (BLCC) Programs

U.S. Department of Energy

http://energy.gov/eere/femp/building-life-cycle-cost-programs

The National Institute of Standards and Technology (NIST) developed the Building Life Cycle Cost (BLCC) Programs to provide computational support for the analysis of capital investments in buildings. They include BLCC5, the Energy Escalation Rate Calculator, Handbook 135, and the Annual Supplement to Handbook 135. The BLCC version 5.3-15 contains the following modules:

1. FEMP Analysis, Energy Project
2. Federal Analysis, Financed Project Office of Management and Budget Analysis
3. MILCON Analysis, Energy Project
4. MILCON Analysis, Energy Conservation Investment Program Project
5. MILCON Analysis, Non-Energy Project

BLCC has the capabilities to evaluate the relative cost effectiveness of alternative buildings and building-related systems or components. BLCC is used to evaluate alternative designs that have higher initial costs but lower operating costs over the project life than the lowest-initial-cost design. The life cycle cost (LCC) of two or more alternative designs are computed and compared to determine which has the lowest LCC and is therefore more economical in the long run.

Barriers to Implementation (Feasibility Considerations)

The costing exercise should engage other stakeholders (engineers, facilities planners, budget professionals who have access to contractor invoices) to ensure that all available and germane information is considered by the planner. Some historic information may be useful to ground truth and benchmark cost estimates generated from scratch through the application of the existing referenced software tools. As a practical matter, some co-workers may have already subscribed to these vendor services as well and may already be familiar with their use. If the planner engages in these first steps the process may seem less daunting and will lead to fewer barriers encountered during the cost development process.

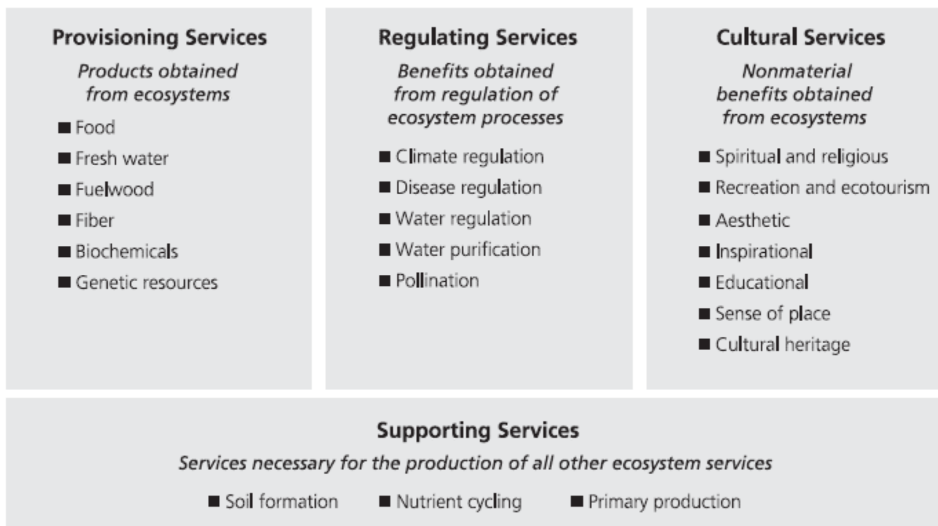
Information Resources

- American Association of Cost Engineers (AACE)
- American Society of Professional Estimators (ASPE)
- CH2M HILL, Draft Technical Memorandum, Task Order No. 1 – Conceptual Cost Estimating Guide, prepared for Eastern New Mexico Rural Water Authority, July 27, 2005
- Department of Energy, Cost Estimating Guide, DOE G 413.3-21, 5-9-2011, https://www.directives.doe.gov/
- DoD UFC 3-700-02A Construction Cost Estimates
- ER 1110-3-1300 Military Programs Cost Engineering by U.S. Army. 1999.
- eVALUator: Building Life-Cycle Cost Assessment Program by DOE
- Federal LCCA Software Tools: Building Life-Cycle Cost Program Version 5 (BLCC5)
- GSA P-120 Project Estimating Requirement for the Public Buildings Service by
- Historical Cost Analysis Generator (HAG)—Used by the Tri-Services to collect historical costs on awarded military construction projects
- International Cost Engineering Council
- Micro Computer-Aided Cost Engineering Systems (MCACES) by U.S. Army Corp of Engineers
- NAVFAC Cost Engineering Policy and Procedures, www.uscost.net/costengineering/documents/policy-procedures-july_2013.pdf
- NAVFAC Building Cost Index (BCI); Consistent with UFC 3-701-01 DoD Facilities Pricing Guide, with Change 10 (03-2011), http://www.wbdg.org/ffc/navy-navfac/cost-engineering-guidance-ceg/navfac-bci
- NAVFAC P-442 Economic Analysis Handbook
- NAVFAC Guidance Unit Costs; Consistent with UFC 3-701-01 DoD Facilities Pricing Guide, with Change 8 (03-2011), http://www.wbdg.org/ffc/navy-navfac/cost-engineering-guidance-ceg
- NAVFAC Success Estimator, http://www.uscost.net/costengineering/successdown.htm
- Royal Institution of Chartered Surveyors (RICS)
- Society of Cost Estimating and Analysis (SCEA)

5. Ecosystem Services Benefits and Valuation

Overview

The assessment and benefits evaluation of ecosystem services is essential for quantifying and valuing the contributions that natural systems make to the productivity, resilience, and livability of the installation and surrounding host community. Benefits from an action alternative may arise when land is converted by an action to one that provides natural environmental benefits, or "ecosystem services" benefits. **Green infrastructure** that may already exist in some form (e.g., a wetland buffer area, water collection impoundment area), may be preserved or enhanced by an action and will generate ecosystem services benefits that will benefit the environment and the installation. Ecosystem services are classified according to the following, widely adopted typology. There are four main classes of ecosystem services: Provisioning, Regulating, Supporting, and Cultural. Within each of these broad categories are several



subcategories shown in **Figure 1**.

Figure 1: Ecosystem Services (Source: Alcamo, J. and E. M. Bennett, eds. 2003)

Coastal related ecosystem services are particularly important to many Navy installations. Consideration of coastal ecosystem services provides a better understanding the full range of environmental, economic, and social/community benefits available from some action alternatives. Coastal wetlands provide flood protection. These wetlands protect upland areas, including valuable installation, residential, commercial properties, structures, and assets. Wetlands protect against flooding due to sea level rise and storm surge events and provide valuable erosion control services. Coastal wetlands can prevent coastline erosion due to their ability to absorb the energy created by ocean currents, rising tides, wind, and storm surges that would otherwise erode the shoreline and compromise the associated adjacent development in structures and assets.

Coastal ecosystem structures also provide habitat supporting wildlife and food production and are essential for providing sanctuaries for many federally threatened and endangered species. In addition, migratory bird flyways pass over the Pacific and Atlantic coasts, where coastal wetlands provide temporary habitat to waterfowl and shorebirds. Coastal wetlands estuarine environments are also an important foundation breeding/rearing habitat supporting commercial and recreational fisheries.

Wetlands also provide valuable water quality services by filtering pollutants, chemicals and sediment out of water before it is discharged into the ocean.

In addition, coastal wetlands can provide numerous recreational opportunities including canoeing, kayaking, wildlife viewing and photography, recreational fishing and hunting. These functions can provide morale building amenities and benefits for both resident personnel and visitors to the installation. Wetlands also provide valuable carbon sequestration services. For example, freshwater/brackish based peat based marshes, salt marshes, and coastal mangroves can sequester and store large amounts of carbon due to their rapid growth rates and slow decomposition rates (U.S. EPA).

The use of Green Infrastructure and coastal wetlands for dissipating storm and tidal energy and for buffering and absorbing impacts from more frequent and severe climate events and hazards has been well established and valued as a "regulating" function. Habitat provision would be an example of a "Supporting" function. To account for these benefits in monetary terms, the ecosystem services valuation approach has been established and has also been formally integrated into some agency benefit cost analysis processes.

Assessment and Valuation Techniques

To value ecosystem services benefits, economists have applied many techniques that have been developed over time, refined, and put to practice in areas such as natural resource damages assessments and environmental economics benefits valuation for non-market goods and services. The total economic value framework (TEV) is a way to acknowledge and systematically organize and assess all forms of use and non-use values associated with ecosystem services. **Figure 2** is adapted from a National Research Council study and shows the relationship between the ecosystem structure and

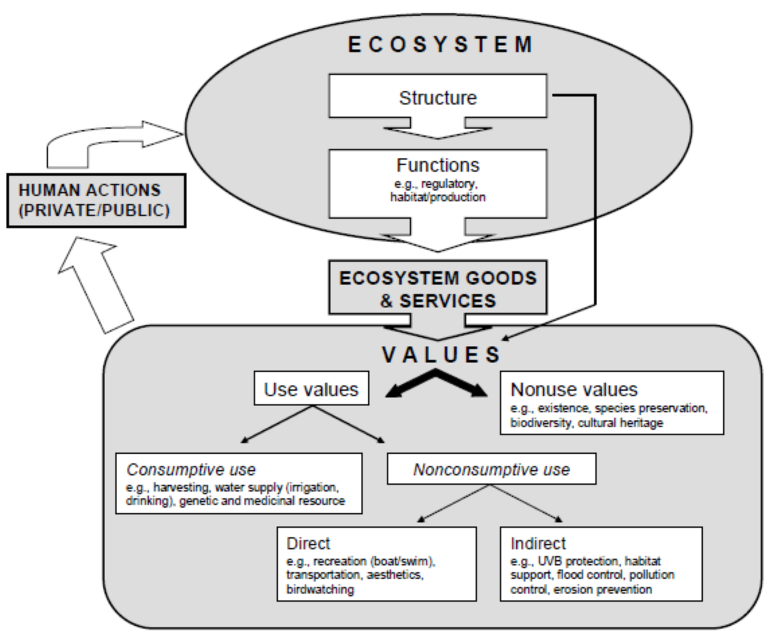


FIGURE 7-1 Connections between ecosystem structure and function, services, policies, and values.

Figure 2: Ecosystem Services and the Total Economic Value Valuation Framework

(Source: National Research Council 2005) functions and the array of total values benefiting humans (NRC 2005). For example, an existing acre of coastal wetlands (part of the natural asset structure) may provide habitat, flood protection, and water filtration functional services (annual service flows). These service flows are valued by humans, not only for their direct use values, but also for non-use values. Non-use values can include the sustainability values such as bequest, existence values, and option values. These values are prized for their worth to future generations and for the options individuals have in the future to enjoy these ecosystem services, irrespective of whether they ever have time to exercise the option, or even directly use the services themselves.

Types of Valuation Techniques

The types of economic valuation techniques applied to convert the ecosystem services physical measures of value (such as acres of habitat or pounds of carbon dioxide equivalent sequestered) into monetary values for use in benefit cost analyses are well documented and are discussed in several resources including those referenced in this fact sheet. Valuation techniques are classified as stated preference and revealed preference. The most widely used and accepted techniques follow. All but the last two are revealed preference; the last two are stated preference.

- Market Price Approaches: There may be market prices available that establish some marginal values to a consumer or purchaser of these services. For example, market prices are available for commercial fish species and other resources harvested for direct use by humans such as timber or plants.
- Avoided Cost Approaches: Some costs may be avoided or not incurred by the installation that are being provided by an existing ecosystem asset. For example, it is possible to assess the value of costs avoided by ecosystem services that would have been incurred in the absence of those services, such as a buffer barrier wetland that protects property along the coast and provides flood control services. Without this ecosystem functional service, the installation would have to pay for some other kind of flood control structure or find protection from an engineered system.
- Replacement Cost: The replacement cost approach examines the revealed cost of replacing some ecosystem services with man-made or engineered systems that provide a similar service. For example, the cost of replacing wetlands filtration services that improve water quality with a system that treats water through chemical or biological processes may be used as a replacement cost proxy.
- Factor Income Approach: This approach examines the enhancement of income by ecosystem service provision. For example, water quality improvements may increase commercial fisheries catch and the incomes of dependent fishermen.
- Travel Cost Method: The travel cost method measures the full cost of what a consumer is willing to pay to consume use, or passively enjoy a resource provided by an ecosystem. For example, suppose a group of recreational anglers travel several hundred miles to fish at a creek park, but the anglers only pay a nominal gate entrance fee to fish at the park. The travel cost method would value the resource (i.e., the full consumer surplus from the recreational fishing trip) based on the total travel cost incurred to reach this resource destination, and not simply the nominal park entrance fee.

- Hedonic Pricing Technique: The hedonic pricing technique examines existing market prices that may reflect what people are willing to pay for a "bundle of goods," or what they may be willing to pay for being in close proximity to an ecosystem providing annual service flows. The attributes of the non-market good or service may be capitalized into the entire market price of the traded good, and the hedonic technique allows one to isolate the implicit value of a particular attribute that does not have a market price attached to it.
- Contingent Valuation Method: This method is a survey based or stated preference method that seeks to elicit values by posing hypothetical scenarios that involve some valuation of land use alternatives or what survey respondents are willing to pay for increased preservation of beaches and shoreline for example.
- Group Valuation: Discourse-based contingent valuation, arrived at by bringing together a group of stakeholders to discuss values to depict society's willingness to pay.

To summarize, these methods include both stated preferences (contingent valuation/survey based techniques) and revealed preference methods (such as the travel cost method, avoided cost, replacement cost, factor income) (Earth Economics). It should be noted that many of these techniques require primary studies, and are data and resource intensive. To correctly identify and account for these services, it is useful to have a multi-disciplinary integrated team consisting of planners, economists, coastal wetland and restoration ecologists, biologists, scientists, and engineers. However, where assembling this kind of specialized team may not be possible, the use and application of the benefits transfer method discussed below can offer a practical way to facilitate your ability to include ecosystem service values into a comprehensive benefit cost analysis.

Barriers to Implementation (Feasibility Considerations)

Understanding the full array of ecosystem services benefits is essential for evaluating action alternatives that include Green Infrastructure or hybrid approaches integrating gray infrastructure. Therefore the assessment and evaluation of ecosystem services and their benefits is critical to helping the installation planner convey to decision makers the circumstances where Green Infrastructure and hybrid approaches are likely to be successful (National Science and Technology Council 2015).

Benefits Transfer Method

It may not be logistically possible for you to implement your own ecosystem services valuation primary study. Nevertheless, if you can locate other resources that are applicable, and that may be adapted to your installation, it may be possible for you to proceed with the ecosystem services valuation. Benefits transfer involves locating primary studies with quantified ecosystem values that reflect ecosystem services that are similar to those functions provided by the natural assets at your installation, or that can succeed as viable communities within your geographic region. Benefit transfer involves comparing, adapting, and adjusting the values obtained from other studies to your study in a manner that accounts for differences in an acceptable way. These differences could be related to geography, habitat, time of the original study, or climatic conditions in your region.

Recognizing the necessity to incorporate ecosystem services values into flood and hazard risk analyses, FEMA has completed a benefits transfer vetted process for incorporating ecosystem services values (on a per acre/year basis) obtained from peer-reviewed literature studies for use in benefits transfer applications. These values, for a given base year, expressed on a per acre basis, can then be updated to current value by applying escalation factors. For the ecosystem services identified in **Figure 1** above, values have been researched for wetlands, green open space, crops, pasture, forest, and riparian land uses. In addition "regulating service values" by state provided by coastal wetlands related to storm hazard risk reduction are also available (FEMA 2012).

Information Resources

- Earth Economics Ecosystem Valuation Toolkit, http://esvaluation.org/ http://esvaluation.org/esv-publications/
- Federal Emergency Management Agency. 2012. Final Sustainability Benefits Methodology Report, Contract: HSFEHQ-10-D-0806, Task Order: HSFEHQ-11-J-1408, August 23, 2012, Federal Emergency Management Agency, Department of Homeland Security. https://www.hudexchange.info/course-content/ndrc-nofa-benefit-cost-analysis-data-resources-and-expert-tips-webinar/Final-Sustainability-Benefits-Methodology-Report.pdf
- Millennium Ecosystem Assessment, http://www.millenniumassessment.org/en/index.html; http://www.millenniumassessment.org/en/Framework.aspx. Alcamo, J. and E. M. Bennett, eds. 2003.
- National Research Council. 2005. *Valuing Ecosystem Services: Towards Better Environmental Decision Making, Committee on Assessing and Valuing the Services of Aquatic and Related Terrestrial Ecosystems, Water Science and Technology Board Division on Earth and Life Studies*. Washington, DC: The National Academies Press. https://www.nap.edu/catalog/11139/valuing-ecosystem-services-toward-better-environmental-decision-making
- National Science and Technology Council. 2015. *Ecosystem Service Assessment: Research Needs for Coastal Green Infrastructure*, Product of the Committee on Environment, Natural Resources, and Sustainability, August 2015, Executive Office of the President. https://www.whitehouse.gov/sites/default/files/microsites/ostp/cgies_research_agenda_final_082515.pdf
- U.S. EPA Coastal Wetlands https://www.epa.gov/wetlands/coastal-wetlands

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Appendix F – Worksheets for Stages I-IV

Stage I – Establish Scope and Characterize Impacts

WS I.1 – Assessment Scope
WS I.2 – Site Information Quality Assessment
WS I.3 – Historical Weather Event and Impacts Information
WS I.4 – Climate Information Requirements and Attributes
WS I.5 – Current and Plausible Future Conditions
WS I.6 – Existing Assessment Evaluation
WS I.7 – Impact Description and Characterization

Stage II – Identify and Screen Action Alternatives

WS II.1 – Potential Action Alternatives

Stage III – Calculate Benefits and Costs Benefits of Action Alternatives

WS III.1 – Life Cycle Cost Analysis
WS III.2 – Cost Effectiveness Analysis
WS III.3 – Benefits
WS III.4 – Benefit Cost Ratio and Net Present Value (Grouping Strategy)
WS III.4 – Benefit Cost Ratio and Net Present Value (Single Action Alternative)

Stage IV – Assemble Portfolio of Action Alternatives

WS IV.1 – Portfolio Summary

Instructions are in red text

Data entry fields are highlighted in blush

Worksheet Overview

Worksheet I.1 - Assessment Scope
Purpose: Develop an assessment scope to maintain focus and discipline through a complex analytical process. Document answers and assumptions to develop an assessment scope and guide preliminary research steps needed to develop a problem statement, which is the output of this stage.
Worksheet I.2 - Site Information Quality Assessment
Purpose:To identify and assess necessary datasets, information, and expertise to evaluate impacts on the focus area established during your assessment scope development. This information will help you prepare Worksheets I.3 and Worksheet I.7.
Worksheet I.3 - Historical Weather Event and Impacts Information
Purpose: Learn about and record information regarding past events and their impacts upon the focus area identified in the assessment scope. Historical event information may provide some sense of how susceptible or sensitive the site and its infrastructure have been and shed light on how future events may impact the focus area. This information could be helpful as you complete Worksheet I.7, but is not critical.
Worksheet I.4 - Climate Information Requirements and Attributes
Purpose: To identify and record which climate data are needed to delineate and evaluate the hazard of concern and weather/climate phenomena identified in the assessment scope and Worksheet I.1, and to assess the quality and type of climate data available.
Worksheet I.5 - Current and Plausible Future Conditions
Purpose: Confirm important site reference information (e.g., site reference datum and unit of measure) and document baseline and plausible future condition information.
Worksheet I-6 - Existing Assessment Analysis
Purpose: Evaluate any existing impact, vulnerability or hazards assessment to determine whether it provides useful information or analysis of the focus area identified in my assessment scope.
Worksheet 1.7 - Impact Description and Characterization
Purpose: Document and describe current and future climate impacts on your focus area from multiple plausible future conditions.
Worksheet II.1 - Potential Action Alternatives
Purpose: Assemble and screen a list of potential action alternatives that are feasible and appropriate for your installation.
Worksheet III.1 - Life Cycle Cost Analysis
Purpose: Develop conceptual costs for action alternatives. You will use the non-monetized benefits identified in Worksheet I.1 as performance metrics, and estimate and assemble life cycle costs for each action alternative.
Worksheet III.2 - Cost Effectiveness Analysis
Purpose: Conduct a preliminary screening of your list of action alternatives by applying cost effectiveness analysis, using information from Worksheets II.1 and III.1. Using this type of analysis before a full benefit cost analysis can inform an objective decision making process.
Worksheet III.3 - Benefits
Purpose: Record and transfer the monetary values for the direct, indirect, and cumulative benefits of each action alternative under consideration.
Worksheet III.4 - Benefit Cost Ratio and Net Present Value
Purpose: Use this worksheet to bring together costs and benefits to calculate BCR and NPV. This sheet could be used to evaluate a combined action alternative approach.
Worksheet IV.1 - Portfolio Summary
Purpose: Assemble information generated in the previous stages into a concise summary that presents the results of the analyses conducted using this Handbook.

