Technical Report

Military Installation Resilience Plan
With 3D Visual Environment Pilot

Naval Support Activity Annapolis / United States Naval Academy
Annapolis, Maryland

June 2022
Military Installation Resilience Plan
With 3D Visual Environment Pilot
for
Naval Support Activity Annapolis / United States Naval Academy
Annapolis, Maryland

Prepared for:
Naval Facilities Engineering Command Washington
Naval Support Activity Annapolis

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All the images depicting flooding on Naval Support Activity Annapolis and the U.S. Naval Academy presented in this document were photographed between September 2021 and November 2021. Naval Support Activity Annapolis would like to thank all the photographers that provided these images for this document.
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Acronyms, Abbreviations & Key Terminology
II. ACRONYMS AND ABBREVIATIONS

3DVE  three-dimensional environment
ac   acres
AR5  Fifth Assessment Report
AR6  Sixth Assessment Report
BCA  benefit cost analysis
BCR  benefit cost ratio
CARSWG  Coastal Assessment Regional Scenario Working Group
CEA  Cost Effectiveness Analysis
cm  centimeter
CMIP6  World Climate Research Programme's Coupled Model Intercomparison Project
COA  course(s) of action
DoD  Department of Defense
DRSL  U.S. Department of Defense Regional Sea Level
EO  Executive Order
EWL  extreme water level
FEMA  Federal Emergency Management Agency
ft  feet
Handbook  Climate Change Adaptation Planning Handbook
IDP  Installation Development Plan
IPCC  Intergovernmental Panel on Climate Change
IRR  internal rates of return
LF  linear feet
m  meter
MHHW  mean higher high water
MILCON  military construction
mm  millimeter
MSL  Mean Sea Level
NDAA  National Defense Authorization Act
NAVD88  North American Vertical Datum of 1988
NAVFAC  Naval Facilities Engineering Systems Command
NOAA  National Oceanic and Atmospheric Administration
NPV  net present values
NSAA  Naval Support Activity Annapolis
NTDE  National Tidal Datum Epoch
ROM  rough order of magnitude
RFA  Regional Frequency Analysis
SLR  sea level rise
SLRAC  Sea Level Rise Advisory Council
sq ft  square feet
UFC  Unified Facilities Criteria
US  United States
USACE  United States Army Corps of Engineers
USNA  United States Naval Academy
### III. KEY TERMINOLOGY

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<td>100-year storm event</td>
<td>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 percent (%) annual chance event.</td>
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<td>Action alternative</td>
<td>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.</td>
</tr>
<tr>
<td>Adaptation</td>
<td>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.</td>
</tr>
<tr>
<td>Adaptive management</td>
<td>Adaptive management is an iterative, informed learning technique that adjusts management interventions in the face of uncertain outcomes.</td>
</tr>
<tr>
<td>Annual chance event</td>
<td>See 100-year storm event.</td>
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<td>Avoided loss</td>
<td>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.”</td>
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<tr>
<td>Benefit cost analysis</td>
<td>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) 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.</td>
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<tr>
<td>Benefit cost ratio</td>
<td>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.</td>
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<td>Built Infrastructure</td>
<td>Built Infrastructure is referred to as capital improvements to land (&quot;Class 2&quot; property) in Department of Defense. Class 2 property can include improvements such as buildings, structures, ground improvement structures, and utilities systems. Class 2 property also includes installed or &quot;built-in&quot; 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.</td>
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<tr>
<td>Climate</td>
<td>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.</td>
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<tr>
<td>Climate change</td>
<td>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.</td>
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<td><strong>Climate change ‘signals’</strong></td>
<td>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.</td>
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<tr>
<td><strong>Climate phenomenon</strong></td>
<td>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.</td>
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<td><strong>Climate projection</strong></td>
<td>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.</td>
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<td><strong>Climate scenario</strong></td>
<td>Plausible and often simplified representation of future climate, based on an internally consistent set of climatological relationships and assumptions of greenhouse gas 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.</td>
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<td><strong>Climate variability</strong></td>
<td>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.</td>
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<td><strong>Confidence level</strong></td>
<td>The confidence level is the statistical likelihood (probability) that random variable lies within the confidence interval of an estimate.</td>
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<td><strong>Cost Effectiveness Analysis</strong></td>
<td>Cost effectiveness analysis 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. Cost effectiveness analysis is applied when project effects can be identified and quantified (through physical metrics) but not adequately valued in monetary terms.</td>
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<td><strong>Critical threshold</strong></td>
<td>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.</td>
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<td><strong>Cumulative benefits</strong></td>
<td>Cumulative benefits are the sum of all direct, indirect, and collateral benefits generated from an action alternative.</td>
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<td><strong>Decision trajectory</strong></td>
<td>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.</td>
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<td><strong>Direct benefit</strong></td>
<td>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. 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.”</td>
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<tr>
<td>Dynamic sea level</td>
<td>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.</td>
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<td>Ecosystem services</td>
<td>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.</td>
</tr>
<tr>
<td>Extreme event (or extreme weather event)</td>
<td>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. The characteristics of what is called “extreme weather” may differ from place to place. Extreme weather events may typically include floods and droughts.</td>
</tr>
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<td>Extreme water level (EWL)</td>
<td>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.</td>
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<td>Facilities approaches (or facilities adaptation approaches)</td>
<td>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.</td>
</tr>
<tr>
<td>Flooding</td>
<td>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.</td>
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<td>Green infrastructure</td>
<td>An approach to managing stormwater by mimicking natural processes. It replaces conventional piped drainage and water treatment systems, or &quot;gray infrastructure,&quot; 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.</td>
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<tr>
<td>Hazard</td>
<td>Hazards are natural events that threaten lives, property, and other assets. Typical hazards are floods, droughts, wildfires, earthquakes, hurricanes, tornadoes, windstorms, and tsunamis.</td>
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<tr>
<td>Hazard assessment</td>
<td>A hazard assessment is the process of evaluating your susceptibility and vulnerability to risks posed from multiple hazards. The hazard identification and risk assessment provide 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 environmental impacts.</td>
</tr>
<tr>
<td>Term</td>
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<tr>
<td>Impact</td>
<td>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.</td>
</tr>
<tr>
<td>Impact assessment</td>
<td>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.</td>
</tr>
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<td>Indirect benefit</td>
<td>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.</td>
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<tr>
<td>Life Cycle Cost Analysis</td>
<td>Technique applied to account for all anticipated costs of an action alternative during its various phases, including preliminary planning, construction, operations, and decommissioning activities.</td>
</tr>
<tr>
<td>Mean higher high water (MHHW)</td>
<td>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 to derive the equivalent datum of the National Tidal Datum Epoch.</td>
</tr>
<tr>
<td>Mean sea level (MSL)</td>
<td>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.</td>
</tr>
<tr>
<td>Military Installation Resilience</td>
<td>The capability of a military installation to avoid, prepare for, minimize the effect of, adapt to, and recover from extreme weather events, or from anticipated or unanticipated changes in environmental conditions, that do, or have the potential to, adversely affect the military installation or essential transportation, logistical, or other necessary resources outside of the military installation that are necessary in order to maintain, improve, or rapidly reestablish installation mission assurance and mission-essential functions.</td>
</tr>
<tr>
<td>Mitigation</td>
<td>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.</td>
</tr>
<tr>
<td>Natural infrastructure</td>
<td>Features of the land and water environments, including their biota and associated ecological processes that directly or indirectly support society.</td>
</tr>
<tr>
<td>Natural/Nature-based approaches</td>
<td>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.</td>
</tr>
<tr>
<td>Net present value</td>
<td>The net present value is the absolute difference between the cumulative present value of benefits and the cumulative present value of costs.</td>
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<tr>
<td><strong>Non-facilities approaches</strong></td>
<td>Range of techniques that rely on changes in siting, management, or maintenance of infrastructure to reduce flood damage.</td>
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<tr>
<td><strong>North American Vertical datum</strong></td>
<td>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 benchmark, 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).</td>
</tr>
<tr>
<td><strong>Nuisance flooding</strong></td>
<td>Recurrent flooding that takes place at high tide. Nuisance or high tide flooding is defined by NOAA as “flooding that leads to public inconveniences such as road closures.” Nuisance flooding is often unrelated to a specific storm but is commonly influenced by sustained wind events, storm systems or astrological phases.</td>
</tr>
<tr>
<td><strong>Performance metric</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>Pivot point</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>Probabilistic projection</strong></td>
<td>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.”</td>
</tr>
<tr>
<td><strong>Problem statement</strong></td>
<td>Characterizes the type and magnitude of potential impacts to infrastructure to guide and bound the identification and evaluation of possible responses to potential impacts. The problem statement sets the goal of the adaptation strategy.</td>
</tr>
<tr>
<td><strong>Reference datum</strong></td>
<td>A geodetic datum or geodetic system is a coordinate system, and a set of reference points, used to locate places on the Earth.</td>
</tr>
<tr>
<td><strong>Residual damages</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>Resilience benefits</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>Resiliency</strong></td>
<td>Ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions.</td>
</tr>
<tr>
<td><strong>Risk</strong></td>
<td>Combination of the magnitude of the potential consequence(s) of climate change impact(s) and the likelihood that the consequence(s) will occur.</td>
</tr>
<tr>
<td><strong>Scenario</strong></td>
<td>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.</td>
</tr>
<tr>
<td>-------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Sea level change</strong></td>
<td>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 were, due to tectonic uplift, sea level is falling in relation to the land surface.</td>
</tr>
<tr>
<td><strong>Sensitivity analysis</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>Storm surge</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>Structural approach</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>Tidal epoch</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>Total water level</strong></td>
<td>Water level resulting from complex interactions between multiple oceanographic, hydrologic, geologic, and meteorological forcing 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.</td>
</tr>
<tr>
<td><strong>Vertical land movement</strong></td>
<td>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 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.</td>
</tr>
<tr>
<td><strong>Vulnerability assessment</strong></td>
<td>The process of measuring susceptibility to harm by evaluating the exposure, sensitivity, and adaptive capacity of systems to climate change and related stressors.</td>
</tr>
<tr>
<td><strong>Weather phenomenon</strong></td>
<td>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.</td>
</tr>
</tbody>
</table>
Introduction
IV. Introduction

Naval Support Activity Annapolis (NSAA) and the United States Naval Academy (USNA) have jointly developed this comprehensive resilience plan, associated project portfolio, and phased execution plan to cohesively address and adapt to current and projected climate-induced threats to installation operations and the resilience of mission-essential assets and infrastructure. The combined effects of sea level rise, coastal flooding (e.g., nuisance and storm surge), groundwater inundation, land subsidence, and surface water flooding from extreme weather events will continue to intensify, and a proactive integrated adaptation strategy is warranted to address these threats.

Located at the confluence of the Severn River and Chesapeake Bay, NSAA/USNA is extremely vulnerable to major localized flooding (Figure 1), resulting from high tides, and sustained easterly or southerly winds. Since 1929, relative sea level in Annapolis has risen approximately 1.06 feet, which has significantly increased the occurrences of nuisance flooding from 2-3 times per year through the 1960’s, to 30-40 times per year today. These frequent flooding events are impacting installation operations (e.g., transportation, emergency management services) and critical infrastructure (e.g., waterfront infrastructure, stormwater management system) and the academic and training mission of the Naval Academy. If current Department of Defense (DoD) Regional Sea Level (DRSL) scenarios for NSAA/USNA are correct and an increase of 2.6 feet in relative sea level rise by 2065 and 4.4 feet by 2100 is anticipated, then these nuisance events will naturally evolve into permanent inundation of low-lying land area and major flooding events that will threaten NSAA/USNA’s ability to maintain mission. Combine these projections with associated changes in groundwater inundation, land subsidence, and precipitation, the need for a comprehensive resilience plan for NSAA/USNA is both timely and vital.

Given the imminent threat of extreme flooding events, as well as probable permanent inundation of some land areas over time, this comprehensive resilience plan and associated products were developed with the purpose of synthesizing the extensive research, studies, planning efforts, and implementation of resilience measures performed by NSAA, USNA Sea Level Rise Advisory Council (SLRAC), United States Army Corps of Engineers (USACE), DoD Strategic Environmental Research and Development Program, and other commands rather than conducting new studies or investigations. By building on over a decade of assessments and analyses, this plan has provided NSAA/USNA extensive documentation of the constraints that will be placed upon the installation and allowed NSAA/USNA an awareness that a single adaptation strategy will not be able to mitigate the constraints identified. As such, the installation will need to combine a variety of alternatives in an integrated adaptation framework to address present-day and future constraints (i.e., 2035, 2065 and 2100) and ensure the successful execution of mission critical and base support activities.

NSAA/USNA’s integrated adaptation framework has been leveraged to develop and refine a portfolio of projects that will improve resilience of assets and infrastructure within the installation’s four planning focal areas which include the Lower Yard, Upper Yard, North Severn, and Greenbury Point. Projected and modeled installation constraints of these areas have emphasized that the risks and vulnerabilities are not isolated to a single area. While the projected impacts to the Lower Yard are severe, projected future constraints will adversely impact NSAA/USNA’s ability to maintain mission and support activities across the

Figure 1. Flooding along Turner Road.
entire installation. To meet these anticipated threats sustainably, NSAA/USNA’s integrated adaptation framework and associated portfolio of projects include a combination of engineered defenses (seawalls, stormwater retrofits); adapted structures (building and infrastructure modifications); green infrastructure (earthen berms, stormwater retention, living shorelines); and temporary solutions (deployable floodwalls or barriers). Several of these projects in the portfolio were previously vetted by NSAA/USNA while others represent new concepts. In every case a concerted effort has been made to establish a framework that improves installation resilience, creates functional redundancies, aesthetically aligns with the national historic landmark, considers operations and management costs, is respectful of community and regional partners, and allows flexibility to meet future constraints. This conceptual framework and resulting plan were developed to provide a foundation and guide for future planning, design, and construction effort. Every adaptation alternative captured in this plan is expected to generate multiple courses of action during design development of each individual project.

NSAA/USNA has considered that the integrated adaptation framework outlined in this comprehensive resilience plan will demand a sustained long-term commitment. The project portfolio presented in this plan recommends some adaptation alternatives to be executed as early as 2023 with other projects continuing through 2065. To assist the installation in the management of this large and extensive portfolio of projects, a phased execution plan has been developed. This execution plan outlines planning, design, and construction phases for individual projects within five-year planning cycles to align with DoD Program Objective Memorandum processes and support future Installation Development Plan (IDP) updates.

It is important to note that this comprehensive resilience plan, associated project portfolio, and phased execution plan are being performed by NSAA/USNA and Naval Facilities Engineering System Command (NAVFAC) Headquarters as a pilot study. These commands anticipate that this pilot will demonstrate a comprehensive application of the NAVFAC Climate Change Adaptation Planning Handbook (Handbook); how the Handbook can support future IDP updates at other Navy installations; and how this reference aligns with current DoD memorandums, policies, guidance, and criteria. Consequently, every effort was made to maximize digital data, resources, and platforms that are currently available to the NAVFAC enterprise. This included the execution of parallel pilot venture to assess how three-dimensional virtual environments (3DVE) can improve the speed and agility of resilience planning effort by allowing leadership to visualize vulnerabilities in combination with recommended resilience and mitigation measures in a highly precise rendering of the installation.

In each case, these pilot efforts, and the resulting comprehensive resilience plan (and associated products) illustrate that the climate change adaptation planning does not have to be a cumbersome and overwhelming endeavor for an installation. If it is understood that these efforts are merely exploiting local knowledge and expertise and resources that currently reside within DoD to identify current and future climate and environment constraints facing a particular installation, then these investments will have huge returns for the installation as the resulting product will inform numerous planning efforts (e.g., IDP, energy, natural resources, range management). In the case of NSAA/USNA, this effort has allowed it to successfully integrate over a decade of resilience efforts into a cohesive plan and products that will assist it to effectively meet the climate-induced threats to installation operations and mission-essential assets and infrastructure.
Background, Project Purpose, & DoD Guidance
V. Background

Located at the confluence of the Severn River and Chesapeake Bay, USNA has been charged with the mission of developing "...Midshipmen morally, mentally, and physically and to imbue them with the highest ideals of duty, honor, and loyalty in order to graduate leaders who are dedicated to a career of naval service and have potential for future development in mind and character to assume the highest responsibilities of command, citizenship, and government." To accomplish this mission, the program of study and training that USNA Midshipmen follow develops junior officers in multiple ways including core academic courses, physical readiness programs, and military training. All USNA Midshipmen receive the intellectual and professional leadership skills required of Navy and Marine Corps officers.

For over 175 years, the installation has evolved to meet these mission requirements. Today, NSAA, home of USNA, has established and maintains state-of-the-art facilities, infrastructure, and environments that inspire and support the pursuit of academic, professional, and athletic excellence. USNA is currently ranked as one of the top liberal arts colleges in the country, and every effort is being made to ensure that it will continue to educate and motivate the next generation of Navy and Marine Corps officers. Looking forward to 2100, USNA Strategic Plan 2020 (USNA, 2015) requests NSAA’s support and commitment to provide:

- Academic facilities consistent with the growing needs of the faculty and midshipmen, and the technological advances of the 21st century;
- Professional development facilities that prepare Midshipmen to face the challenges of present and future warfare; and
- Athletic facilities consistent with need to offer a dynamic and challenging physical preparation program and compete in intercollegiate athletics in keeping with the Naval Service traditions of teamwork, persistence, and victory.

As it has since the installation’s inception in 1845, the Severn River and the Chesapeake Bay will continue to play a pivotal role in the ability of NSAA/USNA to meet these goals and will inform the future of academic, professional, and athletic programs. Since its inception, USNA has had a close and essential relationship with the river and bay and its mission is directly tied to these water environments and the value these resources bring to the Midshipmen development (Figure 2). For example:

- The engineering and physical sciences departments, that compose approximately 50% of the Midshipmen enrollment, consider these bodies of water to be an extension of their classrooms and laboratory facilities;
- The Midshipmen-run Yard Patrol Squadron provides opportunities for Midshipmen to enhance their leadership, seamanship, and navigation skills in a safe and controlled learning environment that mimics that of the Fleet; and
- USNA sailing is the largest athletic program on campus.
There are few undergraduate programs in the nation that have woven their surrounding environment into their programs such as the USNA (Figure 3). Being integrally tied to these water resources provides the installation immeasurable benefits, but they also come with a cost. Coastal flooding (e.g., nuisance and storm surge), sea level rise, groundwater inundation, land subsidence, and surface water flooding from extreme weather events have and will continue to bring water closer to mission-essential facilities and infrastructure.

NSAA/USNA is already experiencing coastal flooding and it will continue to intensify. Since 1929, relative sea level in Annapolis has risen approximately 1.06 feet, which has significantly increased the occurrences of nuisance flooding from 2-3 times per year through the 1960’s to 30-40 times per year today. These frequent flooding events are impacting installation operations (e.g., transportation, emergency management services) and critical infrastructure (e.g., waterfront infrastructure, stormwater management system). If current DRSL scenarios for NSAA/USNA are correct and an increase of 2.6 feet in relative sea level rise by 2065 and 4.4 feet by 2100 is anticipated, then these nuisance events will naturally evolve into major flooding events that will threaten NSAA/USNA’s ability to effectively deliver the mission.

Combined with the increase in the frequency and intensity of nuisance flooding events, the other potential sources of flooding described earlier (i.e., storm surge, ground inundation, land subsidence, and extreme precipitation events) will continue to have a profound impact on the land and infrastructure and pose significant challenges to the successful execution of the NSAA/USNA mission. Of the 338 acres that compose the USNA, current projections would indicate that over 95 acres will be adversely impacted by climate-induced flooding by 2100 including the land designated as a National Historic Landmark District. Within this boundary, 139 facilities comprised of buildings and monuments are contributing elements of the National Historic Landmark District and 42% (59 facilities) of those are projected to be impacted. In addition to the historical significance of USNA, there are 77 facilities categorized as critical or significant to the installation’s mission.