Worksheet I.1 - Assessment Scope **Name:** **Last Update Date:**

Purpose: Develop an assessment scope to maintain focus and discipline through a complex analytical process. Document answers and assumptions to develop an assessment scope and guide preliminary research steps needed to develop a problem statement, which is the output of this stage.

Step 1: Enter your answers, assumptions, and any additional helpful notes (e.g., source or date of requirement) in the columns below.

Question	Answer(s)	Assumption(s)	Additional Notes
What area / sector / asset do you wish to assess? *Considerations: Entire installation? A portion of the installation? A particular sector? A particular system or asset? Does the sector/system provide or require a resource - e.g., drinking water from an aquifer or river? Electricity source?*			
What hazards do you wish to assess? (This also defines the Hazard of Concern.) *Considerations: Flooding? Permanent inundation? Heat stress? Erosion? Drought?*			
What weather or climate phenomena are associated with the hazard of concern you wish to address? *Considerations: Sea level change? Storm surge? Changes in precipitation or temperature? Possibility of heavy or reduced precipitation events?*			
What decision / process / plan do you wish to inform? *Considerations: Did someone direct you to complete the study for a particular purpose? An investment decision? A risk management plan? Installation development planning process? A natural resource management plan? A constraints map?*			
What type of information does that decision/process need? *Considerations: A map with flooding demarcation? A list of impacts to particular infrastructure?*			
Over what timeframe do you wish to assess impacts, in addition to the current condition? *Considerations: How far into the future is your current or planned sector, system or asset expected to perform?*			
Is there any additional direction or criteria that should be included in your assumptions? *Considerations: Were you provided a particular schedule for completion?*			

Step 2: Document your answers in the appropriate rows below. Handbook text will aid you in this step.

Assessment Scope:
Hazard(s) of Concern:
Weather/Climate Phenomena:

Worksheet I.2 - Site Information Quality Assessment **Name:** **Last Update Date:**

Purpose: To identify and assess necessary datasets, information, and expertise to evaluate impacts on the focus area established during your assessment scope development. This information will help you prepare Worksheets I.3 and Worksheet I.7.

Step 1: Document your answers from Worksheet I.1 in the 3 rows below. Remember to focus on the answers and assumptions you recorded in answer to the question - *What type of information does that decision/process need?* in Worksheet I.1.

Assessment Scope:	
Hazard(s) of Concern:	
Weather/Climate Phenomenon	

Step 2: Document your answers in the rows below using the notes located at the bottom of the spreadsheet.

		Metadata / Data Quality Assessment							
Data Set	**Do you have this?**	**Data Type**	**Data Source**	**Data Date**	**Reference Datum**	**Spatial Resolution**	**Limitations**	**Additional Notes**	**From whom and how can you get information?**

Notes	
Data Set	Enter the data set (one in each row) you believe would be useful to evaluate the impacts noted in the assessment scope
Do you have this?	Enter Yes or No depending upon whether this data set is already available
Data Type	Enter data description if known (e.g., spatial, tabular, graphic, descriptive, qualitative, quantitative, modeled, measured, etc.); if not known, enter TBD
Data Source	Enter the source of the data (e.g., name of document, author, database, etc.)
Data Date	Enter the date (e.g., date accessed, report date, etc.)
Reference Datum	Enter reference datum (e.g., NAVD88, MSL, MHW, MHHW, etc.); Note: this data element may not apply to all types of data
Spatial Resolution	Enter the spatial resolution (e.g., measure of the accuracy or detail) of the data
Limitations	Enter information relating to limitations of the data (e.g., could information be outdated? May not cover the focus area, etc.)
Additional Notes	Enter information that does not fall under one of the other column headings
From whom and how can you get information?	Describe how you might get this information and from whom. Note how long it might take and whether a formal procurement might be necessary

Worksheet I.3 - Historical Weather Event and Impacts Information **Name:** **Last Update Date:**

Purpose: Learn about and record information regarding past events and their impacts upon the focus area identified in the assessment scope. Historical event information may provide some sense of how susceptible or sensitive the site and its infrastructure have been and shed light on how future events may impact the focus area. This information could be helpful as you complete Worksheet I.7, but is not critical.

Important: Complete one worksheet for each type of past event (or representative past event)
Step 1: Complete the next 3 rows:
- Hazard(s) of Concern: transfer information from Worksheet I.1
- Event Type/Date: List event type (e.g., snow, wind, flooding due to storm surge, heavy precipitation event, drought, etc.) and date(s) of occurrence; list information source.
- Event Characteristics - List all characteristics you think would be useful to know about the event and its impacts - e.g., duration of event, height of storm surge, number of inches of precipitation. List information source.

Hazard(s) of Concern:		**Information Source / Date**
Event Type / Date(s):		
Event Characteristics:		

Step 2: Document your answers in the rows below using the notes located at the bottom of the spreadsheet.

Impacted Sector/Asset/Area Name	Impact Description	Impact Magnitude	Recovery	Information Source / Date

Notes	
Impacted Sector/Asset/Area Name	Enter the sector / asset / area name or other identifier for which you will describe impacts, etc.
Impact Description	Enter text describing the impact of the event on the sector or asset. Include information regarding critical thresholds (tipping points) at which damage to particular structure/assets occurred (e.g., finished floor height or height of building entry points through which water could penetrate; road height). Include specifics when known (e.g., building #s, linear feet, cubic feet, etc.)
Impact Magnitude	Enter the order of magnitude (i.e., 1-Insignificant, 2-Minor, 3-Moderate, 4-Major, or 5-Catastrophic) for each Sector that best describes the impacts using the definitions below (Table I.2 in Handbook)
Recovery	List any useful information relative to event recovery (e.g., time, cost, actions)
Information Source / Date	Enter information source and date (e.g., date accessed, report date, etc.)

Impact Magnitude
5 - Catastrophic - Permanent damage and/or loss of infrastructure service.
4 - Major - Extensive infrastructure damage requiring extensive repair.
3 - Moderate - Widespread infrastructure damage and loss of service. Damage recoverable by maintenance and minor repair.
2 - Minor - Localized infrastructure service disruption. No permanent damage.
1 - Insignificant - No infrastructure damage.
Adapted from CSIRO, 2007.

Worksheet I.4 - Climate Information Requirements & Attributes **Name:** **Last Update Date:**

Purpose: To identify and record which climate data are needed to delineate and evaluate the hazard of concern and weather/climate phenomena identified in the assessment scope and Worksheet I.1, and to assess the quality and type of climate data available.

Step 1: Complete the next 3 rows using information from Worksheet I.2.

Assessment Scope:	*0*
Hazard of Concern:	*0*
Weather/Climate Phenomena:	*0*

Step 2: Document your answers in the rows below using the notes located at the bottom of the spreadsheet.

Data Needed		**Metadata / Data Quality Assessment**										
Weather/Climate Phenomena	**Do you have this?**	**Data Type**	**Data Source**	**Data Date**	**Spatial Resolution**	**Reference Datum**	**Baseline Year**	**Emissions Scenarios**	**Future Timeslices**	**Future Climate Scenarios or Weather Events**	**Limitations**	**Additional Notes**
Current Conditions												
Future Conditions												

Notes	
Weather/Climate Phenomena	Under both Current Conditions and Future Conditions, enter a new row for each weather/climate phenomena you identified
Do you have this?	Enter Yes or No depending upon whether this data set is already available. If your answer if "no," you have documented what you need and can update this worksheet later when the data is obtained.
Data Type	Enter data description (e.g., values, spatial, graphic, qualitative, quantitative, modeled, measured, etc.); if not known, enter TBD
Data Source	Enter the source of the data (e.g., name of document, author, database, etc.)
Data Date	Enter the date (e.g., date accessed, report date, etc.)
Spatial Resolution	Enter the spatial resolution of the data, where applicable (e.g., 1 degree, 10 meter, 1 foot, etc.)
Reference Datum	Enter reference datum (e.g., NAVD88, MSL, MHW, MHHW, etc.); Note: this data element may not apply to all types of data
Baseline Year	Enter Baseline Year for your data (e.g., center year of a baseline period of time, such as a tidal epoch if associated with sea level change)
Emissions Scenarios	Enter the emission scenario(s) used to generate the data (e.g., SRES B1, RCP 2.6, RCP 8.5, etc.). Note: this data element is relevant only to Future Conditions.
Future Timeslices	Enter the number and dates of available timeslices. Note: this data element is relevant only to Future Conditions.
Future Climate Scenarios or Weather Events	Enter the number and names of available scenarios (e.g., global/regional scenarios) or events (e.g. 1% or 20% annual chance event). Note: this data element is relevant only to Future Conditions.
Limitations	Enter information relating to limitations of the data (e.g., is it qualitative or quantitative? etc.)
Additional Notes	Enter information that does not fall under one of the other column headings

Worksheet I.5 - Current and Plausible Future Conditions

Name: **Last Update Date:**

Purpose: Confirm important site reference information (e.g., site reference datum and unit of measure) and document baseline and plausible future condition information.

Step 1: Complete the next 3 rows using information from Worksheet I.2.

Assessment Scope:	*0*
Hazard of Concern:	*0*
Weather/Climate Phenomena:	*0*

Step 2: Document your site reference datum and what unit of measure (feet or meters) you will use.

Site Reference Information			
Site Reference Datum:		**Unit (Feet or Meters):**	

Step 3: Document the offset values that are necessary to ensure that your data is relative to your preferred reference datum.

Raw Data & Adjustments			
Data Category (Datum or Event)	**Offset**	**Above/Below Indicator**	**Source**

Step 4: Document your answers in the rows below using the notes located at the bottom of the spreadsheet.

Current / Future Condition Parameters ➡	**Current Conditions**		**Plausible Future Conditions**											
Information Source ⬇														
Data Converted to Reference Datum		*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Data														
Data Conversion Notes:														

Notes (In the order they should be performed; not in the order they appear in Column A)	
Information Source	Enter the name of your information source below the title cell (from Worksheet I.4)
Current / Future Condition Parameters	Enter the parameters of your evaluation in the cells to the right (e.g., year and data name for Current Conditions; the chosen timeslices and climate scenarios for the Plausible Future Conditions). Enter the weather/climate phenomena under each set of timeslices and climate scenarios
Data	Enter the values for your chosen timeslices and scenarios for each weather/climate phenomena
Data Converted to Reference	Perform calculations if necessary due to offsets and place those values in this row. Refer to Appendix C, Section 3 for discussion about how to align
Data Conversion Notes	You may wish to document what conversion took place in this row

Worksheet I.6 - Existing Assessment Evaluation **Name:** **Last Update Date:**

Purpose: Evaluate any existing impact, vulnerability or hazards assessment to determine whether it provides useful information or analysis of the focus area identified in my assessment scope.

Step 1: Complete the next 3 rows using information from Worksheet I.2.

Assessment Scope:	*0*
Hazard of Concern:	*0*
Weather/Climate Factor:	*0*

Step 2: Answer the questions below. Refer to the Notes located at the bottom of the spreadsheet for the last question.

Question	**Answer**	**Additional Notes**
Assessment Name / Source / Date		
Does it address the assessment scope?		
Does it address the hazard of concern?		
Does it include data relative to the weather/climate fact of interest?		
Purpose: Evaluate any existing impact, vulnerability or hazards assessment to determine whether it provides useful information or analysis of the focus area identified in my assessment scope.		
What outputs did the assessment generate that you think might be useful to your current purpose statement and why?*		

Step 3: If the existing assessment utilized climate data, complete a new Worksheet I.4.1 and title it Existing Assessment Climate Information & Attributes.

How does this evaluation's climate data relate to your original Worksheet I.4?		

***Notes. Things to consider - Did the assessment:**
- Provide preliminary prioritized inventory and maps of impacted assets, systems and functions?
- Indicate what assets are at risk from projected climate change? What types of climate variables?
- Update constraints maps or flood hazard areas?
- Assess exposure of assets within new Flood Hazard Areas?
- Identify internal and external interdependence and interconnectivity of systems and functions?
- Identify potential Master Plan changes/trends through the selected climate timeslices?
- Identify common risk exposure among community and Installation (current and future milestone years)?

Worksheet 1.7 - Impact Description and Characterization **Name:** **Last Update Date:**

Purpose: Document and describe current and future climate impacts on your focus area from multiple plausible future conditions.

Note: You may decide to complete more than one Worksheet I.7. You may find it useful to address one infrastructure category, sector, asset or area per sheet. You may decide you wish to have only one timeframe per sheet. You may wish to address different types of hazards and associated climate phenomena on the same sheet (e.g., flooding and temperature changes). You can make modifications to this sheet for your use.

Step 1: Complete the next 3 rows using information from Worksheet I.2.

Assessment Scope:	*0*
Hazard of Concern:	*0*
Weather/Climate Factor:	*0*

Step 2: Document your site reference datum and what unit of measure (feet of meters) you are using from Worksheet I.5.

Site Reference Information			
Site Reference Datum:	*0*	**Unit (Feet or Meters):**	*0*

Step 3: Document your answers in the rows and columns below using the notes located at the bottom of the spreadsheet.

Current / Future Condition Parameters ➡	**Current Conditions**		**Plausible Future Conditions**												
	#VALUE!		*#VALUE!*				*#VALUE!*				*#VALUE!*			
Information Source ⬇			*#VALUE!*		*#VALUE!*		*#VALUE!*		*#VALUE!*		*#VALUE!*		*#VALUE!*	
0		*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
		0.0	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Current & Potential Hazards ➡														
Impacted Sector/Asset/Area Name ⬇	**Impact Magnitude**		**Impact Magnitude**		**Impact Magnitude**		**Impact Magnitude**		**Impact Magnitude**		**Impact Magnitude**		**Impact Magnitude**	
Current & Potential Impacts Descriptions														

Notes	
Information Source	Enter this Information from Worksheet I.5
Current / Future Condition Parameters	Enter this Information from Worksheet I.5
Current & Potential Hazards	Use the generated maps and consultation with subject matter experts to identify and enter the hazard associated with each Current or Plausible Future Condition (e.g., flooding, debris, erosion, permanent inundation, etc.) Remember a hazard is how we experience the weather or climate phenomenon. For example, we may experience flooding due to storm surge (a weather phenomenon) or via climate phenomena such as permanent inundation due to sea level change or flooding due to changes in precipitation patterns that yield heavier rainfall events.
Impacted Sector/Asset/Area Name	Enter the sector / asset / area name or other identifier for which you will describe impacts in the rows below the title cell
Impact Magnitude	Enter the order of magnitude (i.e., 1-Insignificant, 2-Minor, 3-Moderate, 4-Major, or 5-Catastrophic) that best describes the impacts for each Sector using the definitions below (Table 1.2 in Handbook). Carryover magnitude information for Current Condition from Worksheet 1.3
Current & Potential Impacts	Enter descriptions of the current impacts (e.g., from Worksheet I. 3) under Current Conditions heading and potential future impacts (e.g., based upon your analyses) under the Plausible Future Conditions headings). Enter as much specificity as you can (e.g., # of buildings, linear feet of road, etc.)

Impact Magnitude
5 - Catastrophic - Permanent damage and/or loss of infrastructure service.
4 - Major - Extensive infrastructure damage requiring extensive repair.
3 - Moderate - Widespread infrastructure damage and loss of service. Damage recoverable by maintenance and minor repair.
2 - Minor - Localized infrastructure service disruption. No permanent damage.
1 - Insignificant - No infrastructure damage.
Adapted from CSIRO 2007.

Worksheet II.1 - Potential Action Alternatives | **Name:** | **Last Update Date:**

Purpose: Assemble and screen a list of potential action alternatives that are feasible and appropriate for your installation.

Step 1: Document the problem statement you generated at the conclusion of Stage I. You may choose to separate out gradual events (e.g., sea level change) from extreme events (e.g. storm surge).

Problem Statement		

Step 2: Document your answers in the rows and columns below using the notes located at the bottom of the spreadsheet.

Column A - Action Alternatives		**Column B - Benefits & Limitations**		**Column C - Feasibility**	**Column D - Appropriateness**	**Column E - Characterization of Strategic Approach to Decisions under Uncertainty**			
Alt ID #	**Description**	**Benefits**	**Limitations (Disbenefits)**			**No Regrets**	**Reversible Flexible**	**Safety Margin**	**Reduced Time Horizon**
	Structural Approaches								
	Natural and Nature-based Approaches								
	Facilities Approaches								
	Non-facilities Approaches								

Notes	
Column A - Action Alternatives	Enter your list of action alternatives. Assign each an Alt ID# and provide a brief description of adaptation measures that would address the impacts identified for one or all sectors. It is expected you will include multiple action alternatives that achieve the same effect. This worksheet is the opportunity to list all possibilities.
Column B - Benefits & Limitations (Disbenefits)	List the main benefits and limitations of each action alternative. Document the size of the area protected. Strive to use the same units (SF, acres) so alternatives can be compared during the Cost Effectiveness Analysis (CEA) in Stage III.
Column C - Feasibility	Document whether potential action alternative is feasible or not; provide a brief reason why an action alternative is currently NOT feasible
Column D - Appropriateness	Document whether potential action alternative is appropriate or not; provide a brief reason why an action alternative is currently NOT appropriate
Column E - Characterization of Strategic Approach to Decision Uncertainty	Indicate which strategy type(s) the action alternative represents

Worksheet III.1 - Life Cycle Cost Analysis

Name: **Last Update Date:**

Purpose: Develop conceptual costs for action alternatives. You will use the non-monetized benefits identified in Worksheet I.1 as performance metrics, and estimate and assemble life cycle costs for each action alternative.

Document your answers in the rows and columns below using the notes located at the bottom of the spreadsheet. More information can be found in Appendix E, Fact Sheet 1: Life Cycle Cost Analysis.

CAPITAL COSTS									Construction Schedule / % Completion by Year				
Alt ID #	Item Description	Quantity	Units	Unit Cost	Estimated Amount	Contingency %	Contingency Amount ($)	Total Cost	Yr 1	Yr 2	Yr 3	.....	Yr t
	Subtotal:							$0	$0	$0			
	Subtotal:							$0	$0	$0			
	Subtotal:							$0		$0			
	Subtotal:							$0	$0	$0	$0		
Total Capital Costs:								$0					

ANNUAL OPERATIONAL & MAINTENANCE (O&M) COSTS							
Alt ID #	Item Description	Frequency	N=	Nominal Annual Amt.	Cumulative Present Value	% of Total:	Assumption
Subtotal:				$ -		0.0%	

PERIODIC REPLACEMENT/RENEWAL COSTS						
Alt ID #	Item Description	Periodic Frequency	N=	Periodic Amount	Cumulative Present Value	Assumption
Subtotal:				$ -		

Notes

CAPITAL COSTS	
Alt ID #	Enter alternative number from WS II.1
Item Description	Enter brief action alternative descriptor and list the materials and inputs that comprise capital costs
Quantity	Enter quantity of material or input
Units	Enter appropriate unit for that material or input (e.g., EA, CY, etc.)
Unit Cost	Enter unit cost for that material or input. Source unit costs from feasibility studies, preliminary engineering design studies/concept costs or use parametric costing tools such as R.S. Means
Estimated Amount	Calculate estimated amount (quantity x unit cost)
Contingency %	Enter contingency %
Contingency Amount ($)	Calculate contingency amount
Total Cost	Sum the Estimated and Contingency Amounts
Construction Schedule / % Completion by Year	Apply the estimated construction schedule, and enter appropriate column headers with Yr # and % completion by year. These are initial costs or upfront capital expenditures. Subtotal row should calculate the subtotaled cost by %.
ANNUAL OPERATIONAL & MAINTENANCE (O&M) COSTS	
Alt ID #	Enter alternative number from WS II.1
Item Description	Enter brief action alternative descriptor
Frequency	Enter frequency that O&M costs would occur (e.g., annual, weekly, etc.)
N=	Enter number of years for the alternative's useful life. Enter number of O&M costs occurrences you anticipate.
Nominal Annual Amt	Enter a nominal annual cost
Cumulative Present Value	Calculate cumulative present value for each O&M cost
% of Total	If you anticipate combining several action alternatives together, you may find it useful to understand the relative size and share of total annual O&M costs per each alternative.
Assumption	Enter your O&M cost assumptions
PERIODIC REPLACEMENT/RENEWAL COSTS	
Alt ID #	Enter alternative number from WS II.1
Item Description	Enter brief action alternative descriptor and periodic activity that should occur
Periodic Frequency	Enter frequency that O&M costs would occur (e.g., annual, weekly, etc.)
N=	Enter number of years for the alternative's useful life. Enter number of replacement/renewal costs occurrences you anticipate over the life of the alternative
Cumulative Present Value	Calculate cumulative present value for each replacement/renewal cost
Assumption	Enter your assumptions

Worksheet III.2 - Cost Effectiveness Analysis **Name:** **Last Update Date:**

Purpose: Conduct a preliminary screening of your list of action alternatives by applying cost effectiveness analysis, using information from Worksheets II.1 and III.1. Using this type of analysis before a full benefit cost analysis can inform an objective decision making process.

Document your answers in the rows and columns below using the notes located at the bottom of the spreadsheet.

Alt ID #	Alternative Description	NPV Life Cycle Costs of Action Alternative	Performance Metric* (xxx)	Cost per Unit	Notes
	Subtotal:			#DIV/0!	
	Subtotal:			#DIV/0!	
	Subtotal:			#DIV/0!	
	Subtotal:			#DIV/0!	
	Subtotal:			#DIV/0!	
	Subtotal:			#DIV/0!	
	Subtotal:			#DIV/0!	

***Performance metric unit**

Notes	
Alt ID #	Enter alternative number from WS II.1
Alternative Description	Enter brief action alternative descriptor
NPV Life Cycle Costs of Action Alternative	Calculate and enter the Net Present Value (NPV) Life Cycle Costs of the action alternative life cycle costs found in WS III.1 LCCA
Performance Metric	Enter the common performance metric you have chosen for the your action alternatives. You may choose to place the performance metric acronym (e.g., SF) in the Performance Metric column header
Cost per Unit	Calculate and enter the cost per unit (NPV life cycle costs divided by performance metric)
Notes	Enter appropriate notes

Worksheet III.3 - Benefits

Purpose: Record and transfer the monetary values for the direct, indirect, and cumulative benefits of each action alternative under consideration.

Step 1. Transfer the monetized benefits for each year from the output from one of the Monetization tools you have applied. The benefits categories below are those that have been monetized. Be advised that you may not be able to monetize all of these category groupings in this phase; in Stage IV you will be able to document non-monetized benefits. You may choose to complete more than one worksheet so that you can back up your detailed analyses with more specific input worksheets or dependent data and information. The Notional Installation Hypothetical Data table is an example of how you can capture your assumptions and data. You can also set up calculations in the Benefits columns themselves, if useful.

Year	Year Number	I. Resilience Benefit Values					II. Economic Revitalization Benefit Values	III. Installation / Community Benefit Values	IV. Environmental / Ecosystem Benefit Values	V. Other Benefits / Intangibles Values	VI. Total Benefits
		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0	$0	$0	$0	$0	#DIV/0!
Cumulative Present Value		#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	$0.00	$0.00	$0.00	$0.00	$0.00	#DIV/0!

This box shows the assumptions and parameters used to develop benefit estimates

Notional Installation Hypothetical Data ↓	Parameters
Buildings at risk/sq. ft.	
Weighted Average Cost/sq.ft. BRV	
Percent of structure damaged at this flood level (USACE Depth	
SLR accretion rate (increment to DDF)	
Return period	
Discount Rate:	
Ecosystem Service Acres Created:	
Value of Supporting Services: New Habitat ($/acre)	
Value of Regulating Services: Hurricane Hazard Risk Reduction	
Contents works out to be 25% of structure BRV:	
(based on applying Tool X)	
Vehicle Assumptions:	
No. of vehicles inundated:	
Value per vehicle	
Percent of vehicle damaged	
Critical Infrastructure Assumption:	
Estimated total value of damage, (obtain from Study X).	

Notes	
Year	Enter first year of alternative implementation from WS III.1
Year #	Start with '0' and include the "N" value from WS III.1
I. Resilience Benefit Values (Avoided Damages to):	
Structures	Take product of Bldg sq. ft. x BRV x % of structure damaged x Annual Probability of occurrence (1%). Insert value every 5 yrs. Increase % of structural damage by 1% every 6 yrs (SLR). Spreadsheet calculates other years automatically.
Building Contents	Enter a $ value or use a building contents damage factor (in this case, 25%) and multiply versus Column (a) values
Vehicles	Enter a $ value or apply some vehicle assumptions x Annual Probability of occurrence (1%)
Critical Infrastructure	Take product of critical infrastructure value x Annual Probability of occurrence (1%)
Other	Placeholder: could potentially be value of displacement costs, emergency costs, injuries etc.
II. Economic Revitalization Benefit Values	Enter a $ value or use a calculation similar to one in Notional Installation Hypothetical Data table
III. Installation / Community Benefit Values	Enter a $ value or use a calculation similar to one in Notional Installation Hypothetical Data table
IV. Environmental / Ecosystem Benefit Values	Enter a $ value or use a calculation similar to one in Notional Installation Hypothetical Data table
V. Other Benefits / Intangibles Values	Enter a $ value or use a calculation similar to one in Notional Installation Hypothetical Data table
VI. Total Benefits	Sum value of each row

Worksheet III.4 - Benefit Cost Ratio and Net Present Value (Grouping Strategy)

Purpose: Use this worksheet to bring together costs and benefits to calculate BCR and NPV. This sheet could be used to evaluate a combined action alternative approach.

Step 1. Enter your Action Alternative descriptor or title. Enter the Discount Rate.

Action Alternative:

Discount Rate, *i* =

Step 2. Document your answers in the rows and columns below using the notes located at the bottom of the spreadsheet.

		Life Cycle Costs: (constant dollars)								Benefits			
Year	**Year #**	**I. Capital Costs**				**II. Annual O&M**	**III. Renewal , Replacement Costs (various years)**		**Total Costs**			**Total Monetized Benefits**	**Total Monetized Benefits less Total Costs**
		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
Cumulative Present Values:		$0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	#DIV/0!	

Benefit Cost Ratio: BCR	#DIV/0!
Internal Rate of Return (IRR)	#VALUE!
Net Present Value (NPV)	#DIV/0!

Notes	
Year	Enter first year of alternative implementation from WS III.1
Year #	Start with '0' and include the "N" value from WS III.1
Life Cycle Costs	Transfer the appropriate values from WS III.1. If helpful, add columns with further detail about the particular costs. Sum the rows to calculate Total Costs.
Benefits	Transfer the appropriate values from WS III.3 or from other spreadsheet or monetization tool you have used to calculate benefit values. Sum the rows to calculate Total Monetized Benefits.
Total Monetized Benefits less Total Costs	Subtract Total Costs from Total Monetized Benefits
Cumulative Present Values	The net present value formula (referencing the discount rate) should be applied to the sum of each column after the 1st year of activity + the 1st year
Benefit Cost Ratio: BCR	Calculate BCR (Total Monetized Benefits divided by Total Costs)
Internal Rate of Return (IRR)	Calculate IRR [The rate that renders the present value of the cost stream (future annual costs) equal to the present value of the benefits stream (future annual benefits)]
Net Present Value (NPV)	Calculate NPV (absolute difference between the cumulative *present* value of benefits and the cumulative *present* value of costs)

The formula for the benefit cost ratio is shown below

$$\frac{\sum_{t=0}^{n} \frac{B_t}{(1+i)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+i)^t}}$$

Worksheet III.4 - Benefit Cost Ratio and Net Present Value (Single Action Alternative)

Purpose: Use this worksheet to bring together costs and benefits to calculate BCR and NPV. This sheet could be used to evaluate a single action alternative.

Step 1. Enter your Action Alternative descriptor or title. Enter the Discount Rate.

Action Alternative:

Discount Rate, *i* =

Step 2. Document your answers in the rows and columns below using the notes located at the bottom of the spreadsheet.

		Life Cycle Costs: (constant dollars)			Benefits			Total Monetized Benefits less Total Costs
Year	Year #	I. Capital Costs	II. Annual O&M	Total Costs			Total Monetized Benefits	
2016	0	$0	$0	$0	$0	$0	$0	$0
2017	1	$0	$0	$0	$0	$0	$0	$0
2018	2	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2019	3	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2020	4	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2021	5	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2022	6	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2023	7	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2024	8	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2025	9	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2026	10	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2027	11	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2028	12	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2029	13	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2030	14	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2031	15	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2032	16	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2033	17	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2034	18	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2035	19	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2036	20	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2037	21	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2038	22	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2039	23	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2040	24	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2041	25	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2042	26	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2043	27	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2044	28	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2045	29	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2046	30	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2047	31	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2048	32	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2049	33	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2050	34	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2051	35	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2052	36	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2053	37	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2054	38	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2055	39	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2056	40	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2057	41	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2058	42	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2059	43	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2060	44	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2061	45	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2062	46	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2063	47	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2064	48	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2065	49	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
2066	50	$0	$0	$0	#DIV/0!	$0	#DIV/0!	#DIV/0!
Cumulative Present Values:		$0	$0	$0	#DIV/0!	$0	#DIV/0!	

Benefit Cost Ratio: BCR	***#DIV/0!***
Internal Rate of Return (IRR)	***#VALUE!***
Net Present Value (NPV)	***#DIV/0!***

Notes	
Year	Enter first year of alternative implementation from WS III.1
Year #	Start with '0' and include the "N" value from WS III.1
Life Cycle Costs	Transfer the appropriate values from WS III.1. If helpful, add columns with further detail about the particular costs. Sum the rows to calculate Total Costs.
Benefits	Transfer the appropriate values from WS III.3 or from other spreadsheet or monetization tool you have used to calculate benefit values. Sum the rows to calculate Total Monetized Benefits.
Total Monetized Benefits less	Subtract Total Costs from Total Monetized Benefits
Cumulative Present Values	The net present value formula (referencing the discount rate) should be applied to the sum of each column after the 1st year of activity + the 1st year
Benefit Cost Ratio: BCR	Calculate BCR (Total Monetized Benefits divided by Total Costs)
Internal Rate of Return (IRR)	Calculate IRR [The rate that renders the present value of the cost stream (future annual costs) equal to the present value of the benefits stream (future annual benefits)]
Net Present Value (NPV)	Calculate NPV (absolute difference between the cumulative *present* value of benefits and the cumulative *present* value of costs)

Worksheet IV.1 - Portfolio Summary

Purpose: Assemble information generated in the previous stages into a concise summary that presents the results of the analyses conducted using this Handbook.

Step 1: Document the problem statement you generated at the conclusion of Stage I. You may choose to separate out gradual events (e.g., sea level change) from extreme events (e.g. storm surge).

Problem Statement	*0*	*0*

Step 2. Document your answers in the rows and columns below using the notes located at the bottom of the spreadsheet.

Column A - Action Alternative Description & Key Benefits			**Column B - Key Metrics**				**Column C - Non-Monetized Benefits & Limitations (Disbenefits)**		**Column D - Key Future Variables**			**Column E - Strategic Approach to Decisions under Uncertainty**	**Column F - Risk Approach Type**
Alt ID #	**Action Alternative Description**	**Key Benefits**	**Total Life Cycle Costs**	**Total Monetized Benefits**	**Total Monetized Benefits Less Costs (Net Present Value)**	**Benefit Cost Ratio**	**Non-monetized Benefits**	**Non-monetized Limitations (Disbenefits)**	**External Events**	**Funding Constraints**	**Pivot Points and Data Gaps**	• No-regrets strategies • Reversible and flexible strategies • Safety margin strategies • Reduced time-horizon strategies	• Assume Risk • Transfer or Share Risk • Control Risk • Avoid Risk
	#VALUE!		*$0*	*#DIV/0!*	*#DIV/0!*	-							
			#REF!	*#REF!*	*#REF!*	*#REF!*							
			#REF!	*#REF!*	*#REF!*	*#REF!*							
			#REF!	*#REF!*	*#REF!*	*#REF!*							

Notes	
Column A - Action Alternative	Transfer the ID#, Description, and Key Benefits of each action alternative evaluated in Stage III
Column B - Key Metrics	Transfer the cumulative values for each of the key metrics from the worksheets in Stage III
Column C - Non-Monetized Benefits	List benefits and limitations (or disbenefits) that have not been monetized and included in the BCR
Column D - Key Future Variables	
External Events	Enter key external events that could impact the action alterative
Funding Constraints	Identify any funding constraints or issues
Pivot Points and Data Gaps	Identify conditions that will require evaluation or reevaluation of the action alternative
Column E - Strategic Approach to Decision under Uncertainty	Re-evaluate the assessment performed in Stage II, Step ⑤, regarding the type of strategic approach to decision uncertainty each action alternative represents. Enter same or new information
Column F - Risk Approach	Characterize the risk approach each action alternative represents

Appendix G – Completed Worksheets for Notional Installation

Instructions are in red text

Data entry fields are highlighted in blush

Blue italic text represents Notional Installation information

Worksheet Overview

Worksheet I.1 - Assessment Scope
Purpose: Develop an assessment scope to maintain focus and discipline through a complex analytical process. Document answers and assumptions to develop an assessment scope and guide preliminary research steps needed to develop a problem statement, which is the output of this stage.
Worksheet I.2 - Site Information Quality Assessment
Purpose: To identify and assess necessary datasets, information, and expertise to evaluate impacts on the focus area established during your assessment scope development. This information will help you prepare Worksheets I.3 and Worksheet I.7.
Worksheet I.3 - Historical Weather Event and Impacts Information
Purpose: Learn about and record information regarding past events and their impacts upon the focus area identified in the assessment scope. Historical event information may provide some sense of how susceptible or sensitive the site and its infrastructure have been and shed light on how future events may impact the focus area. This information could be helpful as you complete Worksheet I.7, but is not critical.
Worksheet I.4 - Climate Information Requirements and Attributes
Purpose: To identify and record which climate data are needed to delineate and evaluate the hazard of concern and weather/climate phenomena identified in the assessment scope and Worksheet I.1, and to assess the quality and type of climate data available.
Worksheet I.5 - Current and Plausible Future Conditions
Purpose: Confirm important site reference information (e.g., site reference datum and unit of measure) and document baseline and plausible future condition information.
Worksheet I-6 - Existing Assessment Evaluation
Purpose: Evaluate any existing impact, vulnerability or hazards assessment to determine whether it provides useful information or analysis of the focus area identified in my assessment scope.
Worksheet 1.7 - Impact Description and Characterization
Purpose: Document and describe current and future climate impacts on your focus area from multiple plausible future conditions.
Worksheet II.1 - Potential Action Alternatives
Purpose: Assemble and screen a list of potential action alternatives that are feasible and appropriate for your installation.
Worksheet III.1 - Life Cycle Cost Analysis
Purpose: Develop conceptual costs for action alternatives. You will use the non-monetized benefits identified in Worksheet I.1 as performance metrics, and estimate and assemble life cycle costs for each action alternative.
Worksheet III.2 - Cost Effectiveness Analysis
Purpose: Conduct a preliminary screening of your list of action alternatives by applying cost effectiveness analysis, using information from Worksheets II.1 and III.1. Using this type of analysis before a full benefit cost analysis can inform an objective decision making process.
Worksheet III.3 - Benefits
Purpose: Record and transfer the monetary values for the direct, indirect, and cumulative benefits of each action alternative under consideration.
Worksheet III.4 - Benefit Cost Ratio and Net Present Value
Purpose: Use this worksheet to bring together costs and benefits to calculate BCR and NPV.
Worksheet IV.1 - Portfolio Summary
Purpose: Assemble information generated in the previous stages into a concise summary that presents the results of the analyses conducted using this Handbook.

Worksheet I.1 - Assessment Scope **Name:** **Last Update Date:**

Purpose: Develop an assessment scope to maintain focus and discipline through a complex analytical process. Document answers and assumptions to develop an assessment scope and guide preliminary research steps needed to develop a problem statement, which is the output of this stage.

Step 1: Enter your answers, assumptions, and any additional helpful notes (e.g., source or date of requirement) in the columns below.

Question	Answer(s)	Assumption(s)	Additional Notes
What area / sector / asset do you wish to assess? *Considerations: Entire installation? A portion of the installation? A particular sector? A particular system or asset? Does the sector/system provide or require a resource - e.g., drinking water from an aquifer or river? Electricity source?*	*Potential negative impacts to existing and planned infrastructure across the entire installation.*	*Current land use will not significantly change; there is some flexibility in siting planned infrastructure.*	*Best to start with whole installation to determine where the primary impacts might be. Initial results may indicate geographic areas or infrastructure sectors that should be the focus of later analyses.*
What hazards do you wish to assess? (This also defines the Hazard of Concern.) *Considerations: Flooding? Permanent inundation? Heat stress? Erosion? Drought?*	*Permanent inundation and flooding.*	*Naval Station A is located along the coast and has experienced flooding impacts due to storm surge in the past. Assets located at lower elevations would be impacted by sea level change.*	*Starting with hazards that have had negative impacts in the past. May need to look at other possible hazards at a later date. For example, impact on water or energy sources.*
What weather or climate phenomena are associated with the hazard of concern you wish to address? *Considerations: Sea level change? Storm surge? Changes in precipitation or temperature? Possibility of heavy or reduced precipitation events?*	*Sea level change and storm surge (the 1% annual chance event or 100-year storm event).*	*These are the weather and climate phenomena that correlate to the hazards of concern - permanent inundation and flooding.*	
What decision / process / plan do you wish to inform? *Considerations: Did someone direct you to complete the study for a particular purpose? An investment decision? A risk management plan? Installation development planning process? A natural resource management plan? A constraints map?*	*Installation development planning*	*This is the best method to capture long-term actions and there is time to feed into the next IDP iteration.*	
What type of information does that decision/process need? *Considerations: A map with flooding demarcation? A list of impacts to particular infrastructure?*	*Base infrastructure map; maps with current and future flooding elevations and extent; description of impacts to site infrastructure.*	*The visualization of flooding and permanent inundation changing over time will allow planners to better understand the potential negative impacts and develop potential adaptation action alternatives.*	*I know my GIS staff and feel confident of their capabilities.*
Over what timeframe do you wish to assess impacts, in addition to the current condition? *Considerations: How far into the future is your current or planned sector, system or asset expected to perform?*	*Over the next 100 years*	*Naval Station A will be sustained in its current location for the long term.*	
Is there any additional direction or criteria that should be included in your assumptions? *Considerations: Were you provided a particular schedule for completion?*	*No additional direction*	*NA*	

Step 2: Document your answers in the appropriate rows below. Handbook text will aid you in this step.