Given the imminent threat of extreme coastal and precipitation-based storm events as well as probable permanent inundation of some land areas over time, NSAA/USNA must be able to predict future conditions with accuracy and precision. The installation must provide improved predictions on adverse impacts to mission-essential facilities and infrastructure and enhance the ability of the installation to prepare and plan for, as well as absorbing and recovering from, adverse events. The overall sensitivity of NSAA/USNA to physical and biological forces determines the impacts of extreme conditions in mission-sustainable activities. The ability of NSAA/USNA to adjust to different conditions is one component of resilience. The ensuing land use planning considerations can increase or decrease the level of resilience.

This comprehensive resilience plan has been developed to provide decision makers the resources they need to make informed decisions. It also provides the justifications and assurances to Navy Leadership to move forward with implementation of these resilience measures. To accomplish this objective, the plan recommends a proactive, integrated adaptation framework and associated portfolio of projects, a phased
execution plan, and digital visualization tools that will assist NSAA/USNA to develop and refine courses of actions (COAs) for adaptation strategies that will meet the NSAA/USNA’s 2100 planning vision. Fundamentally, this planning vision will demand a sustained long-term commitment by NSAA/USNA, and this comprehensive resilience plan and associated products will provide a foundation for future climate resilience endeavors.

VI. Project Purpose

This comprehensive resilience plan and associated products were developed with the purpose of synthesizing and building upon the extensive research, studies, planning efforts, and implementation of resilience measures performed by NSAA, USNA SLRAC, USACE, and DoD Strategic Environmental Research and Development Program with the goal of achieving the following objectives:

- Gain a thorough awareness of the current and future mission of the Installation.
- Assess the impacts of current and future climate-hazards on mission-critical assets and infrastructure for each installation planning area;
- Attain a common NSAA/USNA vision for addressing current and projected flooding threats;
- Obtain comprehensive documentation of existing and designed adaptation alternatives as well as resilience measures that have already been implemented;
- Work with NSAA subject matter experts and USNA SLRAC members to develop and evaluate new adaptation alternatives;
- Establish an integrated adaptation framework that improves installation resilience, creates functional redundancies, aesthetically aligns with the national historic landmark, considers operations and management costs, is respectful of community and regional partners, and evolves to meet future constraints;
- Perform a benefit-cost analysis of the NSAA/USNA preferred adaptation alternatives; and
- Develop a comprehensive resilience plan, project portfolio and phased execution plan to cohesively address and mitigate the combined sources of risks to 2100.

By building on over a decade of assessments and analyses, this plan provides NSAA/USNA an extensive documentation of the constraints that will be placed upon the installation and allows NSAA/USNA to recognize that a single adaptation strategy will not be able to mitigate the constraints identified (See Table 1). As such, the installation will need to combine a variety of alternatives in an integrated adaptation framework to address present-day and future constraints (i.e., 2035, 2065 and 2100) and ensure the successful execution of mission critical and base support activities.

Table 1. Brief of Summation of Key Plans, Studies, Reports, Data, and Designs Administered by NSA Annapolis and U.S. Naval Academy by Date.
VII. DoD Guidance and Policies

To meet the project objectives, a concerted effort has been made to ensure this comprehensive resilience plan and associated deliverables are compliant with all primary federal, DoD and Navy requirements relating to climate change. At the national level, the Navy has issued several overarching planning strategies, guidance, and new authorities that are applicable to NSAA/USNA planning and implementation effort. Specifically, the Navy, and DoD as a whole, has identified climate change as a critical national security issue and threat multiplier (DoD, 2014) and top management challenge (DoD, 2020a). Climate change will continue to amplify operational demands on the force, degrade installations and infrastructure, increase health risks to our service members, and could require modifications to existing and planned equipment. Extreme weather events are already costing the Department billions of dollars and are degrading mission capabilities. These effects and costs are likely to increase as climate change accelerates.

The Navy has determined that not adapting to climate change will be even more consequential with failure measured in degradation of military capability, tensions with community partnerships, deterioration of infrastructure, and missed opportunities for technical innovation. The Navy continues to meet Executive Orders and legislative requirements and has taken bold steps to accelerate adaptation to reduce the
adverse impacts of climate change. In each case, these steps have aligned with the Navy’s strategic objectives and mission requirements and ensure that installations continue to enable force readiness.

Fundamentally, the Navy’s planning strategies, guidance, and new authorities stem from the FY19 and FY20 National Defense Authorization Act (NDAA). These NDAA’s enacted several new climate change provisions for military installation master planning and infrastructure projects. Section 2805 included new requirements for a flood risk disclosure for military construction; minimum flood mitigation requirements; incorporation of changing environmental condition projections in military construction designs and modifications; and inclusion of a Military Installation Resiliency component in the IDP. Specifically related to flooding projections for use in military construction designs, Section 2805 stipulated changes to the Unified Facilities Criteria (UFC 2020, 2021), specifying that during the design life of existing or planned new facilities and infrastructure, projections from reliable and authorized sources such as the U.S. Global Change Research Office and National Climate Assessment shall be considered and incorporated into military construction designs and modifications. Specifically, the UFCs requires:

- **UFC 2-100-01 Installation Master Planning** (updated 30 September 2020) - 10 USC 2864 requires all major military installations have a Master Plan. DoDI 4165.70, Real Property Management, establishes the requirement for installation Master Plans. FY20 NDAA Section 2804(c) (i): 2-2.16, 2-5.1.1, 2-6, 2-8, 2-9, 2-9.1, 2-9.3, 3-5.6.1, 3-6.1.6, 3-5.5, 3-5.6.1, 3-5.7, 3-6.1.1, 3-6.1.3.c, 3-6.1.6, 3-6.4, 3-7, Appendix B (Verbiage changes to specifically identify climate and weather considerations in planning processes). This UFC prescribes DoD minimum requirements for master planning processes and products in accordance with DoDI 4165.70. The process includes the use of a Master Plan and its components as a tool to provide ongoing planning for installations in support of the mission. DoD planners utilize this UFC, the DoDI, and applicable agency instructions to prepare Master Plans and other planning documents.

Affiliated design and programming professionals will refer to the Master Plan as they prepare site-specific design proposals. This UFC outlines a complete process for master planning (and ultimately the development of a Master Plan) through the preparation of linked plans (Functional Annexes) that can be implemented entirely or incrementally based on each installation’s needs and resources. For coastal or tidally influenced installations, use the sea level rise scenarios in the DoD Regional Sea Level (DRSL) database is required to ensure DoD uses a consistent, authoritative data set for DoD sites. Scenarios are not predictions of the future but plausible future conditions.

Additionally, the NDAA, FY20 NDAA section 2804(c) (iv): 2-2.17.1, 3-10.2 required DoD to use NAVFAC Installation Adaptation & Resilience Climate Change Planning Handbook (Handbook) for climate adaptation planning. Released in 2017, the Naval Facilities Engineering Command (NAVFAC) released a guidance document, the Handbook provides Navy master planners with a framework for considering sea level rise in their plans. The Handbook includes a detailed methodology for evaluating various scenarios, assessing potential impacts, and developing adaptation action alternatives. The document presents several adaptation strategies, ranging from structural approaches (i.e., levees and storm surge barriers) to nature-based approaches (i.e., marshes and coastal vegetation) and facilities modifications to withstand flooding, to changes in land use planning (i.e., siting facilities out of flood-prone areas);
• UFC 3-201-01 Civil Engineering, with Change 5 (updated April 1, 2021)- This UFC provides civil engineering requirements for all new and renovated Government facilities for the DoD. Where other criteria, statutory or regulatory requirements, are referenced, the more stringent requirement must be met. Buildings sited within or partially within a flood hazard area must be designed in accordance with UFC 1-200-01 and this UFC. The terms buildings and structures are used interchangeably for flood resistant design criteria. To minimize impacts to the existing floodplain, EO 11988 directs all Federal agencies to elevate buildings rather than filling in land, wherever practicable.

The UFC states that when mission needs require siting a building within or partially within a flood hazard area, the design must utilize the project specific Basis for Flood Risk Design, when available. When the basis for flood risk design is not available, the designer of record is responsible for preparing the Basis for Flood Risk Design.

To meet these NDAA requirements, DoD and Navy actions must include scientific and engineering research to recognize adaptation requirements, new policies and guidance, improved construction codes and standards, tools to assess and evaluate climate exposure at installations, and a requirement for comprehensive installation master planning (See Table 2 & 3). This comprehensive resilience aligns with guidance and activities outlined in the 2021 DoD Climate Adaptation Plan, DoD 2014 Climate Change Adaptation Roadmap (DoD 2014) and meets the requirements of Section 211 of Executive Order (EO) 14008, “Tackling the Climate Crisis at Home and Abroad”.

<table>
<thead>
<tr>
<th>ASCE Flood Design Class</th>
<th>Freeboard Approach ¹</th>
<th>DRSL Approach ²,³,⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (minimal risk; non-essential facilities)</td>
<td>BFE</td>
<td>Lowest 2065</td>
</tr>
<tr>
<td>2 (moderate risk; non-essential facilities)</td>
<td>BFE + 2 ft (600 mm)</td>
<td>Low 2065</td>
</tr>
<tr>
<td>3 Subcategory 3a (high risk; non-essential facilities)</td>
<td>BFE + 2 ft (600 mm)</td>
<td>Medium 2065</td>
</tr>
<tr>
<td>3 Subcategory 3b ⁵ (high risk; essential facilities)</td>
<td>BFE + 3 ft (900 mm)</td>
<td>High 2065</td>
</tr>
<tr>
<td>4 ⁶ (high risk; essential facilities)</td>
<td>BFE + 3 ft (900 mm)</td>
<td>Highest 2065</td>
</tr>
</tbody>
</table>

¹ The freeboard approach complies with PL 115-232, Section 2805(a)(4)(A) and (B).
³ Use the site-specific value from the DoD Regional Sea Level (DRSL) database corresponding to the designated scenario (lowest/low/medium/high/highest) for the year 2065. The DRSL database is available at [https://sealevelscenarios.serdp-estcp.org](https://sealevelscenarios.serdp-estcp.org).
⁴ These are default values in the absence of a Basis for Flood Risk Design. When provided, use the component’s Basis for Flood Risk Design in lieu of the value provided in this column.
⁵ Essential facilities that would not need to remain operational during the design flood event but would need to fully operational immediately following a storm event.
⁶ Essential facilities that would need to remain operational during the design flood event.
Table 3. List of DoD Climate Change Focused Executive Orders and DoD Memorandums, Policies, Guidance and Criteria.

<table>
<thead>
<tr>
<th>Titles</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>EO 13990 Protecting Public Health &amp; the Environment and Restoring Science to Tackle the Climate Crisis</td>
<td>Jan 2021</td>
</tr>
<tr>
<td>EO 14007 President’s Council of Advisors on Science and Technology</td>
<td>Sep 2021</td>
</tr>
<tr>
<td>EO 14008 Tackling the Climate Crisis at Home and Abroad</td>
<td>Jan 2021</td>
</tr>
<tr>
<td>EO 14030 Climate-Related Financial Risks</td>
<td>May 2021</td>
</tr>
<tr>
<td>DoD 2014 Climate Change Adaptation Roadmap</td>
<td>Oct 2014</td>
</tr>
<tr>
<td>2021 DoD Climate Adaptation Plan</td>
<td>Sep 2021</td>
</tr>
<tr>
<td>DoDD 4715.21 Climate Adaptation and Resilience</td>
<td>Jan 2016</td>
</tr>
<tr>
<td>DoDI 4715.03 Natural Resources Conservation Program</td>
<td>Aug 2018</td>
</tr>
<tr>
<td>DoDM 4715.03 Integrated Natural Resources Management</td>
<td>Aug 2018</td>
</tr>
<tr>
<td>DoDI 3200.2 Sustaining Access to the Live Training Domain</td>
<td>Jul 2020</td>
</tr>
<tr>
<td>UFC 1-200-02 High Performance &amp; Sustainable Building Requirements</td>
<td>Oct 2020</td>
</tr>
<tr>
<td>UFC 2-100-01 Installation Master Planning</td>
<td>Sep 2020</td>
</tr>
<tr>
<td>UFC 3-201-01 Civil Engineering</td>
<td>Apr 2021</td>
</tr>
</tbody>
</table>

VIII. Methodology

As a pilot study, a conscientious effort has been made to ensure that the development of this comprehensive resilience plan can be replicated by other Navy installations. Therefore, NSAA/USNA chose to align this effort with the detailed methodology outlined in the NAVFAC Handbook (NAVFAC, 2017a). The Handbook provides Navy planners with a framework for considering climate-induced constraints in the IDP process by establishing a consistent four-stage process for the evaluation of military installation climate-influenced conditions. The four-stages are:

- Stage I: Establish Scope and Characterize Impacts;
- Stage II: Identify and Screen Action Alternatives;
- Stage III: Calculate Benefits and Cost of Action Alternatives; and
- Stage IV: Assemble Portfolio of Action Alternatives.

Additionally, the Handbook provides its users a suite of intuitive tools and resources to capture data, analyses, results, and findings for each Stage (e.g., Microsoft Excel worksheets, photographs, observations). This makes the Handbook an ideal reference and compendium for this resilience planning effort.

1.0 Stage I: Establish Scope and Characterize Impacts

Leveraging the methodology outlined in the Handbook, the first Stage of this plan concentrated on the collection and analysis of the large docket of existing plans, studies, and designs performed by NSAA/USNA in recent years. This required a comprehensive review of technical aspects and assumptions, plan validation, and the identification of data and information gaps that would need to be addressed to support this and future coastal resilience, climate adaptation efforts, and associated engineering concept designs. It also necessitated an extensive modeling effort to assess current and future sea level change (i.e., 2035, 2065 and 2100) and extreme water level scenarios. Therefore, Stage I included the following steps:
• Step 1: Determining the focus of the assessment including the geographic extent, specific infrastructure, climate phenomena, and hazards of interest;
• Step 2: Identifying the information needed and quality of the data;
• Step 3: Assessing, describing, and characterizing the current and future impacts of climate change on infrastructure of concern; and
• Step 4: Developing a Problem Statement that defines the type and magnitude of climate phenomena and hazards to be addressed. The Problem Statement is an outcome of Stage I and forms the basis of Stage II.

It is important to note that a concerted effort was made not to duplicate previous resilience studies, planning endeavors, and adaptation designs undertaken by NSAA/USNA to date, but rather to build upon the outcomes. Specifically, this plan leverages previous NSAA/USNA efforts to model current and future constraints, explores existing and new adaptation action alternatives, implements resilience measures, and finally develops a project portfolio for the installation. While several studies and plans were referenced when performing Steps 1-3 of this Stage (USACE, 2006, 2008, 2015, 2019), Steps 1-3 leaned heavily the SLRAC report to the USNA Superintendent (USNA, 2019a) and the NSAA/USNA Sea Level Rise Planning Charrette (NSAA, 2019). Both reports provided a thorough summation of the previous resilience studies, insights into how results of these studies had informed several adaptation strategies employed by NSAA (e.g., wet- and dry-flood proofing measures), and most importantly, considered how this data and the resulting adaptation concepts would align with NSAA/USNA missions. These reports became the foundational background material in support of this effort. Intuitively, NSAA/USNA recognizes that no one has a better comprehension of elements that compose Steps 1-4 of this Stage than the USNA SLRAC, NSAA subject matter experts, and local stakeholders.

The SLRAC, constituted on July 8, 2015, by USNA Superintendent, has taken the lead role in providing the analysis, guidance, and recommendations on issues surrounding sea level rise, coastal flooding, and increased occurrences of severe weather events, with specific focus on the impacts to operational requirements of USNA. The focus area of the SLRAC includes USNA Lower Yard, Upper Yard, and the federal property on North Severn. In 2019, SLRAC issued a formal report to the Superintendent, “Initial Analysis and Recommendations to Prepare for 21st Century Sea Level Rise and Storm Tides”. The report synthesized the latest sea level rise science, assessed installation vulnerability, outlined resiliency actions taken to-date and recommended specific planning guidance, and steps for further action. Consequently, this report plays an integral role in addressing Steps 1-3 of this Stage and is why the SLRAC members served as key stakeholders in the development of this comprehensive resilience plan.

Additionally, the SLRAC report played an integral role in supporting the November 2019 planning charrette. Hosted by NSAA/USNA this meeting brought together Navy leadership, stakeholders, tenants, and subject matter experts to initiate the comprehensive sea level rise planning process for the installation. Over the course of two-days, attendees worked together to establish the planning vision, define design water levels and other design criteria, explore adaptation action alternatives, and develop COAs for the four planning areas. The Handbook was used to frame the agenda and establish the objectives for the planning charrette. Therefore, the summary report documents the process, decision points and outcomes of the charrette and served as a foundational resource for execution of this project (NSAA, 2019).
Finally, the 2019 SLRAC and NSAA/USNA reports were instrumental in developing two essential components of this comprehensive resilience plan:

- Defining the NSAA/USNA Resilience Planning Vision;
- Defining the NSAA/USNA Problem Statement; and
- Selection of sea level rise and extreme water level scenarios and projections.

These definitions influenced how a variety of parameters will be examined, including the geographic extent of the study, intended timeframe for this plan, the climate phenomena of interest, and the types of decisions that will need to be supported. Without a clearly defined planning vision and a problem statement that succinctly characterizes these issues, this comprehensive plan would lack a solid foundation.

1.1 Planning Vision

Building on its over 175-year history, the USNA planning vision charts a course that provides the infrastructure to support this academic institution as it continues to navigate and adapt to the challenges of the 21st century. The planning vision that resulted from the 2019 NSAA/USNA planning charrette adheres to the guidance and directives that the Superintendent and Navy leadership has placed on the installation. Their vision is for the USNA to be “the premier leadership and educational institution for developing naval officers who will preserve peace and prevail in conflict” until 2100.

Figure 4. Naval Support Activity Annapolis and U.S. Naval Academy 2100 Planning Vision by Geographic Areas and SLR Projections.
This comprehensive resilience plan identifies efforts needed to achieve this vision. It is important to note that this plan does not represent the sum of all NSAA/USNA are or will be doing to meet this vision. There are numerous activities, programs, and efforts already underway across NSAA that will improve the installations resilience to climate-induced constraints (e.g., participation in community resilience studies). For this plan to guide long-term resilience planning actions, adaptation alternatives that were woven into an integrated adaptation framework were not limited to those that can be implemented in the near term (i.e., next 5 years) and as a result, it includes resilience measures that would need to be implemented to meet the projections at 2100.

To support this undertaking, the NSAA/USNA planning vision divided the installation into four geographic planning areas: Lower Yard, Upper Yard, North Severn, and Greenbury Point (See Figure 4). This approach allowed NSAA/USNA to prioritize assessments and adaptation measures that improved the resilience of mission-essential facilities and infrastructure and to ensure that these measures provide the resilience required to meet projected frequency, intensity, and extent of flooding in the future. In Figure 4, DRSL 2065 and 2100 sea level rise scenarios are depicted in the light blue areas. This planning vision provides context for this comprehensive plan and each stage going forward.

1.2 Defining Problem Statement

The Handbook recommends that a problem statement should characterize the type and magnitude of potential impacts to infrastructure as part of Step 4. 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. Specifically, the problem statement should include:

- Infrastructure scope. Identified in the assessment scope (Step 1) at the beginning of Stage I. To align with the planning vision, NSAA/USNA will need to ensure that most of the geographic planning areas were included in the statement (e.g., Lower Yard);
- Hazard(s). Identified in the assessment scope (Step 1), the NSAA/USNA problem statement needed to distinguish between different types of hazards (e.g., permanent inundation);
- Timeframe. The NSAA/USNA planning vision and assessment scope required would require the problem to statement to illustrate potential impacts to the installation to 2100;
- Weather or climate phenomena. NSAA/USNA should distinguish between different climate-induced phenomena (e.g., sea level rise, changing weather patterns, subsidence);
- Time slice and climate scenario. It is vital that NSAA/USNA chooses climate scenarios that align best with its assessment scope and the risk management style of the installation (e.g., 2035, 2050, 2065). Since NSAA/USNA is currently being impacted by climate phenomena. The statement needed to convey the need to implement adaptation and resilience measures now and in the future; and
- Determine which impacts and infrastructure types should be included. The problem statement needs to be clear that a proactive, integrated adaptation approach is warranted and that any delays would undermine the execution of NSAA/USNA mission critical and base support activities.
Most importantly, the NSAA/USNA problem statement needs to be easily communicated and understood by a diverse audience, including, but not limited to, Congressional Representatives, DoD and Navy Leadership, and regional, state, and municipal partners.