Assessment Scope: *Given the stated assumptions in Worksheet I.1, determine how we can protect the installation infrastructure from damage due to flooding and permanent inundation over the next 100 years.*

Hazard(s) of Concern: *Permanent inundation and flooding*

Weather/Climate Phenomena: *Sea level change and storm surge (the 1% annual chance event or 100-year storm event)*

Worksheet I.2 - Site Information Quality Assessment **Name:** **Last Update Date:**

Purpose: To identify and assess necessary datasets, information, and expertise to evaluate impacts on the focus area established during your assessment scope development. This information will help you prepare Worksheets I.3 and Worksheet I.7.

Step 1: Document your answers from Worksheet I.1 in the 3 rows below. Remember to focus on the answers and assumptions you recorded in answer to the question - *What type of information does that decision/process need?* in Worksheet I.1.

Assessment Scope:	*Given the stated assumptions in Worksheet I.1, determine how we can protect the installation infrastructure from damage due to flooding and permanent inundation over the next 100 years.*
Hazard(s) of Concern:	*Permanent inundation and flooding*
Weather/Climate Phenomena	*Sea level change and storm surge (the 1% annual chance event or 100-year storm event)*

Step 2: Document your answers in the rows below using the notes located at the bottom of the spreadsheet.

		Metadata / Data Quality Assessment							
Data Set	**Do you have this?**	**Data Type**	**Data Source**	**Data Date**	**Reference Datum**	**Spatial Resolution**	**Limitations**	**Additional Notes**	**From whom and how can you get information?**
Common Installation Picture (CIP) Base map with vertical and horizontal infrastructure layers	*Yes*	*GIS layers*	*GeoReadiness Center (GRC)*	*2012*	*North American Vertical Datum of 1988 (NAVD 88)*	*1 ft*	*TBD*	*Need to be able to determine flooding height and extent at different flooding scenarios*	*Installation GIS experts*
Topographic map / vertical elevation data	*Yes*	*GIS layer*	*USGS Sandy Restoration Hydro Flattened LiDAR Digital Elevation Model (DEM)*	*2015*	*NAVD 88*	*1 ft*	*None*	*Contains 1 foot contour intervals*	*Installation GIS experts; USGS*
LIDAR	*Yes*	*Raster*	*TBD*	*TBD*	*TBD*	*TBD*	*May not cover the entire focus area*	*Need to go to GeoReadiness POC (too large for CIP)*	*Installation GIS and Remote Sensing experts*
Existing 100-Year Flood Hazard boundary	*Yes*	*GIS layer*	*FEMA*	*TBD*	*North American Vertical Datum of 1988 (NAVD 88)*	*1 ft*	*May be outdated?*	*CIP - link to FEMA data layer*	*Installation GIS experts*
Existing design element - design storm elevation of existing seawall	*Yes*	*Table*	*Seawall Design for Naval Station A*	*2000*	*NAVD 88*	*NA*	*Need to validate information quality*	*May be available in iNFADS or from review of Record Drawings, engineering studies. Perhaps NAVFAC Capital Improvements Business Line (CIBL).*	*Engineers (CIBL); Installation Public Works Depart (PWD)*
Existing design element - finished floor elevation of existing buildings without flood proofing	*Yes*	*Table*	*Record Drawings (As-builts); DD 1354*	*1965*	*NAVD 88*	*NA*	*Need to validate information quality*	*May require review of standards and confirmation in the field of existing conditions by installation staff or as part of Condition Assessment*	*Engineers (CIBL); Installation Public Works Depart (PWD)*
Shoreline Stabilization Project Summary	*Yes*	*Report*	*Engineering Firm X*	*2006*	*NA*	*NA*	*TBD*	*Was written after Hurricane Isabel in 2003 to address shoreline erosion*	*CIBL MILCON Magnagers; Environmental Business Line (ENV)*
After Action Reports	*TBD*	*TBD*	*TBD*	*TBD*	*TBD*	*NA*	*TBD*	*Site has experienced flooding impacts from storm surge in the past; perhaps these reports contain descriptions of impacts and work arounds.*	*Contact my local emergency management office; OPS Contingency Engineering; Contingency Engineering Response Team (CERT); Regional Operations Center (ROC)*
Operations & Maintenance Records	*TBD*	*TBD*	*TBD*	*TBD*	*TBD*	*NA*	*TBD*	*Site has experienced flooding impacts from storm surge in the past; perhaps these reports contain descriptions of impacts and fixes.*	*Contact my local operations and maintenance office at the PWD*

Notes	
Data Set	Enter the data set (one in each row) you believe would be useful to evaluate the impacts noted in the assessment scope
Do you have this?	Enter Yes or No depending upon whether this data set is already available
Data Type	Enter data description if known (e.g., spatial, tabular, graphic, descriptive, qualitative, quantitative, modeled, measured, etc.); if not known, enter TBD
Data Source	Enter the source of the data (e.g., name of document, author, database, etc.)
Data Date	Enter the date (e.g., date accessed, report date, etc.)
Reference Datum	Enter reference datum (e.g., NAVD88, MSL, MHW, MHHW, etc.); Note: this data element may not apply to all types of data
Spatial Resolution	Enter the spatial resolution (e.g., measure of the accuracy or detail) of the data
Limitations	Enter information relating to limitations of the data (e.g., could information be outdated? May not cover the focus area, etc.)
Additional Notes	Enter information that does not fall under one of the other column headings
From whom and how can you get information?	Describe how you might get this information and from whom. Note how long it might take and whether a formal procurement might be necessary

Worksheet I.3 - Historical Weather Event and Impacts Information

Name: **Last Update Date:**

Purpose: Learn about and record information regarding past events and their impacts upon the focus area identified in the assessment scope. Historical event information may provide some sense of how susceptible or sensitive the site and its infrastructure have been and shed light on how future events may impact the focus area. This information could be helpful as you complete Worksheet I.7, but is not critical.

Important: Complete one worksheet for each type of past event (or representative past event)
Step 1: Complete the next 3 rows:
- Hazard(s) of Concern: transfer information from Worksheet I.1
- Event Type/Date: List event type (e.g., snow, wind, flooding due to storm surge, heavy precipitation event, drought, etc.) and date(s) of occurrence; list information source.
- Event Characteristics - List all characteristics you think would be useful to know about the event and its impacts - e.g., duration of event, height of storm surge, number of inches of precipitation. List information source.

		Information Source / Date
Hazard(s) of Concern:	*Permanent inundation and flooding*	
Event Type / Date(s):	*Hurricane Isabel, 18 September 2003*	*14th AF Weather Squadron*
Event Characteristics:	*1 - Storm surge at Naval Station A about 5 ft.* *2 - About the Hurricane - greatest impact was storm surge rather than intensity or heavy rains; coastal high water marks surveyed in Western Shore counties showed surge elevations from 3.0 to 7.9 ft, averaging 6.5 ft*	*1 - Damage Assessment Teams (DAT) After action report, Dec 2003* *2 - Maryland Geological Survey (http://www.mgs.md.gov/coastal_geology/isabel/isabel2.html), accessed 9/9/16*

Step 2: Document your answers in the rows below using the notes located at the bottom of the spreadsheet.

Impacted Sector/Asset/Area Name	Impact Description	Impact Magnitude	Recovery	Information Source / Date
Buildings (Bldg #s)	*Temporary flooding in several building basements (A102, A202, B304, B404)*	*2 - Minor*	*Pumped out water and cleaned basements. Moved some equipment to higher floors.*	*1 - Damage Assessment Teams (DAT) After action report, Dec 2003* *2 - Interviews with operations and maintenance staff* *3 - Public Works maintenance logs*
Natural Infrastructure & Ecosystems	*Shoreline erosion (25K LF)*	*2 - Minor*	*Installed shoreline stabilization*	*Damage Assessment Teams (DAT) After action report, Dec 2003*
Transportation	*Storm debris on several roads caused access issues and service disruption for the waste water treatment plant (WWTP).*	*1 - Insignificant*	*Cleared roads*	*1 - Damage Assessment Teams (DAT) After action report, Dec 2003* *2 - SLVAS, finalized Jan 2015*

Notes	
Impacted Sector/Asset/Area Name	Enter the sector / asset / area name or other identifier for which you will describe impacts, etc.
Impact Description	Enter text describing the impact of the event on the sector or asset. Include information regarding critical thresholds (tipping points) at which damage to particular structure/assets occurred (e.g., finished floor height or height of building entry points through which water could penetrate; road height). Include specifics when known (e.g., building #s, linear feet, cubic feet, etc.)
Impact Magnitude	Enter the order of magnitude (i.e., 1-Insignificant, 2-Minor, 3-Moderate, 4-Major, or 5-Catastrophic) for each Sector that best describes the impacts using the definitions below (Table I.2 in Handbook)
Recovery	List any useful information relative to event recovery (e.g., time, cost, actions)
Information Source / Date	Enter information source and date (e.g., date accessed, report date, etc.)

Impact Magnitude
5 - Catastrophic - Permanent damage and/or loss of infrastructure service.
4 - Major - Extensive infrastructure damage requiring extensive repair.
3 - Moderate - Widespread infrastructure damage and loss of service. Damage recoverable by maintenance and minor repair.
2 - Minor - Localized infrastructure service disruption. No permanent damage.
1 - Insignificant - No infrastructure damage.
Adapted from CSIRO 2007.

Worksheet I.4 - Climate Information Requirements & Attributes **Name:** **Last Update Date:**

Purpose: To identify and record which climate data are needed to delineate and evaluate the hazard of concern and weather/climate phenomena identified in the assessment scope and Worksheet I.1, and to assess the quality and type of climate data available.

Step 1: Complete the next 3 rows using information from Worksheet I.2.

Assessment Scope:	*Given the stated assumptions in Worksheet I.1, determine how we can protect the installation infrastructure from damage due to flooding and permanent inundation over the next 100 years.*
Hazard of Concern:	*Permanent inundation, flooding*
Weather/Climate Phenomena:	*Sea level change and storm surge (the 1% annual chance event or 100-year storm event)*

Step 2: Document your answers in the rows below using the notes located at the bottom of the spreadsheet.

Data Needed		Metadata / Data Quality Assessment										
Weather/Climate Phenomena	**Do you have this?**	**Data Type**	**Data Source**	**Data Date**	**Spatial Resolution**	**Reference Datum**	**Baseline Year**	**Emissions Scenarios**	**Future Timeslices**	**Future Climate Scenarios or Weather Events**	**Limitations**	**Additional Notes**
Current Conditions												
Mean sea level	*Yes*	*Values*	*DoD Regionalized Sea Level Change and Extreme Water Scenarios*	*2016*	*NA*	*MSL*	*1992 (the 1983-2001 tidal epoch)*	*NA*	*NA*	*NA*	*Elevation value in database indicates lowest land elevation associated with the installation's GIS polygon, relative to a designated reference datum.*	*Current value for mean sea level is necessary to compare to future sea level change values*
1% chance event (100 year storm)	*Yes*	*Values*	*DoD Regionalized Sea Level Change and Extreme Water Scenarios*	*2016*	*NA*	*MHHW*	*1992 (the 1983-2001 tidal epoch)*	*NA*	*NA*	*NA*	*Does not account for ALL factors that may affect water levels, such as wave run-up (which include wave-set up and swash) - see Fig 3.12 in Hall et al. 2016.*	
Future Conditions												
Sea level change	*Yes*	*Values*	*DoD Regionalized Sea Level Change and Extreme Water Scenarios*	*2016*	*NA*	*MSL*	*1992 (the 1983-2001 tidal epoch)*	*RCP 2.6, 4.5 and 8.5*	*3 - 2035, 2065, 2100*	*5 - lowest, low, medium, high, highest*	*Elevation value in database indicates lowest land elevation associated with the installation's GIS polygon, relative to a designated reference datum.*	
1% chance event (100 year storm)	*Yes*	*Values*	*DoD Regionalized Sea Level Change and Extreme Water Scenarios*	*2016*	*NA*	*MHHW*	*1992 (the 1983-2001 tidal epoch)*	*NA*	*3 - 2035, 2065, 2100*	*4 - 1%, 2%, 5% and 20% annual chance events*	*Does not account for ALL factors that may affect water levels, such as wave run-up (which include wave-set up and swash) - see Fig 3.12 in Hall et al. 2016.*	

Notes	
Weather/Climate Phenomena	Under both Current Conditions and Future Conditions, enter a new row for each weather/climate phenomena you identified
Do you have this?	Enter Yes or No depending upon whether this data set is already available. If your answer if "no," you have documented what you need and can update this worksheet later when the data is obtained.
Data Type	Enter data description (e.g., values, spatial, graphic, qualitative, quantitative, modeled, measured, etc.); if not known, enter TBD
Data Source	Enter the source of the data (e.g., name of document, author, database, etc.)
Data Date	Enter the date (e.g., date accessed, report date, etc.)
Spatial Resolution	Enter the spatial resolution of the data, where applicable (e.g., 1 degree, 10 meter, 1 foot, etc.)
Reference Datum	Enter reference datum (e.g., NAVD88, MSL, MHW, MHHW, etc.); Note: this data element may not apply to all types of data
Baseline Year	Enter Baseline Year for your data (e.g., center year of a baseline period of time, such as a tidal epoch if associated with sea level change)
Emissions Scenarios	Enter the emission scenario(s) used to generate the data (e.g., SRES B1, RCP 2.6, RCP 8.5, etc.). Note: this data element is relevant only to Future Conditions.
Future Timeslices	Enter the number and dates of available timeslices. Note: this data element is relevant only to Future Conditions.
Future Climate Scenarios or Weather Events	Enter the number and names of available scenarios (e.g., global/regional scenarios) or events (e.g. 1% or 20% annual chance event). Note: this data element is relevant only to Future Conditions.
Limitations	Enter information relating to limitations of the data (e.g., is it qualitative or quantitative? etc.)
Additional Notes	Enter information that does not fall under one of the other column headings

Worksheet I.5 - Current and Plausible Future Conditions

Name: **Last Update Date:**

Purpose: Confirm important site reference information (e.g., site reference datum and unit of measure) and document baseline and plausible future condition information.

Step 1: Complete the next 3 rows using information from Worksheet I.2.

Assessment Scope:	*Given the stated assumptions in Worksheet I.1, determine how we can protect the installation infrastructure from damage due to flooding and permanent inundation over the next 100 years.*
Hazard of Concern:	*Permanent inundation and flooding*
Weather/Climate Phenomena:	*Sea level change and storm surge (the 1% annual chance event or 100-year storm event)*

Step 2: Document your site reference datum and what unit of measure (feet or meters) you will use.

Site Reference Information			
Site Reference Datum:	*NAVD88*	Unit (Feet or Meters):	*Feet*

Step 3: Document the offset values that are necessary to ensure that your data is relative to your preferred reference datum.

Raw Data & Adjustments			
Data Category (Datum or Event)	**Offset**	**Above/Below Indicator**	**Source**
MSL:	*0.092*	*below NAVD88*	*DoD RSLC EWLS Database*
MHHW:	*0.623*	*above NAVD88*	*DoD RSLC EWLS Database*
1% Chance Event (100-year storm)	*3.3*	*above MHHW*	*DoD RSLC EWLS Database - Single Gauge*

Step 4: Document your answers in the rows below using the notes located at the bottom of the spreadsheet.

Current / Future Condition Parameters	**Current Conditions**		**Plausible Future Conditions**											
	2016		*2035*				*2065*				*2100*			
Information Source			*Low scenario*		*Highest scenario*		*Low scenario*		*Highest scenario*		*Low scenario*		*Highest scenario*	
DoD Regionalized Sea Level Change and Extreme Water Scenarios; FOUO internal database		***1% annual chance event***	***Sea level change***	***Sea level change + 1% annual chance event***	***Sea level change***	***Sea level change + 1% annual chance event***	***Sea level change***	***Sea level change + 1% annual chance event***	***Sea level change***	***Sea level change + 1% annual chance event***	***Sea level change***	***Sea level change + 1% annual chance event***	***Sea level change***	***Sea level change + 1% annual chance event***
Data Converted to Reference Datum		***3.9***	***0.5***	***4.4***	***1.5***	***5.4***	***1.2***	***5.1***	***3.5***	***7.4***	***2.2***	***6.1***	***8.2***	***12.1***
Data		*3.3*	*0.6*	*4.5*	*1.6*	*5.5*	*1.3*	*5.2*	*3.6*	*7.5*	*2.3*	*6.2*	*8.3*	*12.2*
Data Conversion Notes:		*+MHHW*	*-MSL*	*-MSL*	*-MSL*	*-MSL*	*-MSL*	*-MSL*	*-MSL*	*-MSL*	*-MSL*	*-MSL*	*-MSL*	*-MSL*

Notes (In the order they should be performed; not in the order they appear in Column A)	
Information Source	Enter the name of your information source below the title cell (from Worksheet I.4)
Current / Future Condition Parameters	Enter the parameters of your evaluation in the cells to the right (e.g., year and data name for Current Conditions; the chosen timeslices and climate scenarios for the Plausible Future Conditions). Enter the weather/climate phenomena under each set of timeslices and climate scenarios
Data	Enter the values for your chosen timeslices and scenarios for each weather/climate phenomena
Data Converted to Reference	Perform calculations if necessary due to offsets and place those values in this row. Refer to Appendix C, Section 3 for discussion about how to align projection data to a common reference datum
Data Conversion Notes	You may wish to document what conversion took place in this row

Worksheet I.6 - Existing Assessment Evaluation **Name:** **Last Update Date:**

Purpose: Evaluate any existing impact, vulnerability or hazards assessment to determine whether it provides useful information or analysis of the focus area identified in my assessment scope.

Step 1: Complete the next 3 rows using information from Worksheet I.2.

Assessment Scope:	*Given the stated assumptions in Worksheet I.1, determine how we can protect the installation infrastructure from damage due to flooding and permanent inundation over the next 100 years.*
Hazard of Concern:	*Permanent inundation and flooding*
Weather/Climate Phenomena:	*Sea level change and storm surge (the 1% annual chance event or 100-year storm event)*

Step 2: Answer the questions below. Refer to the Notes located at the bottom of the spreadsheet for the last question.

Question	Answer	Additional Notes
Assessment Name / Source / Date	*Shoreline Stabilization Project Summary, Engineering Firm X, 2006*	
Does it address the assessment scope?	*Partially; addressed shoreline erosion caused by Hurricane Isabel*	
Does it address the hazard of concern?	*Partially; addressed flooding due to storm surge caused by Hurricane Isabel*	
Does it include data relative to the weather/climate fact of interest?	*No, it does not contain scenarios or projections for future storms*	
Purpose: Evaluate any existing impact, vulnerability or hazards assessment to determine whether it provides useful information or analysis of the focus area identified in my assessment scope.	*Documented the effects of Hurricane Isabel and outlined shoreline stabilization project*	
What outputs did the assessment generate that you think might be useful to your current purpose statement and why?*	*Maps of Hurricane Isabel flooding extent*	

Step 3: If the existing assessment utilized climate data, complete a new Worksheet I.4.1 and title it Existing Assessment Climate Information & Attributes.