To meet all these recommendations and requirements, NSAA/USNA has developed the following problem statement for this comprehensive resilience plan:

<table>
<thead>
<tr>
<th>NSAA/USNA Problem Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate change, sea level rise, changing weather patterns and continued subsidence of the Mid-Atlantic land mass will continue to contribute to an increase in the number and magnitude of coastal flooding events in the near- and long-term future of the Annapolis region.</td>
</tr>
<tr>
<td>These conditions will continue to impact land and infrastructure and pose significant challenges to the successful execution of the Naval Academy mission. Protective measures at the Lower and Upper Yard as well as North Severn will be necessary to reduce damage from these events and facilitate effective mission execution.</td>
</tr>
</tbody>
</table>

2.0 Stage II: Identify and Screen Adaptation Action Alternatives

This Stage of the comprehensive plan creates a preliminary list of action alternatives to address the problem statement. 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 vision of NSAA/USNA. 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 that will constitute the final integrated adaptation framework.

In Stage II, NSAA/USNA focused on the addressing the following items:

- Step 1: Identifying potentially suitable adaptation action alternatives;
- Step 2: Identifying the benefits and limitations of each action alternative;
- Step 3: Evaluating the feasibility of the action alternatives;
- Step 4: Evaluating the appropriateness of the action alternatives; and
- Step 5: Characterizing the strategic approach to decisions under uncertainty.

To accomplish these Steps, NSAA/USNA leveraged the wealth of reports, studies, plans, and designs captured in Table 1 to assist in the identification, assessment, and refinement of a list of existing adaptation action alternatives. These existing alternatives were then further categorized by geographic planning areas and adaptation approaches recommended. NSAA/USNA had chosen to align the
adaptation approaches with current USACE guidance. This guidance defines adaptation approaches as structural, natural, and nature-based, facilities adaptations, and non-facilities 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 (Figure 5 & 6). 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-facility approaches include a range of techniques that rely on changes in siting, management, or maintenance of infrastructure to reduce flood damage.

Following Unified Facilities Criteria (e.g., UFC 2-100-01 and UFC 3-201-01) requirements, these existing adaptations were individually and collectively assessed to determine their efficacy in reducing exposure and sensitivity of mission-essential infrastructure and facilities on the installation under different climate scenarios (i.e., SLRAC and DRSL models).

This approach allowed NSAA/USNA to be recognize that a single adaptation strategy will not be able to mitigate the constraints identified in Stage I. As such, the installation found it would have to combine a variety of alternatives in an integrated adaptation framework to address present-day and future constraints (i.e., 2035, 2065 and 2100) and ensure the successful execution of mission critical and base support activities.

To establish this integrated adaptation framework several new adaptations alternatives were identified and evaluated to overcome perceived limitations in one or more of the existing alternatives. NSAA/USNA worked closely with the SLRAC and installation subject matter experts to develop a variety of new adaptations that would improve the resilience of mission-essential facilities and infrastructure. Like the existing adaptations, these new alternatives were assessed and refined to ensure that cumulatively these
alternatives benefitted an integrated adaptation framework that aligned with NSAA/USNA planning assumptions and considerations (See element 5.0 Planning Assumptions and Considerations).

Many types of benefits can result from adaptation actions. The primary benefit of each action should be the direct benefit 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 was 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 a living shoreline acre 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 living shoreline construction project, such as building running paths around the living shoreline, may provide benefits to the community beyond ecosystem services. Because of its unique mission, NSAA/USNA found it is important to keep track of these indirect benefits and include them in its evaluation of potential action alternatives.

It is also important to identify the limitations of each action alternative. These may include considerations related to feasibility, appropriateness, or external effects (also referred to as externalities), which can be both positive and negative or result in maladaptation. Water pollution or poor water quality is an example of an externality that is a disbenefit or external cost imposed on others that would be cited as a limitation. However, if actions were deemed to be infeasible due to current limitation, they were not removed or omitted as they may become feasible as technology or knowledge is improved. Consequently, NSAA/USNA has retained a record of all the existing and new adaptation alternatives considered and the reason each action alternative had not been further evaluated. This ensured that NSAA/USNA would have the full range of action alternatives available to be reevaluated in the future if information or resources change.

Finally, this new list of adaptation alternatives (i.e., selected existing and new) was evaluated for appropriateness. Appropriateness reflects how well the solution fits into the overall planning context of the installation, in this case, the integrated adaptation framework. As expected, a few adaptation alternatives were eliminated as they were obvious “poor fit” approaches. Potential actions needed be, to the greatest extent possible, consistent with the planning vision goals with a high degree of confidence that they would address the defined problem statement. If they were not consistent, they were not given any further consideration and did not merit further consideration or detailed benefit cost analysis.

At the completion of Stage II, the NSAA/USNA’s list of adaptation action alternatives and an integrated adaptation framework was deemed suitable to address the potential impacts for the installation.

3.0 Stage III: Calculate Benefits and Cost of Action Alternatives

During Stage III, NSAA/USNA assembled the information and available data for each action alternative in from Stage II and developed a preliminary portfolio of action alternatives. Using the information resources and tools in the Handbook, NSAA/USNA set up and completed the benefit cost analysis. This included performing the calculations necessary to arrive at measures of adaptation intervention merit. These
measures of merit - including benefit cost ratios, net present values, and internal rates of return - provided monetized metrics were used to preliminarily rank action alternatives. Unfortunately, NSAA/USNA was not able to monetize all benefits and costs for the action alternatives identified in Stage II. There were non-monetized qualitative benefits and costs, some of which were intangible (e.g., Santee Basin, athletic fields), but were still be carried over to Stage IV, as they are instrumental in providing cohesion to the integrated adaptation framework.

Specifically, NSAA/USNA performed the following Steps outlined in the Handbook:

- Step 1: Gathering and assessing physical performance metrics and estimated life cycle costs;
- Step 2: Conducting preliminary economic screening;
- Step 3: Completing impact analysis framing;
- Step 4: Selecting benefits monetization and action alternatives costing tools; and
- Step 5: Determining benefits to be monetized and perform calculations.

To accomplish these steps, rough order of magnitude cost, engineering feasibility, risk reduction, and historical/cultural, regulatory, and environmental and hydrologic considerations for each adaptation alternative were identified.

At the completion of Stage III, NSAA/USNA had obtained a preliminary portfolio of action alternatives and calculated values for measures of adaptation intervention merit (benefit cost ratio, cumulative discounted benefits, costs, and net present values), with associated documentation. This material augmented the information generated from Stages I and II. The Stage also flagged any intangible non-quantified or non-monetized benefits or limitations that had to be given further evaluation in the portfolio assessment for Stage IV.

4.0 Stage IV: Assemble Portfolio of Adaptation Action Alternatives

The first three Stages of the Handbook and their associated examinations assisted NSAA/USNA down select the final set of adaptation action alternatives to be included in the “portfolio” of adaptations. In the fourth and final Stage, twenty-eight (28) preferred adaptation action alternatives were selected for further analysis. This included the completion of a life cycle cost analysis and a cost-effective analysis to screen these adaptation action alternatives as component of a broader integrated adaptation framework. Specifically, Stage IV identified future variables and formally compiled action alternatives into a Portfolio Summary. The steps of this Stage include:

- Step 1: Assembling the Portfolio Summary;
- Step 2: Identifying key future variables;
- Step 3: Re-evaluate strategic approach to decisions under uncertainty;
- Step 4: Characterizing the risk approach; and
- Step 5: Relating results to the Master Plan Update.

At the completion of Stage IV, NSAA/USNA has constructed a Portfolio Summary that is feasible and adequately address the impacts and constraints identified by Stage I. This summary also identified strategic approaches that addresses decisions under uncertainty and reflect NSAA/USNA leadership’s risk management priorities. More importantly, the Portfolio Summary created recommendations for combining action alternatives for how alternatives should be phased (i.e., creation of an execution plan), where interdependencies between alternatives occurred, and how this portfolio of projects, and the
integrated adaptation framework they enabled, will mitigate risk from all flood sources (land subsidence, sea level rise, coastal flooding/storm surge, stormwater) to 2100.

The development of this Portfolio Summary required engagement across multiple business lines and disciplines within the Navy shore enterprise. It has also required NSAA/USNA and NAVFAC to leverage and maximize existing Navy e-Tools and systems to provide responsive, flexible support to multiple commands and stakeholders by reducing program risk and establish an extensive documentation of the installation resilience challenges and adaptation action alternatives within each geographic planning area. To achieve this compendium, a 3-dimensional virtual environment of the installation was developed to test and evaluate its value in this resilience effort.

In conclusion, the resulting Project Portfolio, associated integrated adaptation framework, and digital visualization tools described in this NSAA/USNA comprehensive resilience plan illustrate that a coordinated investment in both manmade, and natural infrastructure will be needed to sustain readiness and mission resilience for NSAA/USNA. The risks facing NSAA/USNA are dynamic and influenced by a combination of natural hazards, climate change, and aging infrastructure systems that will only increase. The need for innovation and action to create resilient systems on the installation continues to grow. Meeting this need will require new ways of the thinking about complex problems, an openness to new solutions, a willingness to change, and a commitment to adaptation.

Figure 6. Flooding at Rickover Hall.
4.1 Supporting Installation Development Plan

The portfolio of projects that NSAA/USNA has identified 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 liabilities, and maintain flexibility in response to changing conditions, especially considering climate projections that have uncertainties. Several concepts described below will consider to be considered by NSAA/USNA future.

- 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 consider 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;

- 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; and

- 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. Maintaining awareness of 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.

With the recognition that future events may influence an investment decision, a number of future variables should be considered. These events may include changes in climate projection, innovations and advancements in technology, off-installation encroachment and significant changes in land use patterns, addition or removal of mission-essential facilities and infrastructure, and fluctuations in federal appropriations. Consequently, NSAA/USNA will consider that this comprehensive resilience plan will need to be integrally tied to the IDP process. Like this plan, the IDP is expected to be managed as a living document that will allow NSAA/USNA to monitor and address future events.

The recent IDP update (NSAA, 2018) recognized that the “increased incidence with flooding owing to climate change, coupled with potential for sea level rise over the long range, necessitates measures to protect vulnerable assets against flooding.” This update referenced that flooding due to sea level rise and stormwater events poses a significant threat to critical facilities and infrastructure on the USNA Lower Yard. It also noted that those phased projects are planned for implementation over the next 20 years. The IDP is the official planning document that guides the installation’s physical development activities over a
20-year planning horizon. The 2018 IDP established near-term priorities, including a comprehensive seawall planning effort to assess condition and to recommend necessary rehabilitation projects; as well as a comprehensive stormwater study to address deficiencies in the stormwater management infrastructure throughout the installation. Therefore, any future updates to this comprehensive resilience plan should parallel updates to the IDP.

5.0 Planning Assumptions and Consideration

As shared earlier, every effort has been made to ensure that the methodologies employed by NSAA/USNA in the development of this comprehensive plan could be replicated and the Handbook methodology outlined in this section was leveraged to meet this goal. This approach will ensure that NSAA/USNA, NAVFAC, and other decision makers have a better awareness of systematic weaknesses, monitor changes in vulnerability, recognize how to better allocate adaptation alternatives and measures, and justify the allocation of federal funding for the resilience actions outlined in this plan. Therefore, it is important that there is a clear awareness of the planning assumptions and considerations that were adopted in the execution of each of the four Stages in the Handbook process.

5.1 Optimum Conditions

Beginning with the USACE Flood Reduction Analysis for USNA (2006), the installation has undertaken a series of location-specific sea level rise and flood research, planning and studies. Collectively, these studies, reports and data collection efforts have provided the foundation of the NSAA/USNA for Stage I of this methodology. This foundation has been integral informing future Stages and NSAA/USNA have identified topics that will require further investigation in the future. This additional information would assist NSAA/USNA further assess and evaluate alternative (Stage II), inform future benefit cost analyses (Stage III), and improve the mid- and long-term project portfolio (Stage IV). These topics, a brief description of the issue, and why these items should be addressed are captured in Table 4.

At this time, this comprehensive resilience plan has assumed that further investigations into these topics will not generate any significant constraints or weaknesses that would impact NSAA/USNA to implement the integrated framework outlined.
<table>
<thead>
<tr>
<th>Topics</th>
<th>Details</th>
<th>Why?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater and Geology</td>
<td>Water table elevation, Influence of precipitation and tide on water table, Fill soil stratification, Subsidence, Soil bearing capacities</td>
<td>Future adaptation strategies will require alterations to land reclamation areas that were created using fill. A geophysical awareness of these areas and their response to changes in groundwater elevations is required.</td>
</tr>
<tr>
<td>Weather Trends and Projections</td>
<td>Projections for annual rainfall, Frequency of 100/500-year events, Frequency of Nor’easterners and hurricanes</td>
<td>Determine how the frequency and intensity of extreme storm events may adversely impact an aging stormwater infrastructure?</td>
</tr>
<tr>
<td>River Hydrodynamics and Ecology</td>
<td>Numerical modeling to assess interactions between waves, tides, winds, and river flow. Assess alterations to current hydrodynamics</td>
<td>Ensure existing and planned bulkheads can meet future forces and identify natural and manmade alternatives to reduce these anticipated forces. Additionally, to obtain hydrodynamic inputs to quantify and predict related processes such as sediment transport, scour and water quality in the Severn River, Spa and College Creeks, and the Santee Basin.</td>
</tr>
<tr>
<td>Surface and Overland Water Runoff</td>
<td>Impact of precipitation, snow melt, and irrigation water on watersheds; Impact of stormwater pollutants (e.g., nutrients, bacteria, pesticides, metals) on watersheds</td>
<td>Obtain a better awareness of how off-installation stormwater management strategies are impacting College and Spa Creek watersheds.</td>
</tr>
<tr>
<td>Detailed Surveys of Key Infrastructure</td>
<td>Digital as-builts of 1st floors including elevations, Inventories of 1st floor labs and classrooms</td>
<td>To further assess current and potential risks to key assets and infrastructure.</td>
</tr>
<tr>
<td>Traffic and Parking Study</td>
<td>The installation’s adaptation capacity is constrained spatially; Existing roads and parking features need to be assessed</td>
<td>Assess the overall functionality of installation roadways and associated parking. The results of these studies will inform and provide solutions for roadway design and traffic control.</td>
</tr>
<tr>
<td>Installation Energy Plan</td>
<td>Energy availability and reliability are necessary for executing mission essential operations, so improving the ability to avoid, prepare for, minimize, and adapt to energy disruptions and ensure future demands are met.</td>
<td>Climate-induced changes to installation (e.g., increasing ambient temperatures, frequency and intensity of precipitation) will require it to aggressively plan for future energy requirements (e.g., HVAC, pump stations).</td>
</tr>
</tbody>
</table>
5.2 Installation Planning Goals and Consideration

The climate-induced flooding hazards NSAA/USNA are currently and projected to adapt to will require a clear awareness of trade-offs and a holistic approach to decision-making. Hence, it will require a clear awareness of the planning goals and considerations that this comprehensive resilience plan was built upon. The planning goals described in Table 5 have not changed in over a decade. These goals and considerations have consistently been applied to all the studies, reports, data collection efforts, and planning activities performed by NSAA and USNA. This comprehensive resilience plan is no exception.

Table 5. NSA Annapolis and U.S. Naval Academy Resilience Planning Goals and Considerations.

<table>
<thead>
<tr>
<th>Planning Goals</th>
<th>Plan Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce risk to critical assets and infrastructure</td>
<td>Ensure mission-essential facilities and infrastructure are resilient to current and projected climate-induced constraints. (Note: Mission Dependency Index has limitations NSAA/USNA)</td>
</tr>
<tr>
<td>Make installation more resilient</td>
<td>Become more resilient to flood sources (e.g., stormwater, sea level rise, groundwater inundation, and coastal flood/storm surge)</td>
</tr>
<tr>
<td>USNA will not relocate or retreat</td>
<td>NSAA/USNA will continue to meet its mission in the 21st century</td>
</tr>
<tr>
<td>Brigade size and requirements will not change</td>
<td>Graduate Midshipmen who are prepared to be the future leaders of the Navy and United States Marine Corps</td>
</tr>
<tr>
<td>Security posture will remain the same</td>
<td>Ensure a safe and secure environment is maintained for Midshipmen, academy/installation staff, faculty, and visitors</td>
</tr>
<tr>
<td>Respects National Historic Landmark and campus aesthetics</td>
<td>Over 175 years of honor and tradition is represented and memorialized on the campus</td>
</tr>
<tr>
<td>Transportation and emergency management services remain the same</td>
<td>Maintain entry points and critical roads; however, parking and perimeter roads could be altered</td>
</tr>
<tr>
<td>Maximizes relationships with City of Annapolis, local jurisdictions, and the watershed partners</td>
<td>Long-term resilience will be influenced (positively or negatively) on the mitigation strategies others make within the watershed</td>
</tr>
</tbody>
</table>

To meet these planning goals and considerations, NSAA/USNA chose to refine them at the end of Stage I of this methodology. Specifically, NSAA/USNA leveraged the SLRAC report to the Superintendent and the 2019 Planning Charrette products to develop a set of planning goals and consideration that would inform and enable Stages II and III. Every effort was made not to alter the planning goals, but rather considerations that will need to be made to achieve these goals. A summation of these comprehensive resilience plan-specific planning goals and considerations are presented in Table 6.
Table 6. NSA Annapolis and U.S. Naval Academy Resilience Planning Goals and Considerations for this Comprehensive Resilience Plan.

<table>
<thead>
<tr>
<th>Planning Goals</th>
<th>Plan Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce risk to critical assets and infrastructure</td>
<td>Maximize installation resilience. Develop a framework of adaptation alternatives that create redundancies. Reduce number of points of failure.</td>
</tr>
<tr>
<td>Make installation more resilient</td>
<td>Located at the confluence of the Severn River and Chesapeake Bay, flooding is inevitable and will not be prevented. NSAA/USNA needs to be more resilient to these events. Ensure adaptation framework establishes an integrated approach that will meet 2100 Planning Vision.</td>
</tr>
<tr>
<td>The Naval Academy will not relocate or retreat</td>
<td>Phased COAs and associated alternatives need to be cost effective and technically sound.</td>
</tr>
<tr>
<td>Steering away from complexity</td>
<td>Too many interacting adaptation alternatives often give rise to unexpected outcomes. Drive to simplicity.</td>
</tr>
<tr>
<td>Sustainable, low maintenance solutions (operationally and financially)</td>
<td>The costs of operations and maintenance of every adaptation alternative across its design life will need to be evaluated. Consider funding sources.</td>
</tr>
<tr>
<td>Not all assets on the installation align well with Mission Dependency Index</td>
<td>The missions of NSAA and USNA are unique. The development of midshipmen requires a variety of assets and infrastructure to develop mind and character.</td>
</tr>
</tbody>
</table>

In the next several section of this plan, NSAA/USNA will illustrate how this methodology and associated planning goals and assumptions assisted in development of an integrated adaptation framework, project portfolio, execution plan, and a variety of digital tools.
Selection of Sea Level Rise & Extreme Water Level Scenarios
IX. Selection of Sea Level Rise & Extreme Water Level Scenarios

Vulnerability to climate change is one important factor among many that NSAA will need to consider in allocating resources to ensure that installation assets and infrastructure are able to support USNA activities and ensure military readiness. Non-climate stresses on infrastructure (e.g., deterioration, obsolescence) interact with climate-induced stressors; the combined effects of these stressors must be taken into consideration as part of an overall asset management approach. In some cases, climate change considerations may be the critical consideration for project viability. Information about climate change impacts provided to NSAA/USNA decision makers at key planning and facility development stages will help ensure more resilient operations and mission is sustained.

Consequently, this comprehensive plan was developed under the premise that climate change adaptation should not be a separate decision-making process, but rather an aspect of overall management at the installation and installation development planning. This fundamental recognition of the current and future environmental constraints that the installation is currently and projected to cope with is the foundation of this plan and the associated integrated adaptation framework, as well as the digital deliverables that were developed to support this effort (e.g., NSAA/USNA Sea Level Rise and Vulnerability Exposure Analysis Viewer and NSAA/USNA 3DVE Scene). As outlined in Stage I of the Handbook, the climate change vulnerability, impact assessment, and adaptation process need to be an ongoing and iterative process through which vulnerabilities are assessed, adaptation plans are formulated, actions are taken, performance is monitored and evaluated, and conditions are reassessed based on updated data and model projections. As much as possible, climate change considerations should be incorporated into extant planning, management design documents, instructions, and other management tools, in both the short- and long-term installation development planning.