How does this evaluation's climate data relate to your original Worksheet I.4?	*NA*	

***Notes. Things to consider - Did the assessment:**

- Provide preliminary prioritized inventory and maps of impacted assets, systems and functions?
- Indicate what assets are at risk from projected climate change? What types of climate variables?
- Update constraints maps or flood hazard areas?
- Assess exposure of assets within new Flood Hazard Areas?
- Identify internal and external interdependence and interconnectivity of systems and functions?
- Identify potential Master Plan changes/trends through the selected climate timeslices?
- Identify common risk exposure among community and Installation (current and future milestone years)?

Worksheet 1.7 - Impact Description and Characterization **Name:** **Last Update Date:**

Purpose: Document and describe current and future climate impacts on your focus area from multiple plausible future conditions.

Note: You may decide to complete more than one Worksheet I.7. You may find it useful to address one infrastructure category, sector, asset or area per sheet. You may decide you wish to have only one timeframe per sheet. You may wish to address different types of hazards and associated climate phenomena on the same sheet (e.g., flooding and temperature changes). You can make modifications to this sheet for your use.

Step 1: Complete the next 3 rows using information from Worksheet I.2.

Assessment Scope:	*Given the stated assumptions in Worksheet I.1, determine how we can protect the installation infrastructure from damage due to flooding and permanent inundation over the next 100 years.*
Hazard of Concern:	*Permanent inundation and flooding*
Weather/Climate Phenomena:	*Sea level change and storm surge (the 1% annual chance event or 100-year storm event)*

Step 2: Document your site reference datum and what unit of measure (feet of meters) you are using from Worksheet I.5.

Site Reference Information			
Site Reference Datum:	*NAVD88*	**Unit (Feet or Meters):**	*Feet*

Step 3: Document your answers in the rows and columns below using the notes located at the bottom of the spreadsheet.

Current / Future Condition Parameters ➡ **Information Source** ⬇	**Current Conditions**		**Plausible Future Conditions**							
	2016		*2035*				*2065*			
			Low scenario		*Highest scenario*		*Low scenario*		*Highest scenario*	
DoD Regionalized Sea Level Change and Extreme Water Scenarios (FOUO internal database)		**1% annual Chance Event**	*Sea level change*	*Sea level change + 1% annual chance event*	*Sea level change*	*Sea level change + 1% annual chance event*	*Sea level change*	*Sea level change + 1% annual chance event*	*Sea level change*	*Sea level change + 1% annual chance event*
		3.9	*0.5*	*4.4*	*1.5*	*5.4*	*1.2*	*5.1*	*3.5*	*7.4*
Current & Potential Hazards ➡	*flooding*	*flooding, debris, shoreline erosion*	*flooding*	*flooding, debris, shoreline erosion*	*flooding, wave damage*	*flooding, wave damage, debris*			*flooding, wave damage, permanent inundation*	*flooding, wave damage, debris*
Impacted Sector/Asset/Area Name ⬇	**Impact Magnitude**		**Impact Magnitude**		**Impact Magnitude**		**Impact Magnitude**		**Impact Magnitude**	
Buildings	*1-Insignificant*	*2-Minor*	*1-Insignificant*	*2-Minor*	*1-Insignificant*	*2-Minor*	*1-Insignificant*	*2-Minor*	*1-Insignificant*	*4-Major*
Natural Infrastructure & Ecosystems	*1-Insignificant*	*2-Minor*	*1-Insignificant*	*2-Minor*	*1-Insignificant*	*2-Minor*	*1-Insignificant*	*2-Minor*	*2-Minor*	*2-Minor*
Transportation	*1-Insignificant*	*2-Minor*	*1-Insignificant*	*2-Minor*	*1-Insignificant*	*2-Minor*	*1-Insignificant*	*2-Minor*	*1-Insignificant*	*3-Moderate*
Current & Potential Impacts Descriptions	*Nuisance flooding occurs during extreme high tide. Currently addressing with sandbags in front of particular building entrances and re-routing traffic on several roads.*	*Naval Station A experienced a storm in 2003 with a surge height of 5 ft, causing shoreline erosion in several areas (about 25K LF), temporary flooding of some building basements (4), and deposition of debris on several roads causing access issues and service disruption for the waste water treatment plant (WWTP).*	*Potential for: - nuisance flooding during extreme high tide.*	*Potential for: - temporary flooding of 50,000 sqft of building basements and 20,000 sqft of building first floors (including the Hospital and HQ Complex), - debris accumulation on several roads causing access issues and service disruption for WWTP. - WWTP is also impacted by salt water. - 30K LF roadway may be subject to wave erosion damage*	*Potential for: - erosion of access road due to increased sea levels - nuisance flooding during extreme high tide.*	*Potential for: - temporary flooding of 50,000 sqft of building basements and 20,000 sqft of building first floors (including the Hospital and HQ Complex), - debris accumulation on several roads causing access issues and service disruption for WWTP. - WWTP is also impacted by salt water. - 30K LF roadway may be subject to wave erosion damage*	*Potential for: - erosion of access road due to increased sea levels - nuisance flooding during extreme high tide.*	*Potential for: - - temporary flooding of 50,000 sqft of building basements and 20,000 sqft of building first floors (including the Hospital and HQ Complex), - debris accumulation on several roads causing access issues and service disruption for WWTP. - WWTP is also impacted by salt water. - 30K LF roadway may be subject to wave erosion damage*	*Potential for: - erosion of access road due to increased sea levels - nuisance flooding during extreme high tide. - Permanent inundation of 35 acres of fresh water marsh, permanent loss of 2 acres salamander critical habitat*	*Potential for: - temporary flooding of 50,000 sqft of building basements and 20,000 sqft of building first floors (including the Hospital and HQ Complex), - debris accumulation on several roads causing access issues and service disruption for WWTP. - 750K LF roadway may be subject to wave erosion damage - SW outfall #3 is below EWL*

Notes	
Information Source	Enter this Information from Worksheet I.5
Current / Future Condition Parameters	Enter this Information from Worksheet I.5
Current & Potential Hazards	Use the generated maps and consultation with subject matter experts to identify and enter the hazard associated with each Current or Plausible Future Condition (e.g., flooding, debris, erosion, permanent inundation, etc.) Remember a hazard is how we experience the weather or climate phenomenon. For example, we may experience flooding due to storm surge (a weather phenomenon) or via climate phenomena such as permanent inundation due to sea level change or flooding due to changes in precipitation patterns that yield heavier rainfall events.
Impacted Sector/Asset/Area Name	Enter the sector / asset / area name or other identifier for which you will describe impacts in the rows below the title cell
Impact Magnitude	Enter the order of magnitude (i.e., 1-Insignificant, 2-Minor, 3-Moderate, 4-Major, or 5-Catastrophic) that best describes the impacts for each Sector using the definitions below (Table 1.2 in Handbook). Carryover magnitude information for Current Condition from Worksheet 1.3
Current & Potential Impacts	Enter descriptions of the current impacts (e.g., from Worksheet I. 3) under Current Conditions heading and potential future impacts (e.g., based upon your analyses) under the Plausible Future Conditions headings). Enter as much specificity as you can (e.g., # of buildings, linear feet of road, etc.)

Impact Magnitude
5 - Catastrophic - Permanent damage and/or loss of infrastructure service.
4 - Major - Extensive infrastructure damage requiring extensive repair.
3 - Moderate - Widespread infrastructure damage and loss of service. Damage recoverable by maintenance and minor repair.
2 - Minor - Localized infrastructure service disruption. No permanent damage.
1 - Insignificant - No infrastructure damage.
Adapted from CSIRO 2007.

Worksheet 1.7 - Impact Description and Characterization continued

2100			
Low scenario		***Highest scenario***	
Sea level change	***Sea level change + 1% annual chance event***	***Sea level change***	***Sea level change + 1% annual chance event***
2.2	***6.1***	***8.2***	***12.1***
flooding	*flooding, wave damage, debris*	*flooding, wave damage, permanent inundation*	*flooding, wave damage, debris*
Impact Magnitude		**Impact Magnitude**	
1-Insignificant	*3-Moderate*	*4-Major*	*4-Major*
2-Minor	*2-Minor*	*3-Moderate*	*3-Moderate*
1-Insignificant	*3-Moderate*	*4-Major*	*4-Major*
Potential for: - erosion of access road due to increased sea levels - nuisance flooding during extreme high tide. - Permanent inundation of 20 acres of fresh water marsh	*Potential for: - temporary flooding of 40,000 sqft of building basements and 10,000 sqft of building first floors (including the Hospital, HQ Complex, several RDT&E facilities), -debris accumulation on several roads causing access issues and service disruption for WWTP. - 500K LF roadway may be subject to wave erosion damage - SW outfall #3 is below EWL*	*Potential for: - permanent loss of 1000 LF roadway - permanent inundation of 80,000 sqft of building basements and 50,000 sq ft of building first floors (including the Hospital, HQ Complex, several RDT&E facilities) - Impaired drainage due to stormwater outfalls #3 and #4 permanently underwater - permanent inundation of 125 acres of fresh water marsh - permanent loss of all salamander critical*	*In addition to assets already permanently inundated, potential for: - temporary flooding of additional 300,000 sq ft of building basements; 200,000 sqft of building first floors; 3 taxiways with 1.2M SF and aprons with 243K SF - debris accumulation on several roads, limiting access - additional 5000K LF roadway may be subject to wave erosion damage - stormwater outfall #10 would be below flood stage, impairing drainage*

Worksheet II.1 - Potential Action Alternatives **Name:** **Last Update Date:**

Purpose: Assemble and screen a list of potential action alternatives that are feasible and appropriate for your installation.

Step 1: Document the problem statement you generated at the conclusion of Stage I. You may choose to separate out gradual events (e.g., sea level change) from extreme events (e.g. storm surge).

Problem Statement	*The following facilities and ecosystems may be impacted by* ***permanent inundation by 2100 based on a projected sea level change scenario of 8.2 feet adjusted to a common vertical datum:*** *permanent loss of 1,000 linear feet of roadway; permanent inundation of 80,000 sq. ft. of building basements and 50,000 sq. ft. of building first floors (including the Hospital, HQ Complex, and several RDT&E facilities); stormwater outfalls #3 and #4 permanently underwater; permanent inundation of 125 acres of fresh water marsh; and permanent loss of all salamander critical habitat.*

Step 2: Document your answers in the rows and columns below using the notes located at the bottom of the spreadsheet.

Column A - Action Alternatives		Column B - Benefits & Limitations (Disbenefits)	
Alt ID #	**Description**	**Benefits**	**Limitations (Disbenefits)**
	Structural Approaches		
1	*Build a seawall*	*• Protects 2,000,000 SF of landward shore from erosion and flooding* *• Protects 30 buildings, major shoreline road, historic officer's quarters and associated landscape (protects 1,200,000 SF of buildings)* *• Modern equipment can be integrated into new structure, improving efficiency*	*• Visual impacts* *• Reduced/impaired waterfront access* *• Hardened shoreline increases wave height and number of exceedance events, increases erosion on the seaward side potentially exacerbating loss of near shore ecosystem* *• Extensive environmental review process*
2	*Partner with County to install flood gate at mouth of river*	*•Protects 250,000 SF of back river flood zone* *•Reduces storm impact on HQ Complex (600,000 SF)* *•Does not interfere with harbor access* *•Prevention of salt water intrusion* *•Allows storage of fresh water/augment water supply* *•Protects Salamander Critical Habitat*	*• Extensive environmental review process* *• Water quality reduction* *• Habitat impacts*
3	*Install offshore breakwater to attenuate wave height*	*• Protects 1,000,000 SF of landward shore from erosion and flooding* *• Protects 20 buildings, major shoreline road, historic officer's quarters and associated landscape (protects 600,000 SF of buildings)* *• Allows continued operation of waterfront facilities*	*• Interferes with harbor channel navigation* *• Extensive environmental review process*
	Natural and Nature-based Approaches		
4	*Restore and expand fresh water marsh ecosystem*	*• Protects 1,200,000 SF of landward shore from erosion and flooding* *• Protects 500,000 SF of buildings* *• Increases habitat* *• Preserves existing views of historic officers quarters*	*• Extensive environmental review process*
5	*Accommodate expansion of natural marsh buffer by removing hardened shoreline structures and replacing finger piers with adjustable floating piers*	*• Protects 1,200,000 SF of landward shore from erosion and flooding* *• Protects 900,000 SF of buildings* *• Would improve views from historic officers quarters*	*• Loss of operational areas*
6	*Install oyster reef breakwater at mouth of river to attenuate wave impact on salamander habitat*	*• Protects 1,800,000 SF of landward shore from erosion and flooding* *• Protects 30 buildings, major shoreline road, historic officer's quarters and associated landscape (protects 1,200,000 SF of buildings)* *• Accommodates current navigation patterns* *• Attenuates wave height impacting salamander habitat* *• Ecosystem services of water filtration/improved water quality* *• Strengthens community relationship*	*• Requires partnership with Oyster Action Network* *•Adds design constraints to possible flood gate.* *•Unanticipated erosion effects on nearby shoreline*
	Facilities Approaches		
7	*Relocate HQ Complex from existing operational area to land reserved outside flood plain*	*• Protects HQ Complex (600,000 SF)* *• Supports current IDP consolidation plan*	*• Existing MILCON consolidates BRAC in expansion of current HQ Complex; would require revision of 1391*
	Non-facilities Approaches		
8	*Increase maintenance of drainage system to reduce nuisance flooding*	*• Protects 2,000,000 SF of low-lying roads and parking lots from tidal flooding* *• Protects 2,250,000 SF of buildings* *• Scheduled replacement of corroded concrete culverts extends life of drainage system*	*• Requires MOA with County*

Notes	
Column A - Action Alternatives	Enter your list of action alternatives. Assign each an Alt ID# and provide a brief description of adaptation measures that would address the impacts identified for one or all sectors. It is expected you will include multiple action alternatives that achieve the same effect. This worksheet is the opportunity to list all possibilities.
Column B - Benefits & Limitations (Disbenefits)	List the main benefits and limitations of each action alternative. Document the size of the area protected. Strive to use the same units (SF, acres) so alternatives can be compared during the Cost Effectiveness Analysis (CEA) in Stage III.
Column C - Feasibility	Document whether potential action alternative is feasible or not; provide a brief reason why an action alternative is currently NOT feasible
Column D - Appropriateness	Document whether potential action alternative is appropriate or not; provide a brief reason why an action alternative is currently NOT appropriate
Column E - Characterization of Strategic Approach to Decision Uncertainty	Indicate which strategy type(s) the action alternative represents

Worksheet II.1 - Potential Action Alternatives continued

Damage and loss values increase when the ***1% annual chance event of just over 4 feet in storm surge is added to the sea level scenario*** *including: temporary flooding of an additional 300,000 sq. ft. of building basements and 200,000 sq. ft. of building first floors, 3 taxiways with 1.2M SF and aprons with 243K SF; debris accumulation on several roads, limiting access; an additional 5,000 LF roadway may be subject to wave erosion damage; and storm water outfall #10 below flood stage, impairing drainage.*

Column C - Feasibility	Column D - Appropriateness	Column E - Column E - Characterization of Strategic Approach to Decisions under Uncertainty			
		No Regrets	Reversible Flexible	Safety Margin	Reduced Time Horizon
Feasible. Advance to WS III.2 - CEA	*Appropriate. Advance to WS III.2 - CEA*	*Shore facilities modernization already planned for 2045. Incorporating seawall adds minor cost*	*Seawall can be designed to allow future increase in height as SLR increases*		
Feasible. Advance to WS III.2 - CEA	*Appropriate. Advance to WS III.2 - CEA*	*Floodgate can be used to impound fresh water to supplement fresh water supply*	*Floodgate allows flexible operation*		*Reduced time horizon - avoids commitment to relocating HQ Complex*
Feasible. Advance to WS III.2 - CEA	*Not currently appropriate due to interference with harbor channel navigation. Reevaluate if harbor channel use change*		*Construction with relocatable or consumable materials would permit removal or modification*		*Breakwater using relocatables addresses short term impacts and can be replaced as long term SLR is confirmed*
Feasible. Advance to WS III.2 - CEA	*Appropriate. Advance to WS III.2 - CEA*		*Conversion to marsh can be reversed in future if conditions are suitable for other types of shoreline development*		
May not be technically or politically feasible; marsh would encroach on operational areas and strategy would require expansion south of current fence line. Do not advance to WS III.2-CEA.	*Not appropriate - not consistent with planning goals and objectives identified in the IDP*				
Feasible. Advance to WS III.2 - CEA	*Appropriate. Advance to WS III.2 - CEA*	*Installation is already a partner in regional oyster restoration with plans to restore oyster beds.*			*Shares cost with County.*
Feasible. Advance to WS III.2 - CEA	*Not consistent with long-range consolidation of work campuses.*	*This alternative is an irreversible solution that would require conservative assumptions about SLR that may be excessive.*			
Requires MOA with County; not politically feasible at this time	*Appropriate. Advance to WS III.2 - CEA*	*Increased maintenance extends life of drainage system. Benefits desirable regardless of SLR.*			

Worksheet III.1 - Life Cycle Cost Analysis (Strategy Grouping: Multiple Lines of Defense)

Name: **Last Update Date:**

Purpose: Develop conceptual costs for action alternatives. You will use the non-monetized benefits identified in Worksheet I.1 as performance metrics, and estimate and assemble life cycle costs for each action alternative.

Document your answers in the rows and columns below using the notes located at the bottom of the spreadsheet. More information can be found in Appendix E, Fact Sheet 1: Life Cycle Cost Analysis.

CAPITAL COSTS									**Construction Schedule / % Completion by Year**				
Alt ID #	**Item Description**	**Quantity**	**Units**	**Unit Cost**	**Estimated Amount**	**Contingency %**	**Contingency Amount ($)**	**Total Cost**	**Yr 1**	**Yr 2**	**Yr 3**	**.....**	**Yr t**
1	***Build Seawall***												
	excavation	*402*	*CY*	*$24*	*$9,648*	*0.25*	*$2,412*	*$12,060*					
	compacted fill	*2000*	*CY*	*$13*	*$25,000*	*0.25*	*$6,250*	*$31,250*					
	concrete	*900*	*CY*	*$450*	*$405,000*	*0.25*	*$101,250*	*$506,250*					
	gravel bedding	*12000*	*CY*	*$55*	*$660,000*	*0.25*	*$165,000*	*$825,000*					
	reinforced concrete	*23000*	*CY*	*$126*	*$2,898,000*	*0.25*	*$724,500*	*$3,622,500*					
	topsoil/seed	*25*	*SY*	*$95*	*$2,375*	*0.25*	*$594*	*$2,969*	*50%*	*50%*			
	Subtotal:							*$5,000,029*	*$2,500,014*	*$2,500,014*			
2	***Install Floodgate***												
	material input 1		*EA*										
	material input 2		*CY*						*50%*	*50%*			
	Subtotal:							*$125,000*	*$62,500*	*$62,500*			
4	***Restore Marsh Ecosystem***												
	material input 1		*SF*										
	material input 2		*LS*							*100%*			
	Subtotal:							*$200,000*		*$200,000*			
6	***Install Oyster Reef***												
	substrates etc..		*CY*										
	materials input 2 etc..		*EA*							*60%*	*40%*		
	Subtotal:							*$1,000,000*	*$0*	*$600,000*	*$400,000*		
	Total Capital Costs:							*$6,325,029*					

ANNUAL OPERATIONAL & MAINTENANCE (O&M) COSTS							
Alt ID #	**Item Description**	**Frequency**	**N=**	**Nominal Annual Amt.**	**Cumulative Present Value**	**% of Total:**	**Assumption**
1	*Seawall maintenance*	*annual*	*50*	*$ 51,775.16*	*$895,894*	*79.7%*	*(based on X labor, materials etc., labor cost etc.)*
2	*Floodgate maintenance*	*annual*	*50*	*$ 1,294.37*	*$22,397*	*2.0%*	*" "*
4	*Marsh Restoration: vegetation*	*annual*	*50*	*$ 2,020.48*	*$34,962*	*3.1%*	*" "*
6	*Oyster Reef maintenance*	*annual*	*50*	*$ 9,909.99*	*$162,489*	*15.2%*	*" "*
	Subtotal:			*$ 65,000.00*		*100.0%*	

PERIODIC REPLACEMENT/RENEWAL COSTS						
Alt ID #	**Item Description**	**Periodic Frequency**	**N=**	**Periodic Amount**	**Cumulative Present Value**	**Assumption**
6a	*Oyster Reef - Reseeding reefs*	*every 10 yrs.*	*50*	*$ 100,000.0*	*$123,739*	*Requires re-seeding based on deployment of X labor, materials etc. every 10 years..*
6b	*Oyster Reef - Habitat monitoring*	*1st 10 years*	*50*	*$ 45,000*	*$315,173*	*Monitoring activities consist of x, y, z etc.*
	Subtotal:			*$ 145,000.0*		

Worksheet III.1 - Life Cycle Cost Analysis (Strategy Grouping: Multiple Lines of Defense) continued

Notes	
CAPITAL COSTS	
Alt ID #	Enter alternative number from WS II.1
Item Description	Enter brief action alternative descriptor and list the materials and inputs that comprise capital costs
Quantity	Enter quantity of material or input
Units	Enter appropriate unit for that material or input (e.g., EA, CY, etc.)
Unit Cost	Enter unit cost for that material or input. Source unit costs from feasibility studies, preliminary engineering design studies/concept costs or use parametric costing tools such as R.S. Means
Estimated Amount	Calculate estimated amount (quantity x unit cost)
Contingency %	Enter contingency %
Contingency Amount ($)	Calculate contingency amount
Total Cost	Sum the Estimated and Contingency Amounts
Construction Schedule / % Completion by Year	Apply the estimated construction schedule, and enter appropriate column headers with Yr # and % completion by year. These are initial costs or upfront capital expenditures. Subtotal row should calculate the subtotaled cost by %.
ANNUAL OPERATIONAL & MAINTENANCE (O&M) COSTS	
Alt ID #	Enter alternative number from WS II.1
Item Description	Enter brief action alternative descriptor
Frequency	Enter frequency that O&M costs would occur (e.g., annual, weekly, etc.)
N=	Enter number of years for the alternative's useful life. Enter number of O&M costs occurrences you anticipate.
Nominal Annual Amt	Enter a nominal annual cost
Cumulative Present Value	Calculate cumulative present value for each O&M cost
% of Total	If you anticipate combining several action alternatives together, you may find it useful to understand the relative size and share of total annual O&M costs per each alternative.
Assumption	Enter your O&M cost assumptions
PERIODIC REPLACEMENT/RENEWAL COSTS	
Alt ID #	Enter alternative number from WS II.1
Item Description	Enter brief action alternative descriptor and periodic activity that should occur
Periodic Frequency	Enter frequency that O&M costs would occur (e.g., annual, weekly, etc.)
N=	Enter number of years for the alternative's useful life. Enter number of replacement/renewal costs occurrences you anticipate over the life of the alternative
Cumulative Present Value	Calculate cumulative present value for each replacement/renewal cost
Assumption	Enter your assumptions

Worksheet III.2 - Cost Effectiveness Analysis **Name:** **Last Update Date:**

Purpose: Conduct a preliminary screening of your list of action alternatives by applying cost effectiveness analysis, using information from Worksheets II.1 and III.1. Using this type of analysis before a full benefit cost analysis can inform an objective decision making process.

Document your answers in the rows and columns below using the notes located at the bottom of the spreadsheet.

Alt ID #	Alternative Description	NPV Life Cycle Costs of Action Alternative	Performance Metric* (SF)	Cost per Unit	Notes
1	*Build Seawall*				
	Subtotal:	*$5,776,874*	*1,200,000*	*$4.81*	*→ Advance to BCA: See WS III.4 BCR NPV Grouping*
2	*Install Floodgate*				
	Subtotal:	*$144,421*	*600,000*	*$0.24*	*→ Advance to BCA: See WS III.4 BCR NPV Grouping*
3	*Install Breakwater*				
	Subtotal:	*$6,500,000*	*600,000*	*$10.83*	
4	*Restore Marsh*				
	Subtotal:	*$225,438*	*500,000*	*$0.45*	*→ Advance to BCA: See WS III.4 BCR NPV Grouping*
6	*Install Oyster Reef*				
	Subtotal:	*$1,535,642*	*1,200,000*	*$1.28*	*→ Advance to BCA: See WS III.4 BCR NPV Grouping*
7	*Relocate HQ Complex*				
	Subtotal:	*$15,000,000*	*600,000*	*$25.00*	
8	*Increase maintenance of drainage system*				
	Subtotal:	*$15,000,000*	*2,250,000*	*$6.67*	

***Performance metric unit** *Square feet of buildings protected*

Notes	
Alt ID #	Enter alternative number from WS II.1
Alternative Description	Enter brief action alternative descriptor
NPV Life Cycle Costs of Action Alternative	Calculate and enter the Net Present Value (NPV) Life Cycle Costs of the action alternative life cycle costs found in WS III.1 LCCA
Performance Metric	Enter the common performance metric you have chosen for the your action alternatives. You may choose to place the performance metric acronym (e.g., SF) in the Performance Metric column header
Cost per Unit	Calculate and enter the cost per unit (NPV life cycle costs divided by performance metric)
Notes	Enter appropriate notes

Worksheet III.3 - Benefits (Strategy Grouping: Multiple Lines of Defense) **Name:** **Last Update Date:**

Purpose: Record and transfer the monetary values for the direct, indirect, and cumulative benefits of each action alternative under consideration.

Step 1. Transfer the monetized benefits for each year from the output from one of the Monetization tools you have applied. The benefits categories below are those that have been monetized. Be advised that you may not be able to monetize all of these category groupings in this phase; in Stage IV you will be able to document non-monetized benefits. You may choose to complete more than one worksheet so that you can back up your detailed analyses with more specific input worksheets or dependent data and information. The Notional Installation Hypothetical Data table is an example of how you can capture your assumptions and data. You can also set up calculations in the Benefits columns themselves, if useful.

Year	Year Number	I. Resilience Benefit Values					II. Economic Revitalization Benefit Values	III. Installation / Community Benefit Values	IV. Environmental / Ecosystem Benefit Values	V. Other Benefits / Intangibles Values	VI. Total Benefits
		a. Avoided damages to structures.	*b. Avoided damages to building contents*	*c. Avoided damages to vehicles*	*d. Avoided damages to critical infrastructure*	*e. Other avoided damages*					
2016	0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2017	1	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2018	2	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
2019	3	**$270,825**	$67,706	$20,625	$120,000	$0	$0	$0	$184,500	$0	$663,656
2020	4	$273,180	$68,295	$20,625	$120,000	$0	$0	$0	$184,500	$0	$666,600
2021	5	$275,535	$68,884	$20,625	$120,000	$0	$0	$0	$184,500	$0	$669,544
2022	6	$277,890	$69,473	$20,625	$120,000	$0	$0	$0	$184,500	$0	$672,488
2023	7	$280,245	$70,061	$20,625	$120,000	$0	$0	$0	$184,500	$0	$675,431
2024	8	**$282,600**	$70,650	$20,625	$120,000	$0	$0	$0	$184,500	$0	$678,375
2025	9	$284,955	$71,239	$20,625	$120,000	$0	$0	$0	$184,500	$0	$681,319
2026	10	$287,310	$71,828	$20,625	$120,000	$0	$0	$0	$184,500	$0	$684,263
2027	11	$289,665	$72,416	$20,625	$120,000	$0	$0	$0	$184,500	$0	$687,206
2028	12	$292,020	$73,005	$20,625	$120,000	$0	$0	$0	$184,500	$0	$690,150
2029	13	**$294,375**	$73,594	$20,625	$120,000	$0	$0	$0	$184,500	$0	$693,094
2030	14	$296,730	$74,183	$20,625	$120,000	$0	$0	$0	$184,500	$0	$696,038
2031	15	$299,085	$74,771	$20,625	$120,000	$0	$0	$0	$184,500	$0	$698,981
2032	16	$301,440	$75,360	$20,625	$120,000	$0	$0	$0	$184,500	$0	$701,925
2033	17	$303,795	$75,949	$20,625	$120,000	$0	$0	$0	$184,500	$0	$704,869
2034	18	**$306,150**	$76,538	$20,625	$120,000	$0	$0	$0	$184,500	$0	$707,813
2035	19	$308,505	$77,126	$20,625	$120,000	$0	$0	$0	$184,500	$0	$710,756
2036	20	$310,860	$77,715	$20,625	$120,000	$0	$0	$0	$184,500	$0	$713,700
2037	21	$313,215	$78,304	$20,625	$120,000	$0	$0	$0	$184,500	$0	$716,644
2038	22	$315,570	$78,893	$20,625	$120,000	$0	$0	$0	$184,500	$0	$719,588
2039	23	**$317,925**	$79,481	$20,625	$120,000	$0	$0	$0	$184,500	$0	$722,531
2040	24	$320,280	$80,070	$20,625	$120,000	$0	$0	$0	$184,500	$0	$725,475
2041	25	$322,635	$80,659	$20,625	$120,000	$0	$0	$0	$184,500	$0	$728,419
2042	26	$324,990	$81,248	$20,625	$120,000	$0	$0	$0	$184,500	$0	$731,363
2043	27	$327,345	$81,836	$20,625	$120,000	$0	$0	$0	$184,500	$0	$734,306
2044	28	**$329,700**	$82,425	$20,625	$120,000	$0	$0	$0	$184,500	$0	$737,250
2045	29	$332,055	$83,014	$20,625	$120,000	$0	$0	$0	$184,500	$0	$740,194
2046	30	$334,410	$83,603	$20,625	$120,000	$0	$0	$0	$184,500	$0	$743,138
2047	31	$336,765	$84,191	$20,625	$120,000	$0	$0	$0	$184,500	$0	$746,081
2048	32	$339,120	$84,780	$20,625	$120,000	$0	$0	$0	$184,500	$0	$749,025
2049	33	**$341,475**	$85,369	$20,625	$120,000	$0	$0	$0	$184,500	$0	$751,969
2050	34	$343,830	$85,958	$20,625	$120,000	$0	$0	$0	$184,500	$0	$754,913
2051	35	$346,185	$86,546	$20,625	$120,000	$0	$0	$0	$184,500	$0	$757,856
2052	36	$348,540	$87,135	$20,625	$120,000	$0	$0	$0	$184,500	$0	$760,800
2053	37	$350,895	$87,724	$20,625	$120,000	$0	$0	$0	$184,500	$0	$763,744
2054	38	**$353,250**	$88,313	$20,625	$120,000	$0	$0	$0	$184,500	$0	$766,688
2055	39	$355,605	$88,901	$20,625	$120,000	$0	$0	$0	$184,500	$0	$769,631
2056	40	$357,960	$89,490	$20,625	$120,000	$0	$0	$0	$184,500	$0	$772,575
2057	41	$360,315	$90,079	$20,625	$120,000	$0	$0	$0	$184,500	$0	$775,519
2058	42	$362,670	$90,668	$20,625	$120,000	$0	$0	$0	$184,500	$0	$778,463
2059	43	**$365,025**	$91,256	$20,625	$120,000	$0	$0	$0	$184,500	$0	$781,406
2060	44	$367,380	$91,845	$20,625	$120,000	$0	$0	$0	$184,500	$0	$784,350
2061	45	$369,735	$92,434	$20,625	$120,000	$0	$0	$0	$184,500	$0	$787,294
2062	46	$372,090	$93,023	$20,625	$120,000	$0	$0	$0	$184,500	$0	$790,238
2063	47	$374,445	$93,611	$20,625	$120,000	$0	$0	$0	$184,500	$0	$793,181
2064	48	**$376,800**	$94,200	$20,625	$120,000	$0	$0	$0	$184,500	$0	$796,125
2065	49	$379,155	$94,789	$20,625	$120,000	$0	$0	$0	$184,500	$0	$799,069
2066	50	$379,155	$94,789	$20,625	$120,000	$0	$0	$0	$184,500	$0	$799,069
Cumulative Present Value		$5,015,506.49	$1,253,876.62	$338,178.12	$1,967,581.80	$0.00	$0.00	$0.00	$3,025,157.02	$0.00	**$11,600,300**

This box shows the assumptions and parameters used to develop benefit estimates.

Notional Installation Hypothetical Data ↓	Parameters
Buildings at risk/sq. ft.	750,000
Weighted Average Cost/sq.ft. BRV	$157
Percent of structure damaged at this flood level (USACE Depth	23%
SLR accretion rate (increment to DDF)	0.01
Return period	100
Discount Rate:	5.0%
Ecosystem Service Acres Created:	9
Value of Supporting Services: New Habitat ($/acre)	$11,000
Value of Regulating Services: Hurricane Hazard Risk Reduction	$9,500
Contents works out to be 25% of structure BRV:	0.25
(based on applying Tool X)	
Vehicle Assumptions:	
No. of vehicles inundated:	125
Value per vehicle	$50,000
Percent of vehicle damaged	0.33
Critical Infrastructure Assumption:	
Estimated total value of damage, (obtain from Study X)	$12,000,000

Notes	
Year	Enter first year of alternative implementation from WS III.1
Year #	Start with '0' and include the "N" value from WS III.1
I. Resilience Benefit Values (Avoided Damages to):	
Structures	Take product of Bldg sq. ft. x BRV x % of structure damaged x Annual Probability of occurrence (1%). Insert value every 5 yrs. Increase % of structural damage by 1% every 6 yrs (SLR). Spreadsheet calculates other years automatically.
Building Contents	Enter a $ value or use a building contents damage factor (in this case, 25%) and multiply versus Column (a) values
Vehicles	Enter a $ value or apply some vehicle assumptions x Annual Probability of occurrence (1%)
Critical Infrastructure	Take product of critical infrastructure value x Annual Probability of occurrence (1%)
Other	Placeholder: could potentially be value of displacement costs, emergency costs, injuries etc.
II. Economic Revitalization Benefit Values	Enter a $ value or use a calculation similar to one in Notional Installation Hypothetical Data table
III. Installation / Community Benefit Values	Enter a $ value or use a calculation similar to one in Notional Installation Hypothetical Data table
IV. Environmental / Ecosystem Benefit Values	Enter a $ value or use a calculation similar to one in Notional Installation Hypothetical Data table
V. Other Benefits / Intangibles Values	Enter a $ value or use a calculation similar to one in Notional Installation Hypothetical Data table
VI. Total Benefits	Sum value of each row

Worksheet III.4.1 - Benefit Cost Ratio and Net Present Value (Strategy Grouping: Multiple Lines of Defense)

Name: **Last Update Date:**

Purpose: Use this worksheet to bring together costs and benefits to calculate BCR and NPV.

Step 1. Enter your Action Alternative descriptor or title. Enter the Discount Rate.

Action Alternative: ***Strategy Grouping: Multiple Lines of Defense***

Discount Rate, *i* = *0.05*

Step 2. Document your answers in the rows and columns below using the notes located at the bottom of the spreadsheet.

Year	Year #	Life Cycle Costs: (constant dollars) — I. Capital Costs				II. Annual O&M	III. Renewal, Replacement Costs (various years)		Total Costs	Benefits — I. Resilience Benefit Values	IV. Environmental / Ecosystem Benefit Values	Total Monetized Benefits	Total Monetized Benefits less Total Costs
		1. Seawall	*2. Flood gate*	*4. Restore Marsh*	*6. Oyster Reef*	*O&M*	*6a. Reseeding reefs*	*6b. Habitat monitoring*					
2016	0	$2,500,014	$62,500	$0	$0	$0	$0	$0	$2,562,514	$0	$0	$0	-$2,562,514
2017	1	$2,500,014	$62,500	$200,000	$600,000	$0	$0	$0	$3,362,514	$0	$0	$0	-$3,362,514
2018	2	$0	$0	$0	$400,000	$65,000	$0	$0	$465,000	$0	$0	$0	-$465,000
2019	3	$0	$0	$0	$0	$65,000	$0	$45,000	$110,000	$479,156	$184,500	$663,656	$553,656
2020	4	$0	$0	$0	$0	$65,000	$0	$45,000	$110,000	$482,100	$184,500	$666,600	$556,600
2021	5	$0	$0	$0	$0	$65,000	$0	$45,000	$110,000	$485,044	$184,500	$669,544	$559,544
2022	6	$0	$0	$0	$0	$65,000	$0	$45,000	$110,000	$487,988	$184,500	$672,488	$562,488
2023	7	$0	$0	$0	$0	$65,000	$0	$45,000	$110,000	$490,931	$184,500	$675,431	$565,431
2024	8	$0	$0	$0	$0	$65,000	$0	$45,000	$110,000	$493,875	$184,500	$678,375	$568,375
2025	9	$0	$0	$0	$0	$65,000	$0	$45,000	$110,000	$496,819	$184,500	$681,319	$571,319
2026	10	$0	$0	$0	$0	$65,000	$0	$45,000	$110,000	$499,763	$184,500	$684,263	$574,263
2027	11	$0	$0	$0	$0	$65,000	$0	$45,000	$110,000	$502,706	$184,500	$687,206	$577,206
2028	12	$0	$0	$0	$0	$65,000	$100,000	$45,000	$210,000	$505,650	$184,500	$690,150	$480,150
2029	13	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$508,594	$184,500	$693,094	$628,094
2030	14	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$511,538	$184,500	$696,038	$631,038
2031	15	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$514,481	$184,500	$698,981	$633,981
2032	16	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$517,425	$184,500	$701,925	$636,925
2033	17	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$520,369	$184,500	$704,869	$639,869
2034	18	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$523,313	$184,500	$707,813	$642,813
2035	19	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$526,256	$184,500	$710,756	$645,756
2036	20	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$529,200	$184,500	$713,700	$648,700
2037	21	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$532,144	$184,500	$716,644	$651,644
2038	22	$0	$0	$0	$0	$65,000	$100,000	$0	$165,000	$535,088	$184,500	$719,588	$554,588
2039	23	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$538,031	$184,500	$722,531	$657,531
2040	24	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$540,975	$184,500	$725,475	$660,475
2041	25	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$543,919	$184,500	$728,419	$663,419
2042	26	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$546,863	$184,500	$731,363	$666,363
2043	27	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$549,806	$184,500	$734,306	$669,306
2044	28	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$552,750	$184,500	$737,250	$672,250
2045	29	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$555,694	$184,500	$740,194	$675,194
2046	30	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$558,638	$184,500	$743,138	$678,138
2047	31	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$561,581	$184,500	$746,081	$681,081
2048	32	$0	$0	$0	$0	$65,000	$100,000	$0	$165,000	$564,525	$184,500	$749,025	$584,025
2049	33	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$567,469	$184,500	$751,969	$686,969
2050	34	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$570,413	$184,500	$754,913	$689,913
2051	35	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$573,356	$184,500	$757,856	$692,856
2052	36	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$576,300	$184,500	$760,800	$695,800
2053	37	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$579,244	$184,500	$763,744	$698,744
2054	38	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$582,188	$184,500	$766,688	$701,688
2055	39	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$585,131	$184,500	$769,631	$704,631
2056	40	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$588,075	$184,500	$772,575	$707,575
2057	41	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$591,019	$184,500	$775,519	$710,519
2058	42	$0	$0	$0	$0	$65,000	$100,000	$0	$165,000	$593,963	$184,500	$778,463	$613,463
2059	43	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$596,906	$184,500	$781,406	$716,406
2060	44	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$599,850	$184,500	$784,350	$719,350
2061	45	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$602,794	$184,500	$787,294	$722,294
2062	46	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$605,738	$184,500	$790,238	$725,238
2063	47	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$608,681	$184,500	$793,181	$728,181
2064	48	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$611,625	$184,500	$796,125	$731,125
2065	49	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$614,569	$184,500	$799,069	$734,069
2066	50	$0	$0	$0	$0	$65,000	$0	$0	$65,000	$614,569	$184,500	$799,069	$734,069
Cumulative Present Values:		$4,880,980	$122,024	$190,476	$934,240	$1,124,730	$123,739	$315,173	$7,691,363	$8,575,143	$3,025,157	$11,600,300	

Benefit Cost Ratio: BCR	*1.51*
Internal Rate of Return (IRR)	*8.2%*
Net Present Value (NPV)	*$3,908,937*

Notes	
Year	Enter first year of alternative implementation from WS III.1
Year #	Start with '0' and include the "N" value from WS III.1
Life Cycle Costs	Transfer the appropriate values from WS III.1. If helpful, add columns with further detail about the particular costs. Sum the rows to calculate Total Costs.
Benefits	Transfer the appropriate values from WS III.3 or from other spreadsheet or monetization tool you have used to calculate benefit values. Sum the rows to calculate Total Monetized Benefits.
Total Monetized Benefits less Total Costs	Subtract Total Costs from Total Monetized Benefits
Cumulative Present Values	The net present value formula (referencing the discount rate) should be applied to the sum of each column after the 1st year of activity + the 1st year
Benefit Cost Ratio: BCR	Calculate BCR (Total Monetized Benefits divided by Total Costs)
Internal Rate of Return (IRR)	Calculate IRR [The rate that renders the present value of the cost stream (future annual costs) equal to the present value of the benefits stream (future annual benefits)]
Net Present Value (NPV)	Calculate NPV (absolute difference between the cumulative *present* value of benefits and the cumulative *present* value of costs)

The formula for the benefit cost ratio is shown below

$$\frac{\sum_{t=0}^{n} \frac{B_t}{(1+i)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+i)^t}}$$

Worksheet III.4.2 - Benefit Cost Ratio and Net Present Value (Build a Seawall) **Name:** **Last Update Date:**

Purpose: Use this worksheet to bring together costs and benefits to calculate BCR and NPV.