For vulnerability and impact assessment to be relevant to management and policy, it must be “site-specific,” capturing the unique biophysical features that determine how climate-induced hazards interacts with an installation’s assets and infrastructure, and the relative importance of climate change as an environmental stressor. Simultaneously, the process and outputs of vulnerability and impact assessments must be sufficiently consistent with other assessments, such that analyses from multiple locations are scalable and can be compared. Use of compatible analyses enables the Department of Navy, Commander, Navy Installations Command, and NAVFAC to synthesize outputs across multiple locations to identify broad vulnerabilities, assess relative needs, and prioritize actions. The Department of Navy, Commander, Navy Installations Command, and NAVFAC need to meet the analytic requirement for locally tailored analyses while achieving comparability across regions. For this reason, NSAA/USNA made a concerted effort to ensure that current and future projections for sea level rise and EWL were consistent with DoD guidance (i.e., DoD Regional Sea Level Rise database, 2021) and tailored to align with localized analyses (i.e., USNA, 2019a). Additionally, detailed assessments of nuisance flooding and groundwater inundation were also analyzed and evaluated as both causes of flooding will play a profound impact on the installation’s resilience efforts.

This section provides a brief summation into reports and studies NSAA/USNA leveraged in the selection of sea level rise projections, EWL scenarios and other floodwater sources that are currently having an adverse impact on the installation and how flooding from these sources is projected to change in the next century.
1.0 Introduction to DoD Regional Sea Level Rise Database

The DoD Memorandum, Improving Defense Installation Resilience to Rising Sea Levels, requires the DoD to integrate use of the DRSL database “into installation and planning activities at coastal locations to account for future sea level change” and allows each Military Department to choose the planning horizon and regional scenario appropriate to the mission and risk tolerance. UFC that address flood risk and mitigation, such as the UFC 2-100-01, Installation Master Planning, and UFC 3-201-01, Civil Engineering, have been modified to address use of this database to reflect memo requirements.

1.1 The DRSL Database Origins

In 2013, the DoD’s Climate Change Adaptation Working Group, established in response to a 2009 Executive Order, noted the need for a consistent approach to enable portfolio-wide, screening level analysis of vulnerabilities for all DoD coastal sites. They added that the approach must accommodate varying levels of data quality and availability, given the range of data across sites worldwide. No single source of future sea level and extreme water level scenarios was available. Thus, a research effort to develop such a methodology was initiated in 2015. A team of interagency scientists and engineers (i.e., Coastal Assessment Regional Scenario Working Group or CARSWG) conducted research that resulted in a report (Hall et al., 2016) and accompanying database of two datasets (sea level and extreme water levels) for 1,813 military sites around the globe, including NSAA.

The products from the multi-year research effort led to the creation of the DRSL database for sea level change and historical statistical extreme water levels associated with storms and a report.

1.2 The DRSL Database

The database includes site-specific values range of plausible future scenario values for sea level change and historical EWL statistics for NSAA and 1,812 other sites worldwide (See Figure 7). All are either coastal (defined in the report as within 20 kilometers of the shoreline) or tidally influenced (i.e., tidally influenced sites are close enough to the coast such that their water levels will be affected by sea level change and storm surge). It is important to note that DRSL considers “Site” to refer to smaller areas with permanent infrastructure that are administratively assigned to a parent, or primary, installation, regardless of whether the site is located near the parent installation. Thus, one installation may contain several “sites.” The DRSL database provides five sites (i.e., entries) for NSAA: NSA Annapolis, Naval Academy North Severn, NSA Annapolis Chesapeake Bay Detach, NSA Annapolis Gambrills Md, and Upper Yard Annapolis.

The DRSL Database is both CAC-enabled (for OCONUS sites) and publicly available with a Graphical User Interface that provides users access to the scenario information for specific military sites (https://sealevelscenarios.serdp-estcp.org).
The Graphical User Interface allows the user to intuitively search the database for site-specific values for a range of plausible scenario values for sea level change. The data are:

- For several future timeframes—2035, 2065 and 2100;
- Based on 5 global scenarios for SLR = 0.2, 0.5, 1.0, 1.5, 2.0-meter rise by 2100. (Figure 8). A scenario is a plausible, scientifically defensible sea level in the future. The research group chose two global bounding scenarios of 2.0 meters by 2100 and 0.2 meters by 2100. The Lowest bound (0.2-m scenario) is a historical extrapolation; the Highest comes from the maximum in the National Climate Assessment (2014). The group further decided to add three intermediate scenarios, in 0.5-meter increments; and
- Locally or regionally adjusted. Three variables – timeframe, scenario, and geographical location – determine the magnitude of the local sea level adjustments attributed to vertical land movement, land-based ice melt, and dynamical changes. Of the three components, local adjustments to sea level rise due to vertical land movement, either up or down, may effectively “swamp” the smaller regional adjustments from melting ice or dynamical sea levels. This is not always the case, however. Also note that vertical land movement is independent of climate change; the rate of vertical land movement may vary, depending on physical factors and land use decisions (e.g., groundwater pumping practices). See accompanying text box. Example screenshot of NSA Annapolis is shown in Figure 9.
The database also contains historical EWL statistics which reflect the effects of tides and storm surge. In storm events, winds pile up water, pushing water further inland and leading to increased coastal flooding. Of course, storms occurring at high tide have a greater lateral extent.

- The water elevations in the database reflect values for the 1%, 2%, 5%, and 20% annual chance events (or 100-year, 50-year, 20-year, or 5-year storm, respectively), measured from tide gauges at high tide;
- The EWL dataset does not incorporate a climate change signal; it is intended to illustrate storm surge levels that correspond to storm events with specified return intervals. Thus, the EWL elevation value given for a 5-year storm at a site is the same in 2035, 2065, and 2100;
- In addition to using a single tide gauge to estimate EWL statistics, a technique known as Regional Frequency Analysis (RFA) was used. The RFA process employs tide measurements from nearby gauges, using averaging to arrive at estimates for a greater number of military sites than would have been possible without the RFA technique. Each site is categorized according to length of tide gauge records and distance to the tide gauge. For example, Category 1 includes sites with a local tide gauge that has at least 30 years of records and is within 50 kilometers of the site. On the other hand, Category 4 includes sites with fewer than three local or regional tide gauges within 400 kilometers. Sites for which tide gauge data were too heterogeneous were deemed ineligible for a valid RFA process. Thus, in the database some sites have EWLs based on the Single Gauge option, some on the RFA option (labeled as Multiple Gauges), some on both options, and some with no EWL estimates (about 15% of the sites) because of the lack of sufficiently reliable gauge data. Choosing whether to use a single
gauge or multi-gauge approach depends on several factors: the gauge(s) proximity to the site, length of record, and probability (return interval) of the storm of interest. For example, for evaluating 100-year (1%) storm, a gauge(s) with a long record is preferred, 70-80 years if possible. If a gauge is located within 10-15 kilometers of the site in question, and it has 70+ years of records, the single gauge approach is suitable. Otherwise, the RFA approach with multiple gauges may be better. On the other hand, if the 5-year (20%) storm is being assessed, a single gauge with 30-40 years of data may be acceptable, though gauges with more years of data are always better than fewer years. Example screenshots of NSA Annapolis are shown in Figures 9, 10 and 11.

Note: the actions of waves are NOT included. Depending on local bathymetry and shape of the shoreline, wave action may be an important factor to consider.

For planning purposes, it may be valuable to look at sea level rise and storm surge separately, to distinguish between the possibility of permanent inundation from sea level rise versus temporary flooding due to storm surge. Then to assess the possible scenarios of sea level rise and storm surge together, look up the “combined” scenario value in the database (Figure 11).
2.0 Sea Level Rise Advisory Council Report to the Superintendent

The USNA SLRAC was established on July 8, 2015, at the direction of the USNA Superintendent. The Council was charged with providing analyses, guidance, and recommendations to the USNA Superintendent and NSAA/USNA leadership on issues surrounding sea level rise, coastal flooding, and severe weather events, with specific focus on assessing the adverse impacts of the climate-induced hazards on the lower yard, upper yard, and the federal property on North Severn, and their ability to support the missions of NSAA/USNA.

2.1 SLRAC Mission

The mission of the SLRAC is to assist the NSAA/USNA plan and adapt to flooding due to sea level rise and severe weather events in the Annapolis area. In this role, the Council analyzes data, identifies current and future vulnerabilities, and prioritization of solution sets with the primary goal of minimizing negative impact to the daily operations and mission of NSAA/USNA. Working closely with the City of Annapolis, the State of Maryland, and key federal agencies, SLRAC continues to actively identify paths forward for planning for the impacts of sea level rise on the NSAA/USNA through 2100.
2.2 **SLRAC Sea Level Rise and Storm Surge Recommendations**

The SLRAC recommendations were based on the current state of knowledge regarding future sea level rise scenarios using multiple comprehensive and peer-reviewed studies as well as consultation with several subject matter experts (USNA, 2019a). In their report, they summarized how these studies and consultations provided various ranges of anticipated sea level rise and storm surge based on future emissions scenarios, though they did not predict a most likely scenario. The studies are generally consistent with those used by CARSWG to develop the DRSL database in terms of the range of 21st century sea level rise values associated with stabilized and growing emissions scenarios, with the differences between the stabilized and growing emissions scenarios not pronounced until the latter half of this century. The Council documented:

- Since 1928, sea level as measured at the Annapolis tide gauge, located in the Hendrix Oceanography Laboratory at Santee Basin (see [www.tidesandcurrents.noaa.gov](http://www.tidesandcurrents.noaa.gov), Station 8575512), has risen with a long-term linear rate of 0.14 inches (3.61 millimeter or mm) per year, which is equivalent to 1.18 feet (0.36 meters) per century (National Oceanic and Atmospheric Administration, 2019 and Figure 12). This measurement of sea level relative to land, or "relative sea level," includes the effects of local land subsidence as well as changes in global (or absolute) sea level. Approximately half of the relative sea level rise in Annapolis since 1928 is attributed to land subsidence (Boon, Brubaker, and Forrest, 2010, and Boesch et al., 2013);
• Recent studies indicate that the rate of mean sea level rise in Annapolis and other locations on the shores of Chesapeake Bay is accelerating. While the long term (1928-2018) linear trend in sea level rise is approximately 1.2 ft per century, it appears that sea level has risen approximately 6 inches over the past 25 years. The rate of ground subsidence has been about 7.4 inches per century, and is expected to remain constant through 2100, so acceleration since 1992 appears to be due to an increased contribution from land ice melt;

• Recent analysis of sea level between 1969 and 2014 indicates an acceleration in the rate of sea level rise in Annapolis with a value of approximately 0.007 inches / yr^2 (0.18 mm / yr^2), which would raise sea level approximately 19 inches (51 centimeter) by 2050, relative to the current Mean Sea Level datum established by National Oceanic and Atmospheric Administration (NOAA; Boon and Mitchell, 2015), or 14 inches above the average water level computed for 2018;

• Interannual variability in Annapolis is approximately four inches. For short term projections (20 years or less in the future), it is more accurate to use interannual variability vice sea level rise curves, as their differences don’t become pronounced until 2050 or so;

• Regional changes in relative sea level have raised the levels of Chesapeake Bay and the Severn River to the “brim”, such that onshore and southerly wind events coupled with high tide now result in frequent flooding of low-lying areas, such as the City Dock in downtown Annapolis, and Ramsay and McNair Roads at USNA. The frequency of this nuisance flooding has increased from three times a year in the 1960s to 30-40 times a year in the current decade (Sweet et al., 2014);

• To put the rate of current sea level rise into perspective, it is helpful to review changes since the last glacial maximum. Over the past 20,000 years, global sea level has risen approximately 400 ft (120m). This rise occurred episodically, with surges or “melt water pulses” resulting in maximum rates of approximately 15 ft per century (Sweet et al., 2017a). Sea level change had been relatively constant for the past 4,000 years but began rising again with the onset of the industrial revolution. The rate of rise over the last century is the greatest in at least 2,800 years (Sweet et al., 2017a).

However, the Council did differ from the CARSWG report in that they were able to study and evaluate several studies and reports completed between 2015 – 2020. One noteworthy study is a 2017 NOAA technical report (Sweet et al., 2017b) that considered scenarios like those used by CARSWG and the DRSL database (Hall et al., 2016) but added a sixth sea level rise scenario of 8.2 ft (2.5m) by 2100, based on recent findings on the potential for rapid ice sheet collapse and glacial melt in Antarctica. The NOAA study provided projections for several U.S. cities, including the city of Annapolis, and added probabilistic projections, providing the 17%, 50%, and 83% probability value for each sea level rise scenario. For the City of Annapolis, the 50% probability values for 2100 range from 0.9 ft (0.3m) to 11.7 ft (3.6m). Like DRSL, no attempt was made by Sweet et al. (2017b) to predict a most likely scenario, but the scenarios were related to emissions scenarios (i.e., Representative Concentration Pathways) used by the global community of climate modelers. For example, the “Intermediate” scenario corresponds to a growing emissions scenario, in which greenhouse gas emissions continue at their current rate throughout the 21st century. The “Intermediate Low” scenario corresponds to a stabilized emissions scenario, in which greenhouse gas emissions level out around 2050. It should be noted that sea level rise may not proceed
in a smooth manner as depicted in the curves for the various scenarios; rapid ice melt due to ice sheet collapse and acceleration of glacial movements could result in sharp increases in sea level over the course of several decades.

The rate of ground subsidence at Annapolis is assumed to have remained constant at approximately 0.074 inches per year (1.88 mm/year) over the past century (Boon, Brubaker, and Forrester, 2010), and will likely remain so in the century ahead (Boesch et al., 2013). Recent analysis of sea level between 1969 and 2014 indicates an acceleration in the rate of sea level rise in Annapolis with a value of approximately 0.007 inches / yr² (0.18 mm / yr²), which would raise sea level approximately 19 inches (51 cm) by 2050, relative to the current Mean Sea Level datum established by NOAA (Boon and Mitchell, 2015), or 14 inches above the average water level computed for 2018. This projection for local sea level in 2050 is slightly less (2 inches lower) than the value for the Intermediate scenario, but the rate of acceleration could be expected to increase with growing greenhouse gas emissions.

While the rate of ice sheet collapse/glacial melt in Antarctica and ground subsidence have been highlighted in this summation, these are just a few of climate-induced variables that the Council considered and documented in their recommendations to the USNA Superintendent (USNA, 2019a). Their comprehensive, site-specific assessments of sea level rise, storm surge, departures of astronomical tidal projections, repetitive nuisance flooding, and other causes of flooding on NSAA/USNA were integral to the development of this plan. Although, NSAA was charged with adhering to current DoD memorandums, policies, guidance, and criteria, every effort was made to align assessments of NSAA/USNA exposure, sensitivity, and adaptive capacity to their recommendations.

The SLRAC, in their report to the Superintendent, recommended that it would be prudent to plan for MSL rise values associated with a growing emissions (“Intermediate”) scenario for projects with a relatively low risk tolerance (USNA, 2019a). For this scenario, the 50% probability elevations above the currently defined mean sea level are approximately 1.8 ft in 2050, 3 ft in 2075, and 4.4 ft in 2100. This recommendation is in general agreement with the likely local values for Maryland Sea Level Rise identified by the Maryland State Climate Commission. Under this Intermediate scenario, an average daily high tide (i.e., Mean High Water) would reach the threshold for nuisance flooding of Ramsay Road by 2050. Of note, sea level rise (particularly the contribution from glacial melt) is an area of active research, and as such, the SLRAC recommends that estimates will likely need to be revised approximately every five years to incorporate new analysis and data.

In planning for flood protection measures, periodic storms should be considered in addition to MSL rise. The SLRAC recommends adopting the following estimates for storm tides: 1-year storm (2.4 ft), 10-year storm (3.7 ft), 50-year storm (5.2 ft), and 100-year storm (5.8 ft). These storm tide values are relative to MSL, so they must be added to future sea level rise projections. As an example, the water level of an annual flooding event (i.e., associated with a 1-year storm) would reach 4.2 ft above the currently defined MSL (1.8 ft sea level rise plus 2.4 ft storm tide) by 2050, sufficient to flood the Midshipmen Store parking lot, and 6.8 ft above the current MSL by 2100, which would produce flooding like Hurricane Isabel in 2003.

### 3.0 Selection of Sea Level Rise and Extreme Water Level Scenarios

As sea levels rise continues to have adverse impact on the NSAA and preparing for these and other consequences of climate change increases in priority, NSAA/USNA saw an increasing demand for detailed
local sea level rise projections and for guidance that supports their use in planning, operations, and project design. The SLRAC report to the Superintendent (2020) successfully met this demand. The recommendations contained within this report summarized NSAA and USNA efforts since Hurricane Isabel (2003), was grounded in the best available science, and align with State of Maryland values. However, they differ slightly with current and relevant DoD guidance, policies, and criteria. For example, the council’s report did consider NSAA/USNA’s planning vision of 2100, their recommendations aligned to different epoch than the DoD guidance (i.e., 2050 and 2075 versus 2035 and 2065) and different annual chances for extreme water level scenarios. Additionally, as stated earlier, the Council’s recommendations considered recent findings on the potential for rapid ice sheet collapse and glacial melt in Antarctica which meant their recommendations varied slightly from the DRSL database projections for the installation. If this comprehensive plan is to align to DoD guidance, these minor variations would need to be addressed.

Using the Council’s recommendations for sea level rise and EWL tailored to the installation, NSAA/USNA chose to use these projections as a baseline and performed several analyses of DRSL to recognize how this baseline aligned to the range of SLR and EWL magnitudes that the database anticipated it may experience. The goal was to obtain further insight into the potential range of SLR (Table 7) and EWL (Table 8) could experience than has been available before and bringing new information to installation planners, engineers, and decision makers.

<table>
<thead>
<tr>
<th>Year</th>
<th>SLRAC</th>
<th>DRSL Low</th>
<th>DRSL Int</th>
<th>DRSL High</th>
<th>DRSL Highest</th>
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<td></td>
<td>0.7</td>
<td>1.3</td>
<td>1.3</td>
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<tr>
<td>2050</td>
<td>1.8</td>
<td>1</td>
<td>1.64</td>
<td>1.95</td>
<td>2.6</td>
</tr>
<tr>
<td>2065</td>
<td>1.3</td>
<td></td>
<td>2</td>
<td>2.6</td>
<td>3.6</td>
</tr>
<tr>
<td>2075</td>
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<td>1.4</td>
<td>2.75</td>
<td>3.7</td>
<td>5.13</td>
</tr>
<tr>
<td>2100</td>
<td>4.4</td>
<td>1.6</td>
<td>4.3</td>
<td>5.9</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Annual Chance</th>
<th>Description</th>
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<th>DRSL</th>
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</thead>
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</tr>
<tr>
<td>10%</td>
<td>10 Year Event</td>
<td>5.2</td>
<td>4.9</td>
</tr>
<tr>
<td>5%</td>
<td>20 Year Event</td>
<td>5.8</td>
<td>5.9</td>
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<tr>
<td>2%</td>
<td>50 Year Event</td>
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</tr>
<tr>
<td>1%</td>
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</tbody>
</table>

NSAA/USNA assessment of the DRSL and SLRAC recommendations included a review and analysis of Federal Emergency Management Agency (FEMA), NOAA, and State of Maryland estimates. As noted in the Council’s report, the revised FEMA estimates relied on numerical hydrographic modeling while the USNA, DRSL, and NOAA estimates are derived from statistical analysis of measured water levels from the Annapolis tide gauge. While numerical modeling approach might be more appropriate to determine
extreme water levels for a location with little elevation data available, the Annapolis tide gauge spans more than 90 years and provides unique site-specific insights. Consequently, the SLRAC recommended that the NSAA/USNA use the statistically derived elevation values that would be consistent with their estimates and DRSL, rather than the model-derived values provided in the revised FEMA guidance.