Step 1. Enter your Action Alternative descriptor or title. Enter the Discount Rate.

Action Alternative: ***Build a seawall***

Discount Rate, *i* = *0.05*

Step 2. Document your answers in the rows and columns below using the notes located at the bottom of the spreadsheet.

		Life Cycle Costs: (constant dollars)			Benefits			
Year	**Year #**	**I. Capital Costs**	**II. Annual O&M**	**Total Costs**	**I. Resilience Benefit Values**	**IV. Environmental / Ecosystem Benefit Values**	**Total Monetized Benefits**	**Total Monetized Benefits less Total Costs**
2016	0	$2,500,014	$0	$2,500,014	$0	$0	$0	-$2,500,014
2017	1	$2,500,014	$0	$2,500,014	$0	$0	$0	-$2,500,014
2018	2	$0	$51,775	$51,775	$379,358	$146,073	$525,431	$473,655
2019	3	$0	$51,775	$51,775	$381,648	$146,954	$528,602	$476,827
2020	4	$0	$51,775	$51,775	$383,993	$146,954	$530,947	$479,172
2021	5	$0	$51,775	$51,775	$386,337	$146,954	$533,292	$481,516
2022	6	$0	$51,775	$51,775	$388,682	$146,954	$535,636	$483,861
2023	7	$0	$51,775	$51,775	$391,027	$146,954	$537,981	$486,206
2024	8	$0	$51,775	$51,775	$393,371	$146,954	$540,326	$488,551
2025	9	$0	$51,775	$51,775	$395,716	$146,954	$542,670	$490,895
2026	10	$0	$51,775	$51,775	$398,061	$146,954	$545,015	$493,240
2027	11	$0	$51,775	$51,775	$400,406	$146,954	$547,360	$495,585
2028	12	$0	$51,775	$51,775	$402,750	$146,954	$549,704	$497,929
2029	13	$0	$51,775	$51,775	$405,095	$146,954	$552,049	$500,274
2030	14	$0	$51,775	$51,775	$407,440	$146,954	$554,394	$502,619
2031	15	$0	$51,775	$51,775	$409,784	$146,954	$556,739	$504,963
2032	16	$0	$51,775	$51,775	$412,129	$146,954	$559,083	$507,308
2033	17	$0	$51,775	$51,775	$414,474	$146,954	$561,428	$509,653
2034	18	$0	$51,775	$51,775	$416,818	$146,954	$563,773	$511,997
2035	19	$0	$51,775	$51,775	$419,163	$146,954	$566,117	$514,342
2036	20	$0	$51,775	$51,775	$421,508	$146,954	$568,462	$516,687
2037	21	$0	$51,775	$51,775	$423,852	$146,954	$570,807	$519,032
2038	22	$0	$51,775	$51,775	$426,197	$146,954	$573,151	$521,376
2039	23	$0	$51,775	$51,775	$428,542	$146,954	$575,496	$523,721
2040	24	$0	$51,775	$51,775	$430,887	$146,954	$577,841	$526,066
2041	25	$0	$51,775	$51,775	$433,231	$146,954	$580,186	$528,410
2042	26	$0	$51,775	$51,775	$435,576	$146,954	$582,530	$530,755
2043	27	$0	$51,775	$51,775	$437,921	$146,954	$584,875	$533,100
2044	28	$0	$51,775	$51,775	$440,265	$146,954	$587,220	$535,444
2045	29	$0	$51,775	$51,775	$442,610	$146,954	$589,564	$537,789
2046	30	$0	$51,775	$51,775	$444,955	$146,954	$591,909	$540,134
2047	31	$0	$51,775	$51,775	$447,299	$146,954	$594,254	$542,479
2048	32	$0	$51,775	$51,775	$449,644	$146,954	$596,598	$544,823
2049	33	$0	$51,775	$51,775	$451,989	$146,954	$598,943	$547,168
2050	34	$0	$51,775	$51,775	$454,334	$146,954	$601,288	$549,513
2051	35	$0	$51,775	$51,775	$456,678	$146,954	$603,633	$551,857
2052	36	$0	$51,775	$51,775	$459,023	$146,954	$605,977	$554,202
2053	37	$0	$51,775	$51,775	$461,368	$146,954	$608,322	$556,547
2054	38	$0	$51,775	$51,775	$463,712	$146,954	$610,667	$558,891
2055	39	$0	$51,775	$51,775	$466,057	$146,954	$613,011	$561,236
2056	40	$0	$51,775	$51,775	$468,402	$146,954	$615,356	$563,581
2057	41	$0	$51,775	$51,775	$470,746	$146,954	$617,701	$565,926
2058	42	$0	$51,775	$51,775	$473,091	$146,954	$620,045	$568,270
2059	43	$0	$51,775	$51,775	$475,436	$146,954	$622,390	$570,615
2060	44	$0	$51,775	$51,775	$477,781	$146,954	$624,735	$572,960
2061	45	$0	$51,775	$51,775	$480,125	$146,954	$627,079	$575,304
2062	46	$0	$51,775	$51,775	$482,470	$146,954	$629,424	$577,649
2063	47	$0	$51,775	$51,775	$484,815	$146,954	$631,769	$579,994
2064	48	$0	$51,775	$51,775	$487,159	$146,954	$634,114	$582,338
2065	49	$0	$51,775	$51,775	$489,504	$146,954	$636,458	$584,683
2066	50	$0	$51,775	$51,775	$489,504	$146,954	$636,458	$584,683
Cumulative Present Values:		$4,880,980	$895,894	$5,776,874	$7,174,190	$2,542,030	$9,716,220	

Benefit Cost Ratio: BCR	1.68
Internal Rate of Return (IRR)	9.4%
Net Present Value (NPV)	$3,939,346

Notes	
Year	Enter first year of alternative implementation from WS III.1
Year #	Start with '0' and include the "N" value from WS III.1
Life Cycle Costs	Transfer the appropriate values from WS III.1. If helpful, add columns with further detail about the particular costs. Sum the rows to calculate Total Costs.
Benefits	Transfer the appropriate values from WS III.3 or from other spreadsheet or monetization tool you have used to calculate benefit values. Sum the rows to calculate Total Monetized Benefits.
Total Monetized Benefits less	Subtract Total Costs from Total Monetized Benefits
Cumulative Present Values	The net present value formula (referencing the discount rate) should be applied to the sum of each column after the 1st year of activity + the 1st year
Benefit Cost Ratio: BCR	Calculate BCR (Total Monetized Benefits divided by Total Costs)
Internal Rate of Return (IRR)	Calculate IRR [The rate that renders the present value of the cost stream (future annual costs) equal to the present value of the benefits stream (future annual benefits)]
Net Present Value (NPV)	Calculate NPV (absolute difference between the cumulative *present* value of benefits and the cumulative *present* value of costs)

Worksheet III.4.3 - Benefit Cost Ratio and Net Present Value (Install Floodgate) **Name:** **Last Update Date:**

Purpose: Use this worksheet to bring together costs and benefits to calculate BCR and NPV.

Step 1. Enter your Action Alternative descriptor or title. Enter the Discount Rate.

Action Alternative: ***Install a flood gate***

Discount Rate, *i* = *0.05*

Step 2. Document your answers in the rows and columns below using the notes located at the bottom of the spreadsheet.

		Life Cycle Costs: (constant dollars)			Benefits			
Year	Year #	I. Capital Costs	II. Annual O&M	Total Costs	I. Resilience Benefit Values	IV. Environmental / Ecosystem Benefit Values	Total Monetized Benefits	Total Monetized Benefits less Total Costs
2016	0	$62,500	$0	$62,500	$0	$0	$0	-$62,500
2017	1	$62,500	$0	$62,500	$0	$0	$0	-$62,500
2018	2	$0	$1,294	$1,294	$9,526	$3,668	$13,193	$11,899
2019	3	$0	$1,294	$1,294	$9,583	$3,690	$13,273	$11,979
2020	4	$0	$1,294	$1,294	$9,642	$3,690	$13,332	$12,038
2021	5	$0	$1,294	$1,294	$9,701	$3,690	$13,391	$12,097
2022	6	$0	$1,294	$1,294	$9,760	$3,690	$13,450	$12,155
2023	7	$0	$1,294	$1,294	$9,819	$3,690	$13,509	$12,214
2024	8	$0	$1,294	$1,294	$9,878	$3,690	$13,568	$12,273
2025	9	$0	$1,294	$1,294	$9,936	$3,690	$13,626	$12,332
2026	10	$0	$1,294	$1,294	$9,995	$3,690	$13,685	$12,391
2027	11	$0	$1,294	$1,294	$10,054	$3,690	$13,744	$12,450
2028	12	$0	$1,294	$1,294	$10,113	$3,690	$13,803	$12,509
2029	13	$0	$1,294	$1,294	$10,172	$3,690	$13,862	$12,568
2030	14	$0	$1,294	$1,294	$10,231	$3,690	$13,921	$12,626
2031	15	$0	$1,294	$1,294	$10,290	$3,690	$13,980	$12,685
2032	16	$0	$1,294	$1,294	$10,349	$3,690	$14,039	$12,744
2033	17	$0	$1,294	$1,294	$10,407	$3,690	$14,097	$12,803
2034	18	$0	$1,294	$1,294	$10,466	$3,690	$14,156	$12,862
2035	19	$0	$1,294	$1,294	$10,525	$3,690	$14,215	$12,921
2036	20	$0	$1,294	$1,294	$10,584	$3,690	$14,274	$12,980
2037	21	$0	$1,294	$1,294	$10,643	$3,690	$14,333	$13,039
2038	22	$0	$1,294	$1,294	$10,702	$3,690	$14,392	$13,097
2039	23	$0	$1,294	$1,294	$10,761	$3,690	$14,451	$13,156
2040	24	$0	$1,294	$1,294	$10,820	$3,690	$14,510	$13,215
2041	25	$0	$1,294	$1,294	$10,878	$3,690	$14,568	$13,274
2042	26	$0	$1,294	$1,294	$10,937	$3,690	$14,627	$13,333
2043	27	$0	$1,294	$1,294	$10,996	$3,690	$14,686	$13,392
2044	28	$0	$1,294	$1,294	$11,055	$3,690	$14,745	$13,451
2045	29	$0	$1,294	$1,294	$11,114	$3,690	$14,804	$13,510
2046	30	$0	$1,294	$1,294	$11,173	$3,690	$14,863	$13,568
2047	31	$0	$1,294	$1,294	$11,232	$3,690	$14,922	$13,627
2048	32	$0	$1,294	$1,294	$11,291	$3,690	$14,981	$13,686
2049	33	$0	$1,294	$1,294	$11,349	$3,690	$15,039	$13,745
2050	34	$0	$1,294	$1,294	$11,408	$3,690	$15,098	$13,804
2051	35	$0	$1,294	$1,294	$11,467	$3,690	$15,157	$13,863
2052	36	$0	$1,294	$1,294	$11,526	$3,690	$15,216	$13,922
2053	37	$0	$1,294	$1,294	$11,585	$3,690	$15,275	$13,981
2054	38	$0	$1,294	$1,294	$11,644	$3,690	$15,334	$14,039
2055	39	$0	$1,294	$1,294	$11,703	$3,690	$15,393	$14,098
2056	40	$0	$1,294	$1,294	$11,762	$3,690	$15,452	$14,157
2057	41	$0	$1,294	$1,294	$11,820	$3,690	$15,510	$14,216
2058	42	$0	$1,294	$1,294	$11,879	$3,690	$15,569	$14,275
2059	43	$0	$1,294	$1,294	$11,938	$3,690	$15,628	$14,334
2060	44	$0	$1,294	$1,294	$11,997	$3,690	$15,687	$14,393
2061	45	$0	$1,294	$1,294	$12,056	$3,690	$15,746	$14,452
2062	46	$0	$1,294	$1,294	$12,115	$3,690	$15,805	$14,510
2063	47	$0	$1,294	$1,294	$12,174	$3,690	$15,864	$14,569
2064	48	$0	$1,294	$1,294	$12,233	$3,690	$15,923	$14,628
2065	49	$0	$1,294	$1,294	$12,291	$3,690	$15,981	$14,687
2066	50	$0	$1,294	$1,294	$12,291	$3,690	$15,981	$14,687
Cumulative Present Values:		$122,024	$22,397	$144,421	$180,143	$63,830	$243,973	

Benefit Cost Ratio: BCR	*1.69*
Internal Rate of Return (IRR)	*9.4%*
Net Present Value (NPV)	*$99,552*

Notes	
Year	Enter first year of alternative implementation from WS III.1
Year #	Start with '0' and include the "N" value from WS III.1
Life Cycle Costs	Transfer the appropriate values from WS III.1. If helpful, add columns with further detail about the particular costs. Sum the rows to calculate Total Costs.
Benefits	Transfer the appropriate values from WS III.3 or from other spreadsheet or monetization tool you have used to calculate benefit values. Sum the rows to calculate Total Monetized Benefits.
Total Monetized Benefits less Total	Subtract Total Costs from Total Monetized Benefits
Cumulative Present Values	The net present value formula (referencing the discount rate) should be applied to the sum of each column after the 1st year of activity + the 1st year
Benefit Cost Ratio: BCR	Calculate BCR (Total Monetized Benefits divided by Total Costs)
Internal Rate of Return (IRR)	Calculate IRR [The rate that renders the present value of the cost stream (future annual costs) equal to the present value of the benefits stream (future annual benefits)]
Net Present Value (NPV)	Calculate NPV (absolute difference between the cumulative *present* value of benefits and the cumulative *present* value of costs)

Worksheet III.4.4 - Benefit Cost Ratio and Net Present Value (Restore Marsh) **Name:** **Last Update Date:**

Purpose: Use this worksheet to bring together costs and benefits to calculate BCR and NPV.

Step 1. Enter your Action Alternative descriptor or title. Enter the Discount Rate.

Action Alternative: *Restore marsh*

Discount Rate, *i* = *0.05*

Step 2. Document your answers in the rows and columns below using the notes located at the bottom of the spreadsheet.

		Life Cycle Costs: (constant dollars)			Benefits			
Year	**Year #**	**I. Capital Costs**	**II. Annual O&M**	**Total Costs**	**I. Resilience Benefit Values**	**IV. Environmental / Ecosystem Benefit Values**	**Total Monetized Benefits**	**Total Monetized Benefits less Total Costs**
2016	*0*	*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	*$0*
2017	*1*	*$200,000*	*$0*	*$200,000*	*$0*	*$0*	*$0*	*-$200,000*
2018	*2*	*$0*	*$2,020*	*$2,020*	*$14,765*	*$5,685*	*$20,450*	*$18,429*
2019	*3*	*$0*	*$2,020*	*$2,020*	*$14,854*	*$5,720*	*$20,573*	*$18,553*
2020	*4*	*$0*	*$2,020*	*$2,020*	*$14,945*	*$5,720*	*$20,665*	*$18,644*
2021	*5*	*$0*	*$2,020*	*$2,020*	*$15,036*	*$5,720*	*$20,756*	*$18,735*
2022	*6*	*$0*	*$2,020*	*$2,020*	*$15,128*	*$5,720*	*$20,847*	*$18,827*
2023	*7*	*$0*	*$2,020*	*$2,020*	*$15,219*	*$5,720*	*$20,938*	*$18,918*
2024	*8*	*$0*	*$2,020*	*$2,020*	*$15,310*	*$5,720*	*$21,030*	*$19,009*
2025	*9*	*$0*	*$2,020*	*$2,020*	*$15,401*	*$5,720*	*$21,121*	*$19,100*
2026	*10*	*$0*	*$2,020*	*$2,020*	*$15,493*	*$5,720*	*$21,212*	*$19,192*
2027	*11*	*$0*	*$2,020*	*$2,020*	*$15,584*	*$5,720*	*$21,303*	*$19,283*
2028	*12*	*$0*	*$2,020*	*$2,020*	*$15,675*	*$5,720*	*$21,395*	*$19,374*
2029	*13*	*$0*	*$2,020*	*$2,020*	*$15,766*	*$5,720*	*$21,486*	*$19,465*
2030	*14*	*$0*	*$2,020*	*$2,020*	*$15,858*	*$5,720*	*$21,577*	*$19,557*
2031	*15*	*$0*	*$2,020*	*$2,020*	*$15,949*	*$5,720*	*$21,668*	*$19,648*
2032	*16*	*$0*	*$2,020*	*$2,020*	*$16,040*	*$5,720*	*$21,760*	*$19,739*
2033	*17*	*$0*	*$2,020*	*$2,020*	*$16,131*	*$5,720*	*$21,851*	*$19,830*
2034	*18*	*$0*	*$2,020*	*$2,020*	*$16,223*	*$5,720*	*$21,942*	*$19,922*
2035	*19*	*$0*	*$2,020*	*$2,020*	*$16,314*	*$5,720*	*$22,033*	*$20,013*
2036	*20*	*$0*	*$2,020*	*$2,020*	*$16,405*	*$5,720*	*$22,125*	*$20,104*
2037	*21*	*$0*	*$2,020*	*$2,020*	*$16,496*	*$5,720*	*$22,216*	*$20,195*
2038	*22*	*$0*	*$2,020*	*$2,020*	*$16,588*	*$5,720*	*$22,307*	*$20,287*
2039	*23*	*$0*	*$2,020*	*$2,020*	*$16,679*	*$5,720*	*$22,398*	*$20,378*
2040	*24*	*$0*	*$2,020*	*$2,020*	*$16,770*	*$5,720*	*$22,490*	*$20,469*
2041	*25*	*$0*	*$2,020*	*$2,020*	*$16,861*	*$5,720*	*$22,581*	*$20,560*
2042	*26*	*$0*	*$2,020*	*$2,020*	*$16,953*	*$5,720*	*$22,672*	*$20,652*
2043	*27*	*$0*	*$2,020*	*$2,020*	*$17,044*	*$5,720*	*$22,763*	*$20,743*
2044	*28*	*$0*	*$2,020*	*$2,020*	*$17,135*	*$5,720*	*$22,855*	*$20,834*
2045	*29*	*$0*	*$2,020*	*$2,020*	*$17,227*	*$5,720*	*$22,946*	*$20,926*
2046	*30*	*$0*	*$2,020*	*$2,020*	*$17,318*	*$5,720*	*$23,037*	*$21,017*
2047	*31*	*$0*	*$2,020*	*$2,020*	*$17,409*	*$5,720*	*$23,129*	*$21,108*
2048	*32*	*$0*	*$2,020*	*$2,020*	*$17,500*	*$5,720*	*$23,220*	*$21,199*
2049	*33*	*$0*	*$2,020*	*$2,020*	*$17,592*	*$5,720*	*$23,311*	*$21,291*
2050	*34*	*$0*	*$2,020*	*$2,020*	*$17,683*	*$5,720*	*$23,402*	*$21,382*
2051	*35*	*$0*	*$2,020*	*$2,020*	*$17,774*	*$5,720*	*$23,494*	*$21,473*
2052	*36*	*$0*	*$2,020*	*$2,020*	*$17,865*	*$5,720*	*$23,585*	*$21,564*
2053	*37*	*$0*	*$2,020*	*$2,020*	*$17,957*	*$5,720*	*$23,676*	*$21,656*
2054	*38*	*$0*	*$2,020*	*$2,020*	*$18,048*	*$5,720*	*$23,767*	*$21,747*
2055	*39*	*$0*	*$2,020*	*$2,020*	*$18,139*	*$5,720*	*$23,859*	*$21,838*
2056	*40*	*$0*	*$2,020*	*$2,020*	*$18,230*	*$5,720*	*$23,950*	*$21,929*
2057	*41*	*$0*	*$2,020*	*$2,020*	*$18,322*	*$5,720*	*$24,041*	*$22,021*
2058	*42*	*$0*	*$2,020*	*$2,020*	*$18,413*	*$5,720*	*$24,132*	*$22,112*
2059	*43*	*$0*	*$2,020*	*$2,020*	*$18,504*	*$5,720*	*$24,224*	*$22,203*
2060	*44*	*$0*	*$2,020*	*$2,020*	*$18,595*	*$5,720*	*$24,315*	*$22,294*
2061	*45*	*$0*	*$2,020*	*$2,020*	*$18,687*	*$5,720*	*$24,406*	*$22,386*
2062	*46*	*$0*	*$2,020*	*$2,020*	*$18,778*	*$5,720*	*$24,497*	*$22,477*
2063	*47*	*$0*	*$2,020*	*$2,020*	*$18,869*	*$5,720*	*$24,589*	*$22,568*
2064	*48*	*$0*	*$2,020*	*$2,020*	*$18,960*	*$5,720*	*$24,680*	*$22,659*
2065	*49*	*$0*	*$2,020*	*$2,020*	*$19,052*	*$5,720*	*$24,771*	*$22,751*
2066	*50*	*$0*	*$2,020*	*$2,020*	*$19,052*	*$5,720*	*$24,771*	*$22,751*
Cumulative Present Values:		*$190,476*	*$34,962*	*$225,438*	*$279,221*	*$98,936*	*$378,158*	