Since both DRSL and SLRAC appeared to align with NOAA and State estimates, a concerted effort was made to geo-spatially model both the DRSL and SLRAC estimates to assess spatial and temporal variation in sea level rise and EWL flooding extent and depth of each scenario on the installation. These modeling results allowed the NSAA/USNA a better awareness of how these estimates and scenarios impacted asset and infrastructure exposure and sensitivity.

This detailed assessment resulted in the following DRSL scenarios, which were chosen by NSAA/USNA and captured in Appendix E (i.e., Stage 1 Worksheets): DRSL 2035 High (1.3 ft), DRSL 2065 High (2.6 ft), and DRSL 2100 Intermediate (4.3 ft) to be compliant with DoD guidance. Additionally, NSAA/USNA decided to use the SLRAC 2050 estimate (1.8 ft) for discussions with the City of Annapolis. In each case, these selected scenarios aligned to the Council recommendations and their associated geo-spatial models represented the spatial and temporal variation that would support this comprehensive plan.

4.0 Other Sources of Flooding (Nuisance and Groundwater Inundation)

DoD guidance tends to emphasize flooding impacts and occurrence of EWL events (infrequent, e.g., 100- and 500-year return periods), and fundamentally it is important for the department to preparing for and respond to the possibility of disasters the associated acute impacts of flooding. The damage from Hurricane Isabel on NSAA/USNA and the current reconstruction efforts Tyndall Air Force Base and Marine Corps Base Camp Lejeune after EWL events will require substantial investments by DoD. However, what is also important and not receiving as much attention, is the increasing impacts of relatively frequent and small-magnitude events (e.g., annual, or even monthly return periods) mainly due to relative sea level rise (Moftakhari et al., 2018) that present chronic flooding at low levels as seen at NSAA/USNA. Of particular concern are:

- “Nuisance” or “high tide” flooding is defined as “flooding that leads to public inconveniences such as road closures” (Sweet and Marra, 2014). Nuisance flooding is often unrelated to a specific storm but is commonly influenced by sustained wind events, storm systems, or astrological phases. Future sea level rise may increase these flood events at NSAA/USNA; and
- “Groundwater Inundation” which is defined as flooding that occurs from the interaction of sea level with the coastal groundwater table. The groundwater table in unconfined aquifers typically lies above mean sea level, fluctuates with daily tides and other low-frequency sources of ocean energy, and amplitudes decrease exponentially with distance from the shoreline. As sea level rises, the water table will rise simultaneously and eventually cause groundwater inundation.

In both cases, the intensity of flooding (e.g., depth, velocity, and discharge per unit width) is not large enough to cause significant property damage or threaten public safety, but it can disrupt routine activities, putting added stress on infrastructure such as transportation systems, stormwater and sewer systems, installation operations, and heighten public health risks (e.g., impacts to potable water). Moftakhari et al., (2017) showed that, over time, some areas will experience greater cumulative exposure of assets and infrastructure from the repeated occurrence of relatively small events, compared to the infrequent
occurrence of extreme events and thus presented these flooding threats as a cumulative hazard. Overall, these sources of flooding may represent a considerable burden for the installation insofar as assets and infrastructure are impacted gradually, over an extended time and would not precipitate or justify appropriations typically available for events that are usually allocated for declared disasters. Therefore, NSAA/USNA felt it was important to consider these flooding sources, their cumulative hazards, and account for them in this comprehensive plan and the associated integrated adaptation framework.

4.1 Nuisance Flooding

Recent flooding events (e.g., 23 September and 29 October 2021) has highlighted the adverse impacts that tidal flooding does and will continue to have on the installation. The number of flooding events and the number of hours at or above flood stage have been increasing on the installation, as well as at numerous other sites around the United States (Sweet and Park, 2014). Figure 13 depicts the number of nuisance flood events (with minor and moderate flooding) at NSAA/USNA between 1930 and 2018 (USNA, 2019a). The Council’s data indicate that high tide flooding has been increasing at an exponential rate in recent years (USNA, 2019a).

Additionally, the Council reported (USNA, 2019a) that from 1928 to 1950, the annual number of events was typically less than 3, with many consecutive years having no tides impacting transportation and other assets on the installation, and with an average of just one high tide flood every other year. From 1950 to 2000, the average annual number rose through the decades to an average of 4 per year in the 1990’s. Since about 2000, the number of annual flood events has increased dramatically, with about 8 per year from 2000-2010, to an average of 20 per year between 2010 and 2018 (USNA, 2019a). In 2018,
a record high 41 flooding events occurred. With two high tides per day, flooding in 2018 occurred on almost 6% of high tide events.

The SLRAC also analyzed the duration of the flooding as this temporal component allows the installation to quantify the adverse impacts these events have on installation operations. The Council reported NSAA/USNA has experienced a nearly exponential increase in hours above flood stage in recent decades (USNA, 2019a). In the 1930s, Annapolis experienced only 37 total hours of minor coastal flooding over the entire decade, which is currently defined by the NOAA National Weather Service to be water levels 2.6 feet (0.8m) above mean lower low water. The number of hours above minor flood stage have been rising steadily since the 1960s (USNA, 2019a). The Council’s report went on to document that between 1990-1999 and 2000-2009, the hours above minor flood stage nearly doubled, and Annapolis has already experienced more than a doubling of hours above minor flood stage from 2000-2009 to 2010-2018 (USNA, 2019a). In addition, the hours above moderate flood stage (defined as 3.3 ft (1.0m) above mean lower low water) also accelerated at the turn of the century. During 2000-2009, Annapolis experienced 52 hours above moderate flood stage (more than any prior decade by ~30%), and this value nearly tripled between 2010-2018.

The Council report documented that with future relative sea level rise, the expected number of flood events per year rises dramatically. For example, with the next 6 inches of relative sea level rise, the number of annual flood events will likely increase to about 90 per year (USNA, 2019a). With the projected sea level rise increase of a foot above current conditions, the number jumps to about 340 per year so that nearly one out of every two high tides would cause extensive flooding (USNA, 2019a). As the SLRAC stated, the overall operational impact to installation operations, assets, and infrastructure would be so severe that the term “nuisance” is no longer appropriate.

4.2 Groundwater Inundation (Shoaling)

Like nuisance flooding, the threat of groundwater inundation is unique for each coastal installation, hinging largely on the vertical extent of unsaturated space between built infrastructure and tidally influenced coastal groundwater. The denser marine water underlies shallow freshwater aquifers, pushing them upward. In some low-lying areas, shoaling could force groundwater water to the surface. This will produce groundwater inundation in the form of increasingly severe periodic localized flooding that will be exacerbated during periods of extreme high tide increasing the likelihood of flood damage (Befus et al., 2020). Heavy rainfall is also likely to cause more extensive flooding owing to reduced unsaturated space available for infiltration and reduced surface drainage pathways. Befus et al., (2020) reported that while many coastal areas are focused on overland flooding because of sea level rise, the threat of rising groundwater tables, known as “shoaling,” is not as well known or understood.

NSAA/USN has considered that shoaling will impact the installation and that groundwater levels are controlled by the balance among recharge to, storage in, and discharge. Several physical properties such as the porosity, permeability, and thickness of the rocks or sediments that compose the aquifer and unsaturated space affect this balance. Land reclamation drove USNA Lower Yard expansion from 1845 to 1959 and it is assumed that the hydraulic properties of the fill used in each reclamation action is quite different. Soil hydraulic properties (infiltration, hydraulic conductivity, water retention, and available water capacity) are largely influenced by various inherent soil properties such as soil texture, structure,
bulk density, porosity, surface and subsurface crusting, organic matter, and interactions of these properties with each other (USGS, 2001). These variations are going to have a direct impact on groundwater table elevation and will require each of the reclamation areas to be assessed.

Additionally, meteorological changes will have a profound impact on hydrologic balance, such as the timing and amount of recharge provided by precipitation, discharge from the subsurface to surface-water bodies, and evapotranspiration (USGS, 2001). When the rate of recharge to the water tables exceeds the rate of discharge, water levels or hydraulic heads will rise. Heavy rainfall is also likely to cause more extensive flooding owing to reduced unsaturated space available for infiltration and reduced surface drainage pathways. Conversely, when the rate of ground-water withdrawal or discharge is greater than the rate of ground-water recharge, the water stored in the water table becomes depleted and water levels or hydraulic heads will decline.

Water levels usually follow a natural cyclic pattern of seasonal fluctuation, typically rising during the winter and late summer due to greater precipitation and recharge, then declining during the summer and fall owing to less recharge and greater evapotranspiration. The magnitude of fluctuations in water levels can vary greatly from season to season and from year to year in response to varying climatic conditions. Changes in ground water recharge and storage caused by climatic variability commonly occur over decades, and water levels in the water table generally have a delayed response to the cumulative effects of drought. Every effort will need to be made to recognize these meteorological cycles and the influences they have on the groundwater table.

Finally, the majority stormwater infrastructure in each of the USNA Lower Yard drainages are old and antiquated. There are inadequate inlet capacities within the drainage cause inefficient collection pathways for stormwater runoff. This is further complicated by undersized pipes and/or varying pipe sizes on the same line is causing inadequate conveyance pathways resulting in localized overland flooding. Localized ponding is also caused by and amplified due to surcharge of structures, negative slopes in pipe, and tidal mean high water covering existing outfalls. High peak tidal condition impedes gravity drainage into receiving waters may allow storm-drain backflow.

To have a better awareness of the role of groundwater inundation may have on the installation and assets such as the stormwater system may play in current and future flood risk, PWD Annapolis established six groundwater monitoring wells on the Lower Yard in the Fall of 2020. Although, physical properties soils and fill hydraulic properties of each groundwater well has not been ascertained when this comprehensive plan was developed, some preliminary comparisons of groundwater level fluctuations to tide cycles and meteorological changes have been performed.

In October 2022, groundwater monitoring wells, Annapolis tidal gauge, and the USNA meteorological station datasets were collected from 1 January to 31 October 2021 and descriptive statistics were performed (Figure 14). Measures of central tendency (e.g., mean, median, and mode) and of variability (e.g., standard deviation, variance, minimum and maximum variables, kurtosis, and skewness) were performed to standardize the data and identify potential gaps. These datasets were then statistically compared over three survey periods: the entire survey period with all variables (e.g., wind speed, air and water temperature, water levels in wells and tidal gauge, precipitation), periods of drought (14 days or greater days without precipitation), and periods of significant precipitation (24 hours when the installation
received greater than 1.5” of rain). These analyses allowed NSAA to begin to assess what variables may be driving changes in groundwater elevations for each groundwater monitoring well over time.

![Groundwater Monitoring Well Elevation Data](image)

**Figure 14. Naval Support Activity Annapolis Groundwater Monitoring Well Elevation Data for Six Wells from 1 January 2021 to October 29, 2021.**

These preliminary findings indicated that there were two variables that seemed to influence groundwater elevations: the geographic locations of the well (e.g., distance from the shoreline and which land reclamation action was in) and the NSAA/USNA tide cycle. As Figure 15 depicts, the groundwater elevation in monitoring well number one was highly correlated to tidal data, and that this correlation did not statistically vary away from this relationship during a significant precipitation event (i.e., >1.95” in less than 24 hours). It is important note that this monitoring well is approximately 200 feet from College Creek and associated high correlation (i.e., response time of ~90 minutes) is not representative of all the monitoring wells. However, every well did show some relationship between groundwater table elevation and tide cycles.

These preliminary groundwater analyses warrant additional study. If sea level rise projections were to cause shoaling on the installation, these flooding events would exacerbate nuisance flooding and have a profound impact on NSAA/USNA. Fundamentally, the cumulative impacts from nuisance flooding and groundwater inundation may undermine installation operations and mission sustainability than another Hurricane Isabel. Every land reclamation area 1880 and 1960 will be susceptible to these two climate-induced flooding hazards.
5.0 Future Considerations- 2021 Intergovernmental Panel on Climate Change

As stated at the beginning of this section, climate change vulnerability and impact assessment and adaptation process needs be an ongoing and iterative process through which vulnerabilities are assessed, adaptation plans are formulated, actions are taken, performance is monitored and evaluated, and conditions are reassessed based on updated data and model projections. This is noteworthy, as the Intergovernmental Panel on Climate Change (IPCC) prepares comprehensive Assessment Reports about the state of scientific, technical, and socio-economic knowledge on climate change, its impacts and future risks, and options for reducing the rate at which climate change is taking place. Consequently, the Fifth Assessment Report (AR5) (IPCC, 2014) played an integral role in the development of all the DoD, NOAA, and SLRAC technical reports presented in this section of this comprehensive plan.

In October 2021, IPCC published AR6 while this plan was being developed. Entitled the “Sixth Assessment Report (AR6) Climate Change 2021: The Physical Science Basis” this recent report addresses the most up-to-date documentation of the climate system and climate change, bringing together the latest advances in climate science, and combining multiple lines of evidence from paleoclimate, observations, processes, and global and regional climate simulations (IPCC, 2021). It is important to note that the findings of this report were not considered in the development of this plan, and the DRSL database and SLRAC recommendations leveraged to support current and future projections presented in this plan were built using AR5 projections.
One of the key differences between the previous IPCC report, AR5 and AR6 is the climate model data underlying many of the findings and projections. AR6 uses the latest generation of climate models, coordinated by the World Climate Research Programme’s Coupled Model Intercomparison Project, version 6 (CMIP6). This project is a collection of models from scientific institutions around the world, implementing the latest science and technology to produce projections of future climate. In total, more than 30 institutions contributed to over 40 models ultimately used in the IPCC’s assessment.

Divided into several sections that summarize the current state of the climate, possible climate futures, climate information for risk assessment and regional adaptation, and limiting future climate change, AR6 (IPCC, 2021) does is relevant to this comprehensive plan and following findings should be considered:

- “Each of the last four decades has been successively warmer than any decade that preceded it since 1850. Global surface temperature in the first two decades of the 21st century (2001–2020) was 0.99 [0.84 to 1.10] °C higher than 1850–1900. Global surface temperature was 1.09 [0.95 to 1.20] °C higher in 2011–2020 than 1850–1900, with larger increases over land (1.59 [1.34 to 1.83] °C) than over the ocean (0.88 [0.68 to 1.01] °C). The estimated increase in global surface temperature since AR5 is principally due to further warming since 2003–2012 (+0.19 [0.16 to 0.22] °C). Additionally, methodological advances and new datasets contributed approximately 0.1°C to the updated estimate of warming in AR6.”

- “The likely range of total human-caused global surface temperature increase from 1850–1900 to 2010–201911 is 0.8°C to 1.3°C, with a best estimate of 1.07°C. It is likely that well-mixed greenhouse gases contributed a warming of 1.0°C to 2.0°C, other human drivers (principally aerosols) contributed a cooling of 0.0°C to 0.8°C, natural drivers changed global surface temperature by −0.1°C to +0.1°C, and internal variability changed it by −0.2°C to +0.2°C. It is very likely that well-mixed greenhouse gases were the main driver 12 of tropospheric warming since 1979 and extremely likely that human-caused stratospheric ozone depletion was the main driver of cooling of the lower stratosphere between 1979 and the mid-1990s.”

- “Global mean sea level increased by 0.20 [0.15 to 0.25] m between 1901 and 2018. The average rate of sea level rise was 1.3 [0.6 to 2.1] mm yr\(^{-1}\) between 1901 and 1971, increasing to 1.9 [0.8 to 2.9] mm yr\(^{-1}\) between 1971 and 2006, and further increasing to 3.7 [3.2 to 4.2] mm yr\(^{-1}\) between 2006 and 2018 (high confidence).”

The arrival of the IPCC’s AR6 and its use of CMIP6 and improvements to Representative Concentration Pathways are an important milestone in the climate risk space. Monitoring the sources of ongoing sea level rise and the processes driving changes in sea level is critical for assessing scenario divergence and tracking the trajectory of observed sea level rise, particularly during the time when future emissions pathways lead to increased ranges in projected sea level rise. To highlight this point, a recent NOAA technical report (Sweet et al., 2022) illustrates how higher global temperature increases will have a profound impact on sea level rise scenario projections.

5.1 **NOAA 2022 Global and Regional Sea Level Rise Scenarios for the United States**

In February of 2022, the U.S. Sea Level Rise and Coastal Flood Hazard Scenarios and Tools Interagency released the “Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines” (Sweet et al., 2022). This report
and associated datasets were produced to provide key technical input for the Fifth National Climate Assessment. Consequently, it builds upon the 2017 Task Force report (Sweet et al., 2017a) by updating global mean sea level rise scenarios and downscaled with output directly from the United Nations IPCC AR6 (IPCC, 2021) and the National Aeronautics and Space Administration Sea Level Change Team. This update includes adjustments to the temporal trajectories and exceedance probabilities of these scenarios based upon end-of-century global temperatures. In addition, methodology supporting the DRSL database (Hall et al., 2016) is adapted for the extreme water level dataset newly developed for this report.

While the intent of this report is not to provide authoritative guidance or design specifications for a specific project, it is intended to help inform Federal agencies, state and local governments, and stakeholders in coastal communities about current and future sea level rise to help contextualize its effects for decision-making purposes. In particular, the report highlights how “multiple lines of evidence provide increased confidence, regardless of the emissions pathway, in a narrower range of projected global, national, and regional sea level rise in 2050 than previously reported” (Sweet et al., 2022). Both trajectories assessed by extrapolating rates and accelerations estimated from historical tide gauge observations, and model projections, fall within the same range in all cases, giving higher confidence in these relative sea level (land and ocean height changes) rise amounts by 2050. Additionally, relative sea level along the contiguous U.S. coastline is expected to rise on average as much over the next 30 years (0.25–0.30 m over 2020–2050) as it has over the last 100 years (1920–2020).

6.0 Future Consideration - NSAA/USNA Planning

Going forward, NSAA/USNA will need to plan to integrate this latest generation of climate models into their analytics. By utilizing the latest data from CMIP6 and key methodologies identified by the IPCC, NSAA/USNA can continue to ensure their analyses use the latest science to best capture future climate risk and ensure that any integrated adaptation framework employed by the installation can successfully meet the 2100 planning vision outlined in this plan. The installation and the SLRAC should consider updating their recommendations to reflect this latest science.

These modeling efforts should extend beyond sea level rise and extreme water level scenarios and should include a detailed assessment of the installations water table. As this section highlighted, ground inundation will have a profound impact on the installation. Additional monitoring wells should be installed and the variable that may be altering changes in the water table elevation.

This summation should illustrate the lengths that NSAA/USNA has made to assess its climate-induced hazards and anticipated environmental constraints. The selection of these scenarios has a direct bearing on the vulnerability assessments performed under this plan and the integrated adaptation framework that was developed to establish the project portfolio and associated courses of action. To establish scope and characterize impacts other factors like subsidence and meteorological factors (e.g., temperature, drought, precipitation), however only the issues described in this section were found to adversely impact NSAA/USNA operations and mission sustainability to 2100 (i.e., planning vision). Therefore, only these sources of flooding were used to assess the three dimensions of vulnerability to climate change: exposure, sensitivity, and adaptive capacity.
Vulnerability Assessment
X. VULNERABILITY ASSESSMENT

Fundamentally, climate change introduces a level of uncertainty and spatial pervasiveness that challenges the traditional view of hazards as containing distinct phases: pre-event, event, and post-event or distinct impact zones such as a “landfall site” or “epicenter.” In contrast, climate change impacts are long-term, multi-scale, and widely distributed, though potentially impacting different locations unevenly across time and space.

IPCC has defined vulnerability as “the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity” (McCarthy et al., 2001). In this, influential definition, exposure refers to the proximity of units or systems to disturbances resulting from climatic variation and sensitivity refers to the susceptibility of potential loss from these impacts. Adaptive capacity is defined as an element of vulnerability that includes “the characteristics of communities, countries, and regions that influence their propensity or ability to adapt” (McCarthy et al., 2001). These definitions are often represented in the formula:

\[
\text{Exposure} + \text{Sensitivity} + \text{Adaptive Capacity} = \text{Vulnerability}
\]

The definition and representation of vulnerability in this formula has significantly influenced the design of vulnerability assessments as it forces NSAA/USNA and other installations to consider how different factors contribute to vulnerability. However, as recognized in the most recent IPCC report (2021), conceptualizing vulnerability in this simple linear formula neglects the broader social, political, and economic forces shaping how an installation and communities that supports it are affected by natural disturbance. Further, the three terms in the formula often lack clear definitions, and their definitions differ across fields and disciplines (Hinkel, 2011).

Different definitions and conceptual frameworks shape how vulnerability and adaptive capacity are understood and examined. For example, some describe vulnerability as a state of powerlessness (Hewitt, 1997) or the presence of unsafe conditions (Wisner et al., 2004), while others see vulnerability simply as an exposure to some external natural phenomenon. Viewing vulnerability as a function of exposure to natural phenomenon directs the planning effort to examine the extent, magnitude, and probability of different climate-based hazards. In contrast, viewing vulnerability as a state of powerlessness directs attention to the broader socio-political structures and processes that shape the distribution of impact across society. For this plan, NSAA/USNA has chosen to focus on the vulnerability as a function of exposure.

1.0 Vulnerability Analyses

The potential exposure of installation assets and facilities to projected sea level rise and extreme water level events were initially estimated by overlaying the flood inundation extent polygons (i.e., defined in the previous section) over an extremely precise (i.e., sub-meter) three-dimensional virtual elevation (3DVE) model of the installation. This 3DVE model accurately depicts over 3,400 acres (i.e., terrestrial and bathymetry), 253, buildings, 16,590 lf of waterfront infrastructure (i.e., 13 individual designs), five bridges (i.e., 3 roads, a utility bridge, and a pedestrian bridge) and a variety of other assets and facilities. The
3DVE scene (i.e., digital elevation, assets, and infrastructure) were developed from a variety of remote sensing data collected by the USACE Army Geospatial Center (July 2020) and geospatial datasets from the regional NAVFAC GeoReadiness Center and several Federal and State agencies (e.g., USACE elevation surveys, National Oceanic and Atmospheric Administration, U.S. Geological Survey, and Maryland Department of Environment).

To obtain a more thorough assessment of vulnerability, twelve scenarios were analyzed for asset and infrastructure exposure. Preliminary models were updated leveraging a suite of federal open-source models (e.g., NOAA, FEMA, etc.). These new modeling efforts focused historical and current flood events to calibrate and validate modeling results (e.g., Hurricane Isabel, 2003 and tidal flooding in September and October 2021) to identify a modeling approach that best represented observed and historical site data. This final approach was then used to assess (See Figures 16 & 17):

- Current nuisance flooding;
- Current potential flooding from a 5-year, 20-year, 50-year 100-year, and 500-year storm;
- Potential future tidal flooding from flooding at Mean Higher High Water (MHHW) in 2035, 2050, 2065, and 2100; and
- Future potential flooding from a 5-year, 20-year, 50-year 100-year, and 500-year storm surge in 2035, 2050, 2065, and 2100.

![Figure 16. Projected Inundation, Sea-Level Rise Modeling Results.](image)
These modeling results were then merged with authoritative asset and infrastructure data (provided by NSA Annapolis and NAVFAC GeoReadiness Center) to create a new web-based screening level application. Entitled the NSAA/USNA Sea Level Rise and Vulnerability Exposure Analysis Viewer (SRVEAV), this application allowed NSAA/USNA to visualize, as several scales, assets, and infrastructure exposure under each of the referenced scenarios.

The Exposure Analysis scale represents a range of values from 0 to 9, with 0 being the least vulnerable (does not fall within any of the analyzed layers) and 9 being the most vulnerable (falls within all the analyzed layers). Analyses performed on assets and infrastructure in the form of points, lines, and polygons. The exposure value was determined by summing the number of sea level rise and storm surge scenarios the subject fell within.

The analysis was performed on points (e.g., location of generators), line segments (e.g., water pipes or electrical lines), and polygons (e.g., buildings). A polygon, such as a building, was considered exposed to the flood layer if any part of the building if the estimated first floor elevations of that facility were found to below the modeled flood water depth for the associated model. Please be aware, that due to limitations in available data, this analysis could not consider the elevation of all assets (e.g., generators, etc.).

Additionally, it is important to note that SRVEAV allows the user not to just visualize exposure but obtain authoritative metadata associated with that asset and facility (e.g., iNFAFs data) (See Figure 18). This allows the user to obtain the data and metrics required to support future analyses in this plan.

Figure 17. Projected Inundation, Sea-Level Rise + 5-Year Storm Event.
1.1 Vulnerability Analysis Findings

As the previous section highlighted, NSAA/USNA is already experiencing coastal flooding and it will continue to intensify. Since 1929, relative sea level in Annapolis has risen approximately 1.06 feet, which has significantly increased the occurrences of nuisance flooding from 2-3 times per year to 30-40 times per year. These frequent flooding events are impacting installation operations (e.g., transportation, emergency management services) and critical infrastructure (e.g., waterfront infrastructure, stormwater management system). If current Department of Defense (DoD) Regional Sea Level (DRSL) scenarios for NSAA/USNA are correct and an increase of 2.6 feet in relative sea level rise by 2065 and 4.4 feet by 2100 is anticipated, then these nuisance events will naturally evolve into major flooding events that will threaten NSAA/USNA’s ability to maintain mission.

Combine this increase in the frequency and intensity of nuisance flooding events with other potential sources of flooding described earlier (i.e., storm surge, ground inundation, land subsidence, and extreme precipitation events) and these natural hazards will continue to have a profound impact on the land and infrastructure and pose significant challenges to the successful execution of the NSAA/USNA mission. Of the 338 acres that compose the USNA, current projections would indicate that over 95 acres will be adversely impacted by climate-induced flooding by 2100 (i.e., minimally four times per month), this includes land designated as a National Historic Landmark District. Within this boundary, 139 facilities comprised of buildings and monuments, are contributing elements of the National Historic Landmark District, 42% (59 facilities) are projected to be impacted. In addition to the historical significance of USNA, there are 77 facilities categorized as critical or significant to the installation’s mission.
Leveraging SRVEAV and historical flood damage data, NSAA/USNA was able to assess the sensitivity of assets and infrastructure to damage from various projected sea level rise and extreme water level scenarios. Sensitivity was assessed for buildings, transportation, utilities, stormwater, base access, and athletic facilities.

All other things being equal, lower elevation assets are more sensitive to changes in the frequency and intensity of flood-inducing storm and tidal surge events and are also most at risk from sea level rise. For buildings, analysis of geographical information system data reveals the extent to which major systems are in areas that create sensitivity to flooding. Many mission-critical academic buildings, residence halls, and athletic fields and facilities are in the Lower and Upper Yards, often in flood-prone areas. The contents of some buildings have been relocated over time, moving expensive and/or critical equipment and assets to higher floors, in some cases in response to prior flooding events. At the time of this analysis, this was not universally the case—some expensive and mission-critical equipment was in areas sensitive to flooding (See Figure 19). For buildings, this approach has limitations due to variation introduced by relocation of facilities and building contents over time, and its use is a second best to the approaches described above and is useful for data-limited situations.

For transportation assets, the road network at the NSAA/USNA is spread across the Lower Yard, Upper Yard, and North Severn. Approximately 50% of all road area at the Academy is located on the North Severn area with the remaining 50% almost evenly divided between the Upper and Lower Yards. Analysis of road elevation at the USNA across each area revealed that while the lowest road sections are in the Upper Yard, the area most sensitive to changes in the frequency of flooding is the Lower Yard. While the Upper Yard contains the road with the overall lowest elevation point, the Lower Yard, where most of the mission-

![Mission Vulnerability](image-url)
related activities take place, remains the most exposed to flooding in aggregate and the most sensitive to increased flooding. Across the campus, a small percentage of the transportation infrastructure sits below nuisance and minor flood levels (1.1% and 6.6%, respectively). However, 27% of the transportation infrastructure would have partial flooding in the 2100 intermediate SLR scenario. Further, the flooding risk is unevenly distributed across the campus as the Lower Yard infrastructure has the most risk (See Figure 19).

For other assets (i.e., utilities, stormwater, base access, and athletic facilities), they tended to follow the same trends for buildings and transportation. For example, stormwater infrastructure sensitivity appears to mirror the transportation infrastructure. The stormwater infrastructure on the Lower Yard is old and antiquated. There are inadequate inlet capacities within the drainage that cause inefficient collection pathways for stormwater runoff. This is further complicated by undersized pipes and/or varying pipe sizes on the same line causing inadequate conveyance pathways resulting in localized overland flooding. Localized ponding is also caused by and amplified due to surcharge of structures, negative slopes in pipe, and tidal mean high water covering existing outfalls. High peak tidal condition impedes gravity drainage into receiving waters and some locations allow tidal waters to enter the drainage basin by way of the stormwater system. Unfortunately, these deficiencies are allowing flood waters to adversely impact installation transportation, academic halls, and emergency services (See Figure 19 & 20).

The findings of a more detailed analysis are provided in Appendix C. In the Appendix, the vulnerability of an asset includes the combined potential effects of the past flooding impact recorded from Hurricane Isabel, current potential flooding from a 100-year storm and 500-year storm, as well as potential future tidal flooding from flooding at Mean Higher High Water in 2035, 2065, and 2100, as well as future potential flooding from a 100-year storm surge in 2035, 2065, and 2100. The analysis was performed on points (such as the location of generators), line segments (such as water pipes or electrical lines), and polygons (such as buildings). A polygon, such as a building, was considered exposed to the flood layer if any part of the building intersects any part of the flood polygon.

This sensitivity analysis illustrates that sea level rise and extreme water level events will have a profound impact on these assets and infrastructure. However, the NSAA/USNA recognizes that the functions value is more important than the physical assets and infrastructure. Putting this in a familiar lexicon: assets work together in systems to create function; function enables capability; and capability supports installation operation and military mission. It is not the assets themselves that we care about but the missions they ultimately support. Based on this assessment, a key challenge for installation will be to assess the relationship between asset and mission, as this relationship will drive the selection of adaptation alternatives.

1.2 Challenges with Assessing Adaptive Capacity
Adaptations (adjustments in infrastructure, activities, or management) can reduce vulnerability in a variety of ways including upgrading a facility to higher standards or relocating it. However, measuring the effectiveness of different adaptation options is an ongoing research challenge. In evaluating the status of adaptation efforts for infrastructure on the installation, NSAA/USNA identified some measures to harden facilities and systems that were undertaken in the wake of Hurricane Isabel. These included implementations of a phased door dam project to provide approximately 4-5 vertical ft (1.21-1.52 m) of protection to academic. Door dams are deployed approximately four times per year on average at some locations, but less often (once per year) at others. Deployment of the door dams occurs at different predicted flooding levels for each building, based on that building’s elevation. Other buildings are protected by sandbagging. A temporary floodgate can also be deployed between some buildings to create a continuous storm barrier, and balloon plugs have been procured to protect against back flooding through storm drains where needed. While these measures appear to be effective (i.e., October 2021 tidal flooding), it is difficult to develop precise conclusions about the effectiveness of implemented flood-protection adaptations in terms of reduced damages. Anecdotally, however, deployment of door dams for structures exposed to flooding during storm events; the relocation of heating, ventilation, and air conditioning equipment to a less exposed location; and the elevation of sensitive equipment such as electrical substations have reduced vulnerability of the NSAA/USNA to climate-induced hazards.

It was difficult to obtain quantitative metrics for adaptive capacity (the ability to implement relevant adaptation measures) relevant to infrastructure proved to be a more subjective exercise than anticipated to inform this study. Of the many factors that affect adaptive capacity of infrastructure systems, NSAA/USNA identified four that are important for the installation: preparedness, economic capacity, human capital, and management structure. Specifically:

- Preparedness (i.e., having well-developed procedures for handling emergencies) is important for reducing damage from storms. The installation emergency response plan has been recently updated summaries planned responses due to the types and magnitudes of climate events;
- Economic capacity, in this case having access to financial resources for adaptation (through additional funding or budgetary flexibility), was challenging to evaluate as appropriations for maintenance and capital investment vary by fiscal year and demands for these funds are competitive;
- Human capital, having a sufficiently trained workforce that is open to considering the need for adaptation, is a strength, NSAA/USNA staff are aware of increasing exposure to flooding and the potential for costly damages in the event of a strong storm combined with tidal and other conditions; and
- Management structure, NSAA/USNA leadership is committed to implement measures to increase resilience and achieve its 2100 planning vision.
Integrated Adaptation Framework
XI. INTEGRATED ADAPTATION FRAMEWORK

It is important to note, that the vulnerability assessment did not generate any new insights; however, it has refined and validated the extensive research, studies, planning efforts, and implementation of resilience measures performed by NSAA, SLRAC, USACE, SERDP, and other commands since 2003. By building on over a decade of assessments and analyses, this vulnerability assessment provides a more thorough awareness of the constraints that will be placed upon the installation and allows NSAA/USNA to realize that one fact has not changed:

A single adaptation alternative or strategy will not be able to mitigate the constraints identified.

As such, the installation will need to combine a variety of alternatives in an integrated adaptation framework to address present-day and future constraints (i.e., 2035, 2065 and 2100) and ensure the successful execution of mission critical and base support activities.

The proposed integrated adaptation framework that is:

- A Systems Approach
  Reflecting the reality that proposed adaptation alternatives much exist in complex physical, natural, and academic systems, and that a single action influences many other parts of the system.
- Sustainable
  Focused on the long-term sustainability and resilience of the installation and the benefits streams provided by this framework over time (e.g., cultural, aesthetics, recreational, security).
- **Science-based**
  Built on first understanding, then working deliberately with natural forces and processes to accomplish engineering goals. Leverage and build upon NSAA/USNA plans, studies, and designs.

- **Collaborative**
  Based on effective partner and stakeholder communication, engagement, and collaboration to identify ways to mitigate potential risks and obtain financial resources to implement proposed adaptations.

- **Efficient and cost effective**
  Driven to develop resilience measures that are not over-engineered, scalable, and respectful of operation and maintenance appropriations.

- **Socially responsive**
  Aligned with the stewardship values, objectives, interests, and priorities of DoD, Department of Navy, partners, stake holders and society at larger. Most importantly, is respectful of the USNA’s cultural heritage and its National Historic Landmark designation.

- **Innovative**
  Embracing new and emerging technologies and incorporating continuous learning, technology transfer and adoption of new and leading practices.

- **Adaptive**
  Demonstrating adaptive attitudes, structures and processes that enable a living, evolving and sustainable practice.

Therefore, every effort was made to compile a list of adaptation alternatives that proposed by previous studies of the installation (e.g., USACE, 2003, 2006), the 2019 planning charrette (NSAA, 2019), and a variety of new alternatives. In total, more than 120 adaptation alternatives were captured and assessed.

Consequently, a concerted effort was made to develop a ‘Defense in Depth’ framework (See Figure 22). This integrated adaptation framework employs a multilayered defense posture (i.e., exterior defenses, perimeter protection, interior adaptations, and sub-surface improvements) that strives to create resilience through redundancies, remove single points of failure, avoid over-engineered solutions that significant maintenance costs, and can allow the installation to meet it 2100 planning vision.

Adaptation is not a straightforward task. Long-term planning must be balanced with near-term remedies. It requires the installation to navigate uncertainties and competing priorities. Fundamentally, NSAA/USNA must weigh the daunting up-front costs of adaptation projects against the future losses the installations hope to see avoided. And, NSAA/USNA must accept that, no matter the scale of efforts, the installation will never truly be “flood-proof.” However, by instilling resilience with informed decision-making, proactive planning, and smart investments, NSAA/USNA will continue to sustain a mission of national importance and overcome multi-decade, insurmountable hurdles.

Sustainable water resources infrastructure is achieved through the beneficial integration of engineering and natural systems. With recent advances in the fields of engineering and ecology, there is an opportunity to combine these fields of practice into a single collaborative and cost-effective approach for infrastructure development and environmental management. This proposed integrated adaptation framework strives to leverage advances in both fields has evaluated nature-based and green infrastructure when developing the proposed ‘Defense in Depth’ strategy. This framework:
- Uses science and engineering to produce operational efficiencies supporting sustainable delivery of project benefits.
- Uses natural processes to maximum benefit, thereby reducing demands on limited resources, minimizing the environmental footprint of projects, and enhancing the quality of project benefits.
- Broaden and extend the base of benefits provided by projects to include substantiated economic, social, and environmental benefits.

Adaptation is not a straightforward task. Long-term planning must be balanced with near-term remedies. It requires the installation to navigate uncertainties and competing priorities. Fundamentally, NSAA/USNA must weigh the daunting up-front costs of adaptation projects against the future losses the installations hope to see avoided. And, NSAA/USNA must accept that, no matter the scale of efforts, the installation will never truly be “flood-proof.” However, by instilling resilience with informed decision-making, proactive planning, and smart investments, NSAA/USNA will continue to sustain a mission of national importance and overcome multi-decade, insurmountable hurdles.
Project Portfolio
XII. PROJECT PORTFOLIO

A multi-layered, integrated adaptation framework is recommended to meet the NSAA/USNA 2100 planning vision. This framework presents a holistic method for addressing flood risks, with high-level strategic objectives to guide adaptation efforts across the entire installation. By weaving adaptation alternatives together to provide comprehensive flood protection; each of the proposed alternative presents a specific benefit against flooding and complements each other.

This framework of complementary, layered defenses is anchored by a portfolio of potential adaptation alternatives that provide the resilience characteristics that align the NSAA/USNA resilience goals. Composed of engineered structural adaptations, existing facility adaptations, non-facilities adaptations, and natural and nature-based approaches, the installation selected 28 adaptation alternatives for further analysis and advancement.

Prior to initiating Stage III, a more detailed assessment of each adaptation alternatives was performed. This evaluation assisted the installation in determine the alternatives suitability (i.e., taking base operations and geographic planning area in context), the effectiveness of the alternative in reducing vulnerability or enhancing resilience, and whether the alternative is sustainable (i.e., both to mission and in costs to operation and maintain). The objective was to avoid choosing unsuitable actions that would fail due to their inability to adjust adequately to a changing environment.

Working closely with the SLRAC and NSAA subject matter experts during these analyses, NSAA/USNA has developed a conceptual approach that mirrored the current NAVFAC military construction (MILCON) process. This decision was made for several reasons. By mirroring this MILCON process, this approach could be easily replicated in the future, and would effortlessly inform the Stage III process as well as support future NSAA Public Works planning and requirements. Specifically, this ensured that each adaptation alternative would consider:

- The rough order of magnitude (ROM);
- A description of the proposed project;
- The specific requirement(s) for the project (e.g., a change in mission or deterioration of facilities already in use), the current facility situation at the installation);
- The impact on installation mission if the project is not approved; and
- Any other needed justification information.

This concerted effort ensures that the analyses and resulting summations would align with the Department of Defense Form 1391 (DD Form 1391, Military Construction Project Data). Fundamentally, the MILCON process is an intuitive and logical approach; much like the MILCON process, the implementation of this comprehensive plan and associated adaptation framework will require a top-down initiative or it may be the result of needed modernization or replacement of existing facilities determined by installation. In either case, the process begins with a preliminary project justification and a facility requirements analysis by the installation’s public works department.

Additionally, much like the Stages outlined earlier in this plan’s methodology, the installation engineers and other public works staff will need to evaluate the proposed need for new or improved facilities and compare them to the facilities that already exist as part of the MILCON process. The engineers will weigh
the costs and time required to rehabilitate or alter structures on site against the cost and time required to replace them. Engineers and other members of the installation’s planning team then make a preliminary determination of whether renovation of an existing facility, new construction, or leasing is more appropriate to satisfy the proposed need. An initial project evaluation is followed by a more comprehensive evaluation once a determined need generates a formal request for MILCON.

Finally, the prioritization of prospective MILCON at an installation, or in this case adaptation alternatives, generally begins with meetings between the installation’s engineers and representatives of all major resident organizations and other installation tenants. As a result of these meetings, a prioritized list of construction needs is presented to the senior installation commander, who then accepts or adjusts the priorities to create a final list of proposed projects for service-level review.

In this section, the majority of the 28 adaptation alternatives will be presented in a format like the DD Form 1391. The alternatives have been broken out by geographic planning area and are summarized in the following tables (Tables 9, 10, 11, and 12). As several of the adaptation alternatives are addressing a similar vulnerability or are being applied at in more than one geographic planning area, the same language has been used in more than one alternative summation. It is important to highlight that for Stage III and future NSAA Public Works requirements, each summation is being evaluated on its own merit.