Benefit Cost Ratio: BCR	***1.68***
Internal Rate of Return (IRR)	***9.6%***
Net Present Value (NPV)	***$152,720***

Notes	
Year	Enter first year of alternative implementation from WS III.1
Year #	Start with '0' and include the "N" value from WS III.1
Life Cycle Costs	Transfer the appropriate values from WS III.1. If helpful, add columns with further detail about the particular costs. Sum the rows to calculate Total Costs.
Benefits	Transfer the appropriate values from WS III.3 or from other spreadsheet or monetization tool you have used to calculate benefit values. Sum the rows to calculate Total Monetized Benefits.
Total Monetized Benefits less Total	Subtract Total Costs from Total Monetized Benefits
Cumulative Present Values	The net present value formula (referencing the discount rate) should be applied to the sum of each column after the 1st year of activity + the 1st year
Benefit Cost Ratio: BCR	Calculate BCR (Total Monetized Benefits divided by Total Costs)
Internal Rate of Return (IRR)	Calculate IRR [The rate that renders the present value of the cost stream (future annual costs) equal to the present value of the benefits stream (future annual benefits)]
Net Present Value (NPV)	Calculate NPV (absolute difference between the cumulative *present* value of benefits and the cumulative *present* value of costs)

Worksheet III.4.5 - Benefit Cost Ratio and Net Present Value (Install Oyster Reef) **Name:** **Last Update Date:**

Purpose: Use this worksheet to bring together costs and benefits to calculate BCR and NPV.

Step 1. Enter your Action Alternative descriptor or title. Enter the Discount Rate.

Action Alternative: ***Install oyster reef***

Discount Rate, *i* = *0.05*

Step 2. Document your answers in the rows and columns below using the notes located at the bottom of the spreadsheet.

		Life Cycle Costs: (constant dollars)					Benefits			
				III. Renewal , Replacement Costs						
Year	Year #	I. Capital Costs	II. Annual O&M	*Reseeding reefs*	*Habitat monitoring*	Total Costs	I. Resilience Benefit Values	IV. Environmental / Ecosystem Benefit Values	Total Monetized Benefits	Total Monetized Benefits less Total Costs
2016	*0*	*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	*$0*	*$0*
2017	*1*	*$600,000*	*$0*	*$0*	*$0*	*$600,000*	*$0*	*$0*	*$0*	*-$600,000*
2018	*2*	*$400,000*	*$0*	*$0*	*$0*	*$400,000*	*$72,395*	*$27,876*	*$100,270*	*-$299,730*
2019	*3*	*$0*	*$9,910*	*$0*	*$45,000*	*$54,910*	*$72,832*	*$28,044*	*$100,876*	*$45,966*
2020	*4*	*$0*	*$9,910*	*$0*	*$45,000*	*$54,910*	*$73,279*	*$28,044*	*$101,323*	*$46,413*
2021	*5*	*$0*	*$9,910*	*$0*	*$45,000*	*$54,910*	*$73,727*	*$28,044*	*$101,771*	*$46,861*
2022	*6*	*$0*	*$9,910*	*$0*	*$45,000*	*$54,910*	*$74,174*	*$28,044*	*$102,218*	*$47,308*
2023	*7*	*$0*	*$9,910*	*$0*	*$45,000*	*$54,910*	*$74,622*	*$28,044*	*$102,666*	*$47,756*
2024	*8*	*$0*	*$9,910*	*$0*	*$45,000*	*$54,910*	*$75,069*	*$28,044*	*$103,113*	*$48,203*
2025	*9*	*$0*	*$9,910*	*$0*	*$45,000*	*$54,910*	*$75,516*	*$28,044*	*$103,560*	*$48,650*
2026	*10*	*$0*	*$9,910*	*$0*	*$45,000*	*$54,910*	*$75,964*	*$28,044*	*$104,008*	*$49,098*
2027	*11*	*$0*	*$9,910*	*$0*	*$45,000*	*$54,910*	*$76,411*	*$28,044*	*$104,455*	*$49,545*
2028	*12*	*$0*	*$9,910*	*$100,000*	*$45,000*	*$154,910*	*$76,859*	*$28,044*	*$104,903*	*-$50,007*
2029	*13*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$77,306*	*$28,044*	*$105,350*	*$95,440*
2030	*14*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$77,754*	*$28,044*	*$105,798*	*$95,888*
2031	*15*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$78,201*	*$28,044*	*$106,245*	*$96,335*
2032	*16*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$78,649*	*$28,044*	*$106,693*	*$96,783*
2033	*17*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$79,096*	*$28,044*	*$107,140*	*$97,230*
2034	*18*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$79,544*	*$28,044*	*$107,588*	*$97,678*
2035	*19*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$79,991*	*$28,044*	*$108,035*	*$98,125*
2036	*20*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$80,438*	*$28,044*	*$108,482*	*$98,572*
2037	*21*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$80,886*	*$28,044*	*$108,930*	*$99,020*
2038	*22*	*$0*	*$9,910*	*$100,000*	*$0*	*$109,910*	*$81,333*	*$28,044*	*$109,377*	*-$533*
2039	*23*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$81,781*	*$28,044*	*$109,825*	*$99,915*
2040	*24*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$82,228*	*$28,044*	*$110,272*	*$100,362*
2041	*25*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$82,676*	*$28,044*	*$110,720*	*$100,810*
2042	*26*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$83,123*	*$28,044*	*$111,167*	*$101,257*
2043	*27*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$83,571*	*$28,044*	*$111,615*	*$101,705*
2044	*28*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$84,018*	*$28,044*	*$112,062*	*$102,152*
2045	*29*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$84,465*	*$28,044*	*$112,509*	*$102,599*
2046	*30*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$84,913*	*$28,044*	*$112,957*	*$103,047*
2047	*31*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$85,360*	*$28,044*	*$113,404*	*$103,494*
2048	*32*	*$0*	*$9,910*	*$100,000*	*$0*	*$109,910*	*$85,808*	*$28,044*	*$113,852*	*$3,942*
2049	*33*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$86,255*	*$28,044*	*$114,299*	*$104,389*
2050	*34*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$86,703*	*$28,044*	*$114,747*	*$104,837*
2051	*35*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$87,150*	*$28,044*	*$115,194*	*$105,284*
2052	*36*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$87,598*	*$28,044*	*$115,642*	*$105,732*
2053	*37*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$88,045*	*$28,044*	*$116,089*	*$106,179*
2054	*38*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$88,493*	*$28,044*	*$116,537*	*$106,627*
2055	*39*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$88,940*	*$28,044*	*$116,984*	*$107,074*
2056	*40*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$89,387*	*$28,044*	*$117,431*	*$107,521*
2057	*41*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$89,835*	*$28,044*	*$117,879*	*$107,969*
2058	*42*	*$0*	*$9,910*	*$100,000*	*$0*	*$109,910*	*$90,282*	*$28,044*	*$118,326*	*$8,416*
2059	*43*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$90,730*	*$28,044*	*$118,774*	*$108,864*
2060	*44*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$91,177*	*$28,044*	*$119,221*	*$109,311*
2061	*45*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$91,625*	*$28,044*	*$119,669*	*$109,759*
2062	*46*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$92,072*	*$28,044*	*$120,116*	*$110,206*
2063	*47*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$92,520*	*$28,044*	*$120,564*	*$110,654*
2064	*48*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$92,967*	*$28,044*	*$121,011*	*$111,101*
2065	*49*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$93,414*	*$28,044*	*$121,458*	*$111,548*
2066	*50*	*$0*	*$9,910*	*$0*	*$0*	*$9,910*	*$93,414*	*$28,044*	*$121,458*	*$111,548*
Cumulative Present Values:		*$934,240*	*$162,489*	*$123,739*	*$315,173*	*$1,535,642*	*$1,369,086*	*$485,108*	*$1,854,194*	

Benefit Cost Ratio: BCR	***1.21***
Internal Rate of Return (IRR)	***6.8%***
Net Present Value (NPV)	***$318,552***

Notes	
Year	Enter first year of alternative implementation from WS III.1
Year #	Start with '0' and include the "N" value from WS III.1
Life Cycle Costs	Transfer the appropriate values from WS III.1. If helpful, add columns with further detail about the particular costs. Sum the rows to calculate Total Costs.
Benefits	Transfer the appropriate values from WS III.3 or from other spreadsheet or monetization tool you have used to calculate benefit values. Sum the rows to calculate Total Monetized Benefits.
Total Monetized Benefits less Total	Subtract Total Costs from Total Monetized Benefits
Cumulative Present Values	The net present value formula (referencing the discount rate) should be applied to the sum of each column after the 1st year of activity + the 1st year
Benefit Cost Ratio: BCR	Calculate BCR (Total Monetized Benefits divided by Total Costs)
Internal Rate of Return (IRR)	Calculate IRR [The rate that renders the present value of the cost stream (future annual costs) equal to the present value of the benefits stream (future annual benefits)]
Net Present Value (NPV)	Calculate NPV (absolute difference between the cumulative *present* value of benefits and the cumulative *present* value of costs)

Worksheet IV.1 - Portfolio Summary **Name:** **Last Update Date:**

Purpose: Assemble information generated in the previous stages into a concise summary that presents the results of the analyses conducted using this Handbook.

Step 1: Document the problem statement you generated at the conclusion of Stage I. You may choose to separate out gradual events (e.g., sea level change) from extreme events (e.g. storm surge).

Problem Statement	*The following facilities and ecosystems may be impacted by **permanent inundation by 2100 based on a projected sea level change scenario of 8.2 feet adjusted to a common vertical datum:** permanent loss of 1,000 linear feet of roadway; permanent inundation of 80,000 sq. ft. of building basements and 50,000 sq. ft. of building first floors (including the Hospital, HQ Complex, and several RDT&E facilities); stormwater outfalls #3 and #4 permanently underwater; permanent inundation of 125 acres of fresh water marsh; and permanent loss of all salamander critical habitat.*

Step 2. Document your answers in the rows and columns below using the notes located at the bottom of the spreadsheet.

Column A - Action Alternative Description & Key Benefits			**Column B - Key Metrics**				**Column C - Non-Monetized Benefits & Limitations (Disbenefits)**	
Alt ID #	**Action Alternative Description**	**Key Benefits**	**Total Life Cycle Costs**	**Total Monetized Benefits**	**Total Monetized Benefits Less Costs (Net Present Value)**	**Benefit Cost Ratio**	**Non-monetized Benefits**	**Non-monetized Limitations (Disbenefits)**
1	*Build a seawall*	*• Protects 2,000,000 SF of landward shore from the impacts of erosion and flooding • Protects 30 buildings, major shoreline road, historic officer's quarters and associated landscape (protects 1,200,000 SF of buildings)*	*$5,776,874*	*$9,716,220*	*$3,939,346*	*1.68*	*• Protects historic landscape • Modern equipment can be integrated into new structure, improving efficiency*	*• Visual impacts • Reduced/impaired waterfront access • Hardened shoreline increases wave height and number of exceedance events, increases erosion on the seaward side potentially exacerbating loss of near shore ecosystem • Extensive environmental review process*
2	*Partner with County to Install flood gate at mouth of river*	*• Protects HQ Complex, other riverfront facilities from storm surge • Reduces storm impact on HQ Complex (600,000 SF) • Protects Salamander Critical Habitat*	*$144,421*	*$243,973*	*$99,552*	*1.69*	*• Does not interfere with harbor access • Prevention of salt water intrusion • Allows storage of fresh water/augment water supply*	*• Extensive environmental review process • Water quality reduction • Habitat impacts*
4	*Restore and expand fresh water marsh ecosystem*	*• Protects 500,000 SF of infrastructure from erosion and flooding • Provides stormwater storage, reducing precipitation flooding • Improves water quality and improves and expands freshwater wetland species habitat*	*$225,438*	*$378,158*	*$152,720*	*1.68*	*• Increases habitat • Preserves existing views of historic officers quarters*	*• Extensive environmental review process*
6	*Install oyster reef breakwater at mouth of river*	*• Serves as living shoreline, protecting 1.2 M SF of infrastructure from erosion and flooding. • Attenuates wave energy and storm surge. • Protects salamander habitat*	*$1,535,642*	*$1,854,194*	*$318,552*	*1.21*	*• Accommodates current navigation patterns • Attenuates wave height impacting salamander habitat • Ecosystem services of water filtration/improved water quality • Strengthens community relationship*	*• Requires partnership with Oyster Action Network • Adds design constraints to possible flood gate. • Unanticipated erosion effects on nearby shoreline*

Notes	
Column A - Action Alternative	Transfer the ID#, Description, and Key Benefits of each action alternative evaluated in Stage III
Column B - Key Metrics	Transfer the cumulative values for each of the key metrics from the worksheets in Stage III
Column C - Non-Monetized	List benefits and limitations (or disbenefits) that have not been monetized and included in the BCR
Column D - Key Future	
External Events	Enter key external events that could impact the action alterative
Funding Constraints	Identify any funding constraints or issues
Pivot Points and Data Gaps	Identify conditions that will require evaluation or reevaluation of the action alternative
Column E - Strategic Approach to Decision under Uncertainty	Re-evaluate the assessment performed in Stage II, Step⑤, regarding the type of strategic approach to decision uncertainty each action alternative represents. Enter same or new information
Column F - Risk Approach	Characterize the risk approach each action alternative represents

Worksheet IV.1 - Portfolio Summary continued

*Damage and loss values increase when the **1% annual chance event of just over 4 feet in storm surge is added to the sea level scenario** including: temporary flooding of an additional 300,000 sq. ft. of building basements and 200,000 sq. ft. of building first floors, 3 taxiways with 1.2M SF and aprons with 243K SF; debris accumulation on several roads, limiting access; an additional 5,000 LF roadway may be subject to wave erosion damage; and storm water outfall #10 below flood stage, impairing drainage.*

Column D - Key Future Variables			Column E - Strategic Approach to Decisions under Uncertainty • No-regrets strategies • Reversible and flexible strategies • Safety margin strategies • Reduced time-horizon strategies	Column F - Risk Approach Type • Assume Risk • Transfer or Share Risk • Control Risk • Avoid Risk
External Events	**Funding Constraints**	**Pivot Points and Data Gaps**		
• Third party protective measures (e.g. surge barrier protecting larger region) can render investment redundant • Incremental asset protection (flood proofing, elevation) can reduce cost effectiveness of the Action Alternative	*None, funding is allocated through established procedures*	*• Status change in county plans for surge barrier • Data on performance of marsh in limiting surge height • BCA if implemented with other adaptation measures in a hybrid solution • Data on loss of marsh area, effect on seawall performance*	***No regrets*** *Shore facilities modernization already planned for 2045. Incorporating seawall adds minor cost* ***Reversible/Flexible*** *Seawall can be designed to allow future increase in height as sea level rises*	***Control Risk*** *Increases physical flood barrier protection level to reduce risk*
County requires matching funds from several municipalities.	*Existing MILCON consolidates BRACed functions to HQ Complex, loss of HQ would require revision of entire 2021 POM and GSIP; unlikely to be funded*	*BCA if implemented with other adaptation measures in a hybrid solution*	***Reduced time horizon*** *Avoids commitment to relocating HQ Complex and revising other GSIP goals*	***Transfer/Share Risk*** *Shares cost with County. Reduces investment risk. County pays for 95% of the project and coordinates with other jurisdictions. Navy contribution limited to donation of land and $500M.*
Impact of water level on species mix, viability and extent of marsh	*None, funding is allocated through established procedures*	*• Data on performance of marsh in limiting surge height • Data on loss of marsh area, effect on resiliency values • BCA if implemented with other adaptation measures in a hybrid solution*	***Reversible/flexible*** *Conversion to marsh can be reversed in future if conditions are suitable for other types of shoreline development*	***Control Risk*** *Minor Risk Reduction for small storms only*
Third party protective measures (e.g. surge barrier protecting larger region) can change aquatic habitat (salinity) such that oyster reef may not be viable and investment is lost	*None, funding is allocated through established procedures*	*BCA if implemented with other adaptation measures in a hybrid solution*	***No Regrets*** *Installation is already a partner in regional oyster restoration with plans to restore oyster beds in partnership with Oyster Action Network as part of Chesapeake Bay Partnership obligations under E.O. 13508*	***Share risk*** *Shares cost with County*

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Appendix H – Sources Cited

This appendix contains the sources cited throughout the Handbook, including the appendices.

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