Table 9. NSA Annapolis Lower Yard Adaptation Alternatives Advancing for further Analysis.

<table>
<thead>
<tr>
<th>Lower Yard Action Alternatives</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Design and Construction of Wave Attenuation Features</td>
<td>Advance to Stage III</td>
</tr>
<tr>
<td>2. Design and Construction of an Earthen Berm</td>
<td>Advance to Stage III</td>
</tr>
<tr>
<td>3. Implement Integrated Stormwater Management Program (assessments, emergency repairs,</td>
<td>Advance to Stage III</td>
</tr>
<tr>
<td>stormwater trunk lines, pump stations, and LID water)</td>
<td></td>
</tr>
<tr>
<td>4. Santee Basin Resilience Efforts</td>
<td>Advance to Stage III</td>
</tr>
<tr>
<td>5. Repair and Raise Height of Bulkhead/Seawalls/Riprap (Farragut Seawall, Farragut Riprap,</td>
<td>Advance to Stage III</td>
</tr>
<tr>
<td>Dewey Field Bulkhead, Halsey Quay Wall/Bulkhead)</td>
<td></td>
</tr>
<tr>
<td>6. Repairs and Improvements to Interior Roads</td>
<td>Advance to Stage III</td>
</tr>
<tr>
<td>7. Implement Athletic Field Improvement (Modify grades of Dewey and Farragut fields)</td>
<td>Advance to Stage III</td>
</tr>
<tr>
<td>8. Improving Resilience NSA Annapolis/US Naval Academy Underground Utility Tunnels</td>
<td>Advance to Stage III</td>
</tr>
<tr>
<td>9. Implement Main Gate (Gate 1) Flood Protection</td>
<td>Advance to Stage III</td>
</tr>
<tr>
<td>10. Protect and Relocate Critical Services on First Floor</td>
<td>Advance to Stage III</td>
</tr>
<tr>
<td>11. Repair and Expansion of Hill Bridge and Associated College Creek Shorelines</td>
<td>Advance to Stage III</td>
</tr>
</tbody>
</table>
Table 10. NSA Annapolis Upper Yard Adaptation Alternatives Advancing for further Analysis.

<table>
<thead>
<tr>
<th>Upper Yard Action Alternatives</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Design and Construction of Wave Attenuation Features</td>
<td>Advance to Stage III</td>
</tr>
<tr>
<td>2. Implement Integrated Stormwater Management Program (assessments, emergency repairs, stormwater trunk lines, pump stations, cisterns/vaults, and LID water retention features)</td>
<td>Advance to Stage III</td>
</tr>
<tr>
<td>3. Repair and Raise Height of Bulkhead along Sherman Field</td>
<td>Advance to Stage III</td>
</tr>
<tr>
<td>4. Improve Elevation of Interior Road Implement Sherman Resilience Measures</td>
<td>Advance to Stage III</td>
</tr>
</tbody>
</table>

Table 11. NSA Annapolis North Severn Adaptation Alternatives Advancing for further Analysis.

<table>
<thead>
<tr>
<th>North Severn Action Alternatives</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Design and Construct Wave Attenuation Features (in scope beyond what is included in current project design w/recommended mid-long term implementation priority)</td>
<td>Advance to Stage III</td>
</tr>
<tr>
<td>2. Repair and Raise Height of Bulkhead along North Severn</td>
<td>Advance to Stage III</td>
</tr>
</tbody>
</table>

Table 12. NSA Annapolis Greenbury Point Adaptation Alternatives Advancing for further Analysis.

<table>
<thead>
<tr>
<th>Greenbury Point Action Alternatives</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Greenbury Point Shoreline Protection- Combination of Hardened and Living Shoreline Reaches (in line with current INRMP plan priorities)</td>
<td>Advance to Stage III</td>
</tr>
<tr>
<td>2. Stabilization of Greenbury Point Berm</td>
<td>Advance to Stage III</td>
</tr>
</tbody>
</table>
A. Lower Yard Project Portfolio

1.0 Design and Construction of Wave Attenuation Features

Current Mission:
NSAA/USNA’s existing 19,334 linear feet of waterfront infrastructure is critical to reducing the vulnerability of Navy property, assets, and mission-essential elements of the USNA academic programs from flooding. Consequently, NSAA/USNA has planned repairs and restoration actions that would address structural deficiencies on the existing Lower Yard infrastructure (e.g., seawalls, bulkheads, revetments) and potential impacts from future extreme weather events, storm surge, sea level rise, and land subsidence. While a concerted effort has been made to ensure that these repairs and restoration will address the changes in sea level rise elevation, wave energy, and associated forces, additional efforts will need to be made to improve the design life of this waterfront infrastructure (Figure 23).

Requirement:
The proposed installation of wave attenuation features is built on the educated assumption that planned repairs and restoration of the Lower Yard waterfront infrastructure will be a significant financial investment by the Navy. Every effort should be made to ensure that the planned design life of this infrastructure is met or exceeded. The proposed wave attenuation features would provide reduced wave height and energy prior to it reaching the infrastructure and other adaptation alternatives and thereby reducing the likelihood of degradation to the waterfront infrastructure. Any protection to the waterfront infrastructure is expected to extend the design life to meet the installation’s 2100 planning vision.

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Figure 23. Lower Yard Project Portfolio.
Current Situation:
Located at the confluence of the Severn River and Chesapeake Bay, NSAA/USNA is vulnerable to storm surge associated with major weather events and localized, high-tide flooding that is exacerbated by sustained easterly or southerly winds. Recent studies by USNA have suggested that three-, six-, and twelve-hour sustained, prevailing winds significantly influences these flooding events in Annapolis. Sustained wind forcing out of the northeast, east, southeast and south is associated with positive nuisance flooding events, and sustained wind forcing out of the northwest and north is associated with negative or negligible flooding (Davies et al., 2022). While these results suggest a relationship, it must be understood that in geomorphological complex coastal systems like the Chesapeake Bay and Severn River, this relationship can be influenced and complicated by other factors (Lyddon et al., 2018). Specifically, shallow-water, channel convergence, fetch length, along with the wind speed (wind strength), and duration, determines the size of waves produced. If the wind direction is constant, the longer the fetch and the greater the wind speed, the more wind energy is transferred to the water surface and the larger the resulting wave size will be. Wave size will increase over time until local energy dissipation balances energy transfer to the water from the wind and a fully developed wave is achieved. The resulting wave will amplify high-tide flooding and can adversely impact existing waterfront infrastructure in a variety of ways (e.g., power and energy impacting the structure, and no overtopping).

Current projections would indicate that the frequency and intensity of these wind driven impacts will increase with sea level rise. Since 1929, the relative sea level in Annapolis has risen slightly more than one foot, which has significantly increased the occurrences of nuisance flooding from 2-3 times per year to over 40 times per year and left the NSAA more vulnerable to major storms. If this trend continues, impacts from high-tide flooding, and sustained, prevailing winds will affect daily operations of NSAA/USNA through closures of roads, sidewalks, building entry points, and flooding of buildings.

Impacts if not Provided:
The most recent Waterfront Facilities Inspections and Assessments at United States Naval Academy Annapolis, Maryland report (NAVFAC, 2017b), provided an assessment of the general physical condition of the facilities, operational restrictions, and recommendations. At the time of the inspection, Farragut Field and the east wall of the Santee Basin bulkheads exhibited increased deterioration of the steel sheet piles with corrosion holes developing below the concrete pile caps. In these areas, backfill was observed escaping through the corrosion holes, with sinkholes developing behind the bulkheads. While this infrastructure has exceeded its design life, it is starting exhibit the degradation expected with >70-year-old facilities and illustrate that this infrastructure will need to be integrated with other adaptation measures to ensure repairs and restoration efforts will meet the 2100 planning vision defined by NSAA/USNA.

Objective:
The installation of wave attenuation features will assist repaired and restored waterfront infrastructure to address projected changes in the intensity, frequency, and duration of wave energy that will arise with sea level rise.

General Comments:
Preliminary modeling efforts indicate that Farragut Field bulkhead and the Turner Joy Road revetment is incurring most of the fetch and wave energy currently and projected to impact the Lower Yard. Unfortunately, recent hydrographic surveys along this waterfront infrastructure would indicate that stone breakwaters would be expensive and adversely impact navigable waters if constructed, due to water
depth and substrate composition. Consequently, in any wave attenuation features employed would need to consider a suite of innovative, manmade engineering solutions. USACE ERDC has tested and extensively evaluated a new family of prefabricated concrete elements as Reefmaker, URGEBREAKER offshore reef system, BEACHSAVER reef, WAVEblock, T-sill elements and others that have been developed and applied.

Recommendations are based on the Reefmaker technology that was originally developed and upgraded for the wave environment found along the Atlantic coastline. The Reefmaker technology is a pile-based wave attenuation system. This system allows water to flow through it while providing improved wave protection characterized by a traditional breakwater system. The system consists of concrete ‘eco-disks’ individually stacked on top of one another. The eco-disks are perched above the benthic substrate by a mechanical support system. The product is an octagonal shape to create additional surface area to reduce wave energy, accommodate irregular shorelines and reduce structure weight. The eco-disks are designed to direct and dissipate wave energy.

2.0 Design and Construction of an Earthen Berm

Current Mission:
NSAA/USNA’s current waterfront infrastructure (e.g., seawalls, bulkheads, revetments) will continue to be the installation’s first line of protection against current and future flooding from the Chesapeake Bay, Severn River, and its associated creeks. Planned repairs and restoration of this infrastructure will have a profound impact on the installation’s ability to meet anticipated changes in sea level rise. However, these 19,334 linear feet of infrastructure will not be able to prevent flooding from sustained, wind driven flooding or storm surge without raising the waterfront infrastructure height to the extent that it will not have a profound impact on aesthetics of this National Historic Landmark. Additionally, these substantial heights (+8.0 ft North American Vertical Datum of 1988, or NAVD88) are complex and require engineering solutions that would be costly. Consequently, NSAA/USNA is proposing to establish an earthen berm behind the existing waterfront infrastructure. As part of an integrated adaptation framework that layers flood protection, this proposed earthen berm network would improve the resilience of the installation against potential impacts, including future extreme weather events, storm surge, sea level rise, and land subsidence.

Requirement:
The proposed adaptation alternative will assist NSAA/USNA meet several mission requirements:

- Improve the coastal resilience of the installation from current and projected flooding from sea level rise, storm surge, and nuisance flooding by creating another level defense behind the existing waterfront infrastructure;
• Provide an elevated path on the crest of the earth berm that will allow Midshipmen to meet physical fitness goals without using existing transportation network. Thereby reducing likelihood of accidents with motor vehicles; and
• Enhance the anti-terrorism / force protection of the installation by creating an elevated boundary that will assist the installation in achieving the highest possible levels of safety for both personnel and assets.

Any additional protection near the waterfront infrastructure will enhance flood protection and assist the installation meet its 2100 planning vision.

Current Situation:
The current waterfront infrastructure has well exceeded its design life and is beginning to show its age. A recent waterfront infrastructure inspection found, Farragut Field and the east wall of the Santee Basin bulkheads exhibited increased deterioration of the steel sheet piles with corrosion holes developing below the concrete pile caps. In these areas, backfill was observed escaping through the corrosion holes, with sinkholes developing behind the bulkheads. Regrettably, associated geotechnical surveys of these areas would indicate that these deteriorations appear to have compromised the soils between the quay walls and their associated deadman. Soil quality is poor, and it limits the number of engineering designs that would allow the repairs and restoration of this infrastructure to obtain to elevation to meet current projections for combined sea level rise and extreme water level events. Based on recent cost benefit analyses, it would be more cost effective for the installation to add another flood protection feature such as an earthen berm than develop an engineered solution for the existing waterfront infrastructure.

Impacts if not Provided:
The integrated adaptation framework for NSAA/USNA is built on multilayers of defenses that create redundancies. Current projections of sea level rise and extreme water level events would indicate that the installation will not be able to achieve the 2100 planning vision it expects without implementing these layered defenses. Not meeting this planning vision will adversely impact the installation’s ability to sustain its current mission.

Objective:
The design and construction of the proposed earthen berm network is an integral component of the NSAA/USNA integrated adaptation framework. Working in combination with existing waterfront infrastructure and the proposed wave attention features, the earthen berm network provides the first lines of defense and receive the majority projected changes in the intensity, frequency, and duration of wave energy that will arise with sea level rise.

General Comments:
An earthen berm is an embankment that provides flood protection from seasonal and periodic flooding events. At NSAA, this adaptation alternative is expected to provide flood protection for short periods of time when waters from the Severn River and associated creeks overtop existing waterfront infrastructure. It is expected that this flooding would occur from a few days to a few weeks per year based on current projections. This means that this network of earthen berms is expected to become saturated beyond the limit of capillary saturation for only a short period of time.

As this proposed earthen berm will be woven into other adaptation alternatives (e.g., flood walls and raised roads) to encircle the Lower Yard from flooding along Spa Creek, Severn River, and College Creek, attention will need to be given to ensure proper design and construction of the berm which is vital to
prevent failure. There are four primary causes of berm failure: overtopping, surface erosion, internal erosion (piping), and slides within the levee embankment or the foundation soils.

Consequently, in designing an earthen berm, a variety of factors will need to be considered to providing the resilience characteristics that NSAA/USNA desire including soil profile of the area, load capacity of the foundation materials, slope stability, settlement, and the loads on the berm surface (i.e., athletic and security requirements). In order to address these factors, NSAA/USNA will require extensive geophysical investigations (e.g., shear strength, groundwater, and pore pressure).

Current modeling efforts recommend that the proposed earthen berm would be placed slightly behind the deadman location for each of the quay walls that compose each segment of the Lower Yard waterfront infrastructure. This will ensure that there will be adequate space for the waterfront infrastructure to continue to support current operational requirements and as well as space to repair this infrastructure if required. Along the Turner Joy Road revetment, the earthen berm will be located between the revetment and existing varsity athletic fields. This will provide adequate spaces to tie the existing revetment into berm (i.e., rip rap over heavy-duty woven drainage fabric will be added to Spa Creek side slope) and the addition of toe trench/drain between the berm and athletic field lighting.

The earthen berm elevations will vary by location on the Lower Yard; however, design and construction will ensure that as built elevation of the crest is approximately 9ft above NAVD88 after expected settlement. Embankment stability will need to be assessed at each location, but the ideal goal will be to achieve a 3:1 slope. This will require foundation preparation and treatment to improve stability. In some areas this may require the creation of a non-permeable core (i.e., concrete secant, steel sheet piles) in the foundation to create additional stability for sections of the berm projected to receive significant wave energy during extreme water level events.

The entire earthen berm network will have a nine-foot-wide athletic path on its crest. The composite of the path will be determined during the design process, but efforts will be made to consider permeable materials (e.g., gravel, cobble stone, brick) that mirror similar approaches employed elsewhere in the National Historic Landmark. Every effort will be made to translocate existing waterfront infrastructure assets (e.g., lamp posts, memorials, etc.) into the berm. The slopes will be planted with turf grasses.

It is important to note that the establishment of this earthen berm network will require the demolition of Sims Road, Turner Joy Road, and the Brownson Road extension into the Halsey Field House/Admissions parking lot. Consequently, it will also result in the loss of the associated student parking on these roads.

Recommended Execution Timeframe: Long-term. Phased between 2037 -2057. Phasing will begin with construction from Halsey Field House to Santee Basin followed by Santee Basin to McNair Road. The last segment will Nimitz Hall to Hill Bridge and this design should be incorporated in the Hill Bridge improvements.
3.0 Implement Integrated Stormwater Management Program

3.1 Lejeune Hall/Porter Road Drainage Basin Stormwater Improvements for Flood Risk Mitigation

Current Mission:
The Lejeune Hall/Porter drainage basin supports several mission critical assets and infrastructure. Most notably is Gate 1. Gate 1 is the visitor entrance on the Lower Yard and is open to both pedestrians and vehicles. Gate 8 is on Bowyer Road on the Upper Yard with 24-hour access for official traffic, contractors, deliveries, and large automobiles. Consequently, Gate 1 serves as the primary entrance for most of the installation’s traffic, and the surrounding visitor-focused assets and facilities (e.g., Armel-Leftwich Visitor Center, Admissions, and short-term parking) have been aggregated near and adjacent to the Gate to create an open and welcome environment for its visitors.

Requirement:
As the primary access point to the installation, it is vital that this Gate 1 is able ensure safety, provide a physical and psychological deterrent, and is ultimately a representation of the installation and the community that lives and works on NSAA. To meet this goal, every effort needs be made to ensure that Gate 1 and surrounding assets and facilities are resilient and capable of supporting NSAA/USNA’s 2100 planning vision.

This drainage basin is susceptible to frequent nuisance flooding at Gate 1, King George Street, Brownson Road, and Porter Road. Proposed repairs will improve stormwater conveyance in these areas and allow this storm water infrastructure to support current and projected climate-induced flood events.

Current Situation:
The majority stormwater infrastructure in the Lejeune Hall/Porter Road drainage is old and antiquated. There are inadequate inlet capacities within the drainage causing inefficient collection pathways for stormwater runoff. This is further complicated by undersized pipes and/or varying pipe sizes on the same
line is causing inadequate conveyance pathways resulting in localized overland flooding. Localized ponding is also caused by and amplified due to surcharge of structures, negative slopes in pipe, and tidal mean high water covering existing outfalls. High peak tidal condition impedes gravity drainage into receiving waters.

**Impacts If Not Provided:**
The proposed recommendations are built on the educated assumption that there is an imminent threat of extreme coastal and precipitation-based storm events as well as probable permanent inundation of some land areas over time. Any improvements to the stormwater infrastructure will address present-day and projected to 2100 impacts. This would ensure mission-essential infrastructure and facilities within this drainage will maintain mission critical and base support activities at the U.S. Naval Academy.

**Objective:**
To meet these challenges, the proposed improvements to the stormwater network are viewed as a component of broader integrated adaptation framework. This framework presents a holistic method for addressing flood risks across the installation and consists of four complementary layers. Each layer presents a specific approach to flood risk management—working through the lenses of natural engineered defenses, adapted structures, natural mitigations, and prepared communities. These layers are designed to support each other, integrating structural and non-structural measures to ensure comprehensive flood protection across a range of environmental conditions.

The stormwater improvement recommendations presented in this document have been built on several underlining assumptions. Specifically, proposed pipe improvements and upgrades will occur in the same locations as existing network components and associated planned pump stations will be in areas that are currently open land. Consequently, no utility conflicts have been identified based on current layout.
General Comments:

Stormwater infrastructure priority objectives include

- Reducing the amount of nuisance flooding and damage;
- Moving funding toward more long-term goals and adaptation measures;
- Providing a foundation for other adaptation alternatives by providing relief from recurring flooding; increasing storage volumes and detention times within the system to reduce peak flows during all storm events; and
- Increasing water quality and protect natural resources in surrounding Bay waters.

Figure 26. Gate 1 Nuisance Flooding (2015).

A phased approach to this proposed design build will address gaps and needs before committing to 95% design: The proposed phases of the MILCON project would include:

1) Identify and predict changing groundwater elevations over the planning horizon (influence of precipitation and tides).
   a) Add four groundwater monitoring wells to the drainage basin (e.g., Porter Road/Gate 1, Rotunda/King George Street, Between Lejeune/Bancroft Halls, and Farragut Field/Football Practice Field).

2) Determine if existing stormwater system is working efficiently and is not in disrepair.
   a) Assessment should focus on negative slopes and how tide cycles impede gravity drainage.
   b) CCTV and diver investigations of the existing stormwater system is inclusive. Recommend deployment an integrated, turnkey solution like Stormsensor (https://www.stormsensor.io/) to assess function and monitor changes concurrently with groundwater monitoring wells.

3) Build on existing digital elevation models to evaluate overland flooding and how alterations to slope and grade.
   a) Efforts should be made to direct overland runoff away from critical infrastructure to areas that can retain water.
b) New retention areas should be planted with native trees that can reduce soil erosion and increase soil absorption capacity.

4) Phases 1-3 should be performed while preliminary designs to the drainage stormwater system is being developed.

5) Final designs for Improvement of stormwater system infrastructure.
   a) Design should consider splitting existing drainage network into three subnetworks to address pipe capacity constraints and leverage gravity drainage toward main outfall. This would divide the current drainage into high and low elevation networks with the low elevation networks located east and west segments.
   b) This will consist of larger diameter pipes (trunk lines) necessary to convey runoff and manage localized overland flooding. Drainage gradient will be positive towards the outfall. A large portion of the pipes will continue to be below tide levels under both existing and future conditions.
   c) Install tidal gates at 18 outfalls in the drainage.
   d) Wet wells and pump stations (with 100 cfs peak pumping capacity) will be required in the east and west low elevation networks (i.e., at the rotunda at King George Street and football practice field). The subsurface storage system sizes for each wet well be contingent on previous studies.

Recommended Execution Timeframe: Short-term. 2023-2027. The proposed repairs and improvements in this drainage basin should be performed before other basins.
Figure 27. Creation of Lejeune Hall/Porter Road Drainage Stormwater System into Subnetwork as a Component of Integrated Adaptation Framework.
3.2 **Ingram Field Drainage Basin Stormwater Improvements for Flood Risk Mitigation**

**Current Mission:**
Located at the confluence of the Severn River and Chesapeake Bay, NSAA is vulnerable to storm surge associated with major weather events and localized, high-tide flooding that is exacerbated by sustained easterly or southerly winds. Since 1929, the relative sea level in Annapolis has risen slightly more than one foot, which has significantly increased the occurrences of nuisance flooding from 2-3 times per year to over 40 times per year and left the NSAA more vulnerable to major storms. Impacts from precipitation, storm surge, and high-tide flooding affect daily operations through closures of roads, sidewalks and building entry points.

Consequently, stormwater resiliency is an integral component of the NSAA integrated adaptation framework. Composing approximately 1,670,000 sq ft, the Ingram Field Drainage Basin is one of the largest on the Lower Yard (See Figure 28). The stormwater infrastructure within the basin ability must be able function through a wide range of climate conditions if base operations are to be maintained. These improvements will improve the resilience of the stormwater system. Assessing and improving the resiliency of a stormwater system can reduce flooding risk, long term operational costs, and provide a better opportunity for that system to adapt to future climate changes.

**Requirement:**
The proposed improvements are built on the educated assumption that there is current and imminent adverse impacts from coastal and precipitation-based overland flooding that will have a profound impact on installation operations and mission. Any improvements to the stormwater infrastructure are expected to address present-day and provide a foundation to meet the installation’s 2100 planning vision.

To meet these challenges, the proposed improvements to the stormwater network within the Ingram Field Basin are viewed as a component of broader integrated adaptation framework. This framework presents a holistic method for addressing flood risks across the installation and consists of four complementary layers. Each layer presents a specific approach to flood risk management—working through the lenses of natural engineered defenses, adapted structures, natural mitigations, and prepared communities. These layers are designed to support each other, integrating structural and non-structural measures to ensure comprehensive flood protection across a range of environmental conditions.

The stormwater improvement recommendations presented in this document have been built on several underlining assumptions. Specifically, proposed pipe improvements and upgrades will occur in the same
locations as existing network components and associated planned pump stations will be in areas that are currently open land. Consequently, no utility conflicts have been identified based on current layout.

**Current Situation:**
The majority stormwater infrastructure in the Ingram Field drainage is old and antiquated. There are inadequate inlet capacities within the drainage that cause inefficient collection pathways for stormwater runoff. This is further complicated by undersized pipes and/or varying pipe sizes on the same line causing inadequate conveyance pathways resulting in localized overland flooding in parking lots (adjacent to Luce and Rickover Halls) and Holloway Road. Localized ponding is also caused by and amplified due to surcharge of structures, negative slopes in pipe, and tidal mean high water covering existing outfalls. High peak tidal condition impedes gravity drainage into receiving waters and some locations allow tidal waters to enter the drainage basin by way of the stormwater system. Unfortunately, these deficiencies are allowing flood waters to adversely impact installation transportation, academic halls, and emergency services.

In 2019, NSAA developed designs for repairing and retrofitting the Stribling Walk Watershed Drainage system. This design included underground storage system designed to retain storm water runoff for reuse along with ancillary site improvements and reconstruction of parking lot, roadways, sidewalks and track and field associated with the project due to impact associated with installing the underground storage facility and general improvements and reconstruction along Holloway Road and incidental related work. While innovative, additional studies are warranted before these improvements are implemented. These include detailed stormwater assessments outlined below (i.e., determine rates of sedimentation in existing lines), groundwater analyses (i.e., determine if changes in groundwater will affect function of proposed system), associated geotechnical surveys (i.e., determine if the site can bear the weight of the storage system), and an installation energy plan (i.e., proposed submersible pumps will require a lot of energy).

**Impact if not provided:**
Risk assessments of current and future flooding from sea level rise, storm surge, and precipitation will continue to adversely impact installation operations and damage mission essential assets and infrastructure if not addressed. Preliminary assessments of the types and number of features that would be impacted by a failure, the frequency of impact, the severity of the impact, and the displacement associated with a failure would indicate that further delays in improving the stormwater system within the Ingram Field drainage basin could be profound.

**Objective:**
The proposed improvements to the stormwater management system with the Ingram Field drainage basin will reduce flood risk and improve stormwater conveyance by:

- Reducing the amount of nuisance flooding and damage;
- Moving funding toward more long-term goals and adaptation measures;
- Providing a foundation for other adaptation alternatives by providing relief from recurring flooding; increasing storage volumes and detention times within the system to reduce peak flows during all storm events; and
- Increasing water quality and protect natural resources in surrounding Bay waters.
General Comments:
A phased approach to this proposed design build will address gaps and needs before committing to 95% design: The proposed phases of the MILCON project would include:

6) Identify and predict changing groundwater elevations over the planning horizon (influence of precipitation and tides).
   a) Maintain the existing six groundwater monitoring wells in the drainage basin.

7) Determine if existing stormwater system is working efficiently and is not in disrepair.
   a) Assessment should focus on negative slopes and how tide cycles impede gravity drainage.
   b) CCTV and diver investigations of the existing stormwater system is inclusive. Recommend deployment an integrated, turnkey solution like Stormsensor (https://www.stormsensor.io/) to assess function and monitor changes concurrently with groundwater monitoring wells.

8) Build on existing digital elevation models to evaluate overland flooding and how alterations to slope and grade.
   a) Efforts should be made to direct overland runoff away from critical infrastructure to areas that can retain water.
   b) New retention areas should be planted with native trees that can reduce soil erosion and increase soil absorption capacity.

9) Phases 1-3 should be performed while preliminary designs to the drainage stormwater system is being developed.

10) Final designs for Improvement of stormwater system infrastructure (See Figure 29).
    a) Design should consider splitting existing drainage network into three subnetworks to address pipe capacity constraints and leverage gravity drainage toward main outfall. This would divide the current drainage into high and low elevation networks with the low elevation networks located east and west segments.
    b) This will consist of larger diameter pipes (trunk lines) necessary to convey runoff and manage localized overland flooding. Drainage gradient will be positive towards the outfall. A large portion of the pipes will continue to be below tide levels under both existing and future conditions.
    c) Install tidal gates at 18 outfalls in the drainage.
    d) Wet wells and pump stations (with 100 cfs peak pumping capacity) will be required in the east and west low elevation networks (i.e., parking lots north of Luce Hall and south of Rickover Hall). The subsurface storage system sizes for each wet well will be contingent on previous studies.

Recommended Execution Timeframe: Short-term. 2023-2027. These proposed repairs and improvements should be performed after the Lejeune Drainage Basin has been completed.
Figure 29. Creation of Ingram Field Drainage Stormwater System into Subnetwork as a Component of Integrated Adaptation Framework.
3.3 Brownson Road Drainage Basin Stormwater Improvements for Flood Risk Mitigation

**Current Mission:**
Stormwater management and its resilience is an integral component of the NSAA integrated adaptation framework. Composing approximately 820,000 sq ft, the Brownson Road Drainage Basin contains several mission-essential facilities (See Figure 30). Consequently, the stormwater infrastructure within the basin ability must be able function through a wide range of climate conditions if base operations are to be maintained. These proposed improvements will improve the resilience of the stormwater system by reducing flooding risk, minimize long term operational costs, and provide a better opportunity for that system to adapt to future climate changes.

**Requirement:**
The proposed repairs and improvements are built on the educated assumption that there is current and imminent adverse impacts from coastal and precipitation-based overland flooding that will have a profound impact on installation operations and mission. Any improvements to the stormwater infrastructure are expected to address present-day and provide a foundation to meet the installation’s 2100 planning vision.

To meet these challenges, the proposed improvements to the stormwater network within the Brownson Road Drainage Basin are viewed as a component of broader integrated adaptation framework. This framework presents a holistic method for addressing flood risks across the installation and consists of four complementary layers of flood protection. Each layer presents a specific approach to flood risk management—working through the lenses of natural engineered defenses, adapted structures, natural mitigations, and prepared communities. These layers are designed to support each other, integrating structural and non-structural measures to ensure comprehensive flood protection across a range of environmental conditions.

The stormwater improvement recommendations presented have been built on several underlining assumptions. Specifically, proposed pipe improvements and upgrades (e.g., trunk lines) will occur in the same locations as existing network components and an associated planned pump station will be in areas that are currently open land. Thereby, reducing any potential utility conflicts.

**Current Situation:**
The majority stormwater infrastructure in the Brownson Road Drainage Basin is old and antiquated. There are inadequate inlet capacities within the drainage that cause inefficient collection pathways for stormwater runoff. This is further complicated by undersized pipes and/or varying pipe sizes on the same line is causing inadequate conveyance pathways resulting in localized overland flooding in parking lots.
Annapolis / U.S. Naval Academy
Military Installation Resilience Plan with 3D Visual Environment Pilot

(within the Bancroft Hall wings) and along Brownson Road. Localized ponding is also caused by and amplified due to surcharge of structures, negative slopes in pipe, and uneven grades around facilities (i.e., most likely associated with subsidence). High peak tidal condition impedes gravity drainage into other drainages that support the Brownson Road Drainage Basin. Unfortunately, these deficiencies are allowing flood waters to adversely impact installation transportation, emergency services, housing, and athletic facilities.

Impact if not provided:
Recent vulnerability assessments of current and projected flooding from sea level rise, storm surge, and precipitation indicate that any delays in implementing these stormwater repairs and improvements will have an adverse impact installation operations. Further, these assessments would indicate that the increases in the frequency and intensity of flooding within this drainage will result in significant damage to mission essential assets and infrastructure if not addressed.

Objective:
The proposed stormwater management improvements within the Brownson Road Drainage Basin will reduce flood risk and improve stormwater conveyance by:
- Reducing the amount of nuisance flooding and damage;
- Providing a foundation for other adaptation alternatives by providing relief from recurring flooding; increasing storage volumes and detention times within the system to reduce peak flows during all storm events; and
- Increasing water quality and protect natural resources in surrounding Bay waters.

General Comments:
A phased approach to this proposed design build will address gaps and needs before committing to 95% design: The proposed phases of the MILCON project would include:
1) Identify and predict changing groundwater elevations over the planning horizon (influence of precipitation and tides).
2) Determine if existing stormwater system is working efficiently and is not in disrepair.
   a) Assessment should focus on negative slopes and how tide cycles impede gravity drainage.
   b) CCTV and diver investigations of the existing stormwater system is inclusive. Recommend deployment an integrated, turnkey solution like Stormsensor (https://www.stormsensor.io/) to assess function and monitor changes concurrently with groundwater monitoring wells.
3) Build on existing digital elevation models to evaluate overland flooding and how alterations to slope and grade.
   a) Efforts should be made to direct overland runoff away from critical infrastructure to areas that can retain water.
   b) New retention areas should be planted with native trees that can reduce soil erosion and increase soil absorption capacity.
4) Phases 1-3 should be performed while preliminary designs to the drainage stormwater system is being developed.
Figure 31. Repair and Improvement of the Brownson Road Drainage Basin Stormwater System into Subnetwork as a Component of Integrated Adaptation Framework.
5) Final designs for Improvement of stormwater system infrastructure (See Figure 31).
   a) Design should consider splitting existing drainage network into three subnetworks to address pipe capacity constraints and leverage gravity drainage toward main outfall. This would divide the current drainage into high and low elevation networks with the low elevation networks located east and west segments.
   b) This will consist of larger diameter pipes (trunk lines) necessary to convey runoff and manage localized overland flooding. Drainage gradient will be positive towards the outfall. A large portion of the pipes will continue to be below tide levels under both existing and future conditions.
   c) Install tidal gates at 6 outfalls in the drainage.
   d) Wet wells and a single pump station (with 100 cfs peak pumping capacity) will be required in the lower basin (i.e., along Brownson Road). The subsurface storage system sizes for each wet well will be contingent on previous studies.

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**Recommended Execution Timeframe:** Medium-term. 2027-2037. Proposed Brownson Road drainage basin repairs and improvements should be initiated after the Ingram Field drainage basin.

3.4 **Alumni Hall Drainage Basin Stormwater Improvements for Flood Risk Mitigation**

**Current Mission:**
The Alumni Hall Drainage Basin is approximately 893,000 sq ft and support the National Historic Landmark that is located on the NSAA Lower Yard (See Figure 32). The stormwater infrastructure contained within this drainage basin continues to support a wide range of climate conditions while ensuring that base operations are continued to be maintained.

**Requirement:**
The repairs and improvements will reduce flooding risk, minimize long term operational costs, and provide a better opportunity for that system to adapt to future climate changes. These recommendations are built on the educated assumption that current climate projections indicate that the frequency and intensity of coastal and precipitation-based overland flooding will increase. For this drainage, preliminary results from surface-water modeling indicates that surface flow will continue be influenced by slope and grade (i.e., surface flow from original bluffs to reclamation sites). Repairs and improvements to the existing stormwater infrastructure within the Alumni Hall Drainage Basin are expected to address these surface flows and ensure that present-day stormwater requirements and provide a foundation for the installation to meet its 2100 planning vision.
To meet these challenges, the proposed repairs improvements to the stormwater network within the Alumni Hall Drainage Basin are viewed as a component of broader integrated adaptation framework. This framework presents a holistic method for addressing flood risks across the installation and consists of four complementary flood protection layers. Each layer presents a specific approach to flood risk management—working through the lenses of natural engineered defenses, adapted structures, natural mitigations, and prepared communities. These layers are designed to support each other, integrating structural and non-structural measures to ensure comprehensive flood protection across a range of environmental conditions.

The stormwater improvement recommendations presented in this document have been built on several underlining assumptions. Specifically, repairs and improvements of infrastructure will enhance protection of the underground utility tunnels, proposed pipe improvements and upgrades will occur in the same locations as existing network components and associated planned pump stations will be in areas that are currently open land. Consequently, no utility conflicts have been identified based on current layout.

Current Situation:
The stormwater infrastructure in the Alumni Hall Drainage Basin is some of the oldest on the installation. Most of this infrastructure is extremely old and antiquated with some of it still in terracotta. While all the drainages on the Lower Yard are inadequate, the age of the stormwater infrastructure has generated some unique problems. Inlet capacities within the drainage that cause inefficient collection pathways for stormwater runoff, several of roads in the drainage have been present since the 18th century and are acting as runoff conduits (e.g., Maryland Ave.), and undersized pipes and/or varying pipe sizes on the same line is causing inadequate conveyance pathways resulting in localized overland flooding. Surface flows from precipitation events continue to be directed to mission critical infrastructure (e.g., Nimitz Library and academic halls). Localized ponding is also caused by and amplified due to surcharge of structures, negative slopes in pipe, and tidal mean high water covering existing outfalls. High peak tidal condition impedes gravity drainage into receiving waters and some locations allow tidal waters to enter the drainage basin by way of the stormwater system. Unfortunately, these deficiencies are allowing flood waters to adversely impact installation transportation, academic halls, and emergency services.

Figure 32. Alumni Hall Drainage Basin on NSA Annapolis.
Impact if not provided:
Vulnerability assessments of current and future flooding from sea level rise, storm surge, and precipitation will continue to adversely impact installation. Specifically, these assessments would indicate that the Alumni Hall Drainage Basin will observe an increase in the frequency and the severity of flooding if repairs and improvements are not made. These impacts will have a profound impact on installation operations and damage mission essential assets and infrastructure if not addressed.

Objective:
The proposed repairs and improvements to the stormwater management system withing Alumni Hall Drainage Basin will reduce flood risk and improve stormwater conveyance by:

- Reducing the amount of nuisance flooding and damage;
- Enhancing protection of underground utility tunnels by directing surface flows and tidal flooding away from tunnel entrances;
- Providing a foundation for other adaptation alternatives by providing relief from recurring flooding; increasing storage volumes and detention times within the system to reduce peak flows during all storm events; and
- Increasing water quality and protect natural resources in surrounding water bodies.

General Comments:
A phased approach to this proposed design build will address gaps and needs before committing to 95% design: The proposed phases of the MILCON project would include:

1) Identify and predict changing groundwater elevations over the planning horizon (influence of precipitation and tides).
   a) Maintain existing six groundwater monitoring wells in and adjacent to this drainage basin

2) Determine if existing stormwater system is working efficiently and is not in disrepair.
   a) Assessment should focus on negative slopes and how tide cycles impede gravity drainage.
   b) CCTV and diver investigations of the existing stormwater system is inclusive. Recommend deployment an integrated, turnkey solution like Stormsensor (https://www.stormsensor.io/) to assess function and monitor changes concurrently with groundwater monitoring wells.

3) Build on existing digital elevation models to evaluate overland flooding and how alterations to slope and grade.
   a) Efforts should be made to direct overland runoff away from critical infrastructure to areas that can retain water.
   b) This should include termination of Maryland Ave at the intersection of Decatur Road. The segment of road and associated parking lot in front of Mahan, Sampson, and Maury Halls. This would prevent rainwater runoff from pooling near Rickover Terrace.
c) New retention areas should be planted with native trees that can reduce soil erosion and increase soil absorption capacity.

d) Every effort should be made to leverage green infrastructure in the watershed to inhibit the movement of or redirect surface flows from precipitation. More than any other watershed, the slopes, and grades of the watershed direct surface water to critical infrastructure. Green infrastructure can be cost effective adaptation measure for this part of the Lower Yard (See Appendix D).

4) Phases 1-3 should be performed while preliminary designs to the drainage stormwater system is being developed.

5) Final designs for Improvement of stormwater system infrastructure (See Figure 34).
   a) Design should consider splitting existing drainage network into three subnetworks to address pipe capacity constraints and leverage gravity drainage toward main outfall. This would divide the current drainage into high and low elevation networks with the low elevation networks located east and west segments.
   b) This will consist of larger diameter pipes (trunk lines) necessary to convey runoff and manage localized overland flooding. Drainage gradient will be positive towards the outfall. A large portion of the pipes will continue to be below tide levels under both existing and future conditions.
   c) Install tidal gates at 7 outfalls in the drainage.
   d) Wet wells and pump stations (with 100 cfs peak pumping capacity) will be required in the upper and lower drainages networks (i.e., between Nimitz Library and Alumni Hall and near the parking garage). The subsurface storage system sizes for each wet well be contingent on previous studies.

Recommended Execution Timeframe: Medium-term. 2027-2037.
Figure 34. Repair and Improvement of the Alumni Hall Drainage Basin Stormwater System into Subnetwork as a Component of Integrated Adaptation Framework.
4.0 Santee Basin Resilience Efforts

Current Mission:
The NSAA/USNA Santee Basin and its associated assets play a unique and integral role in the professional development of Midshipmen at USNA. First and foremost, Santee is the primary resource for creating competent leaders and seaman of midshipmen while developing endurance, self-reliance, and the will to win in an environment like that in which they will serve. This small vessel harbor is the home the USNA sailing program, the largest athletic program at USNA. Every Midshipmen will be afforded the opportunity to participate in sailing activities during their four years at USNA.

To meet this sole mission, Santee Basin houses several state-of-the-art vessels, facilities (e.g., Robert Crown Center, Cutter Shed), and berthing arrangements to support this large and dynamic program. Currently, the Santee Wharf (Facility 225, constructed in 1914) provides 650 feet of berthing and Reina Mercedes Wharf (Facility 226, constructed in 1911) provides 242 feet of berthing. Additionally, another 2,400 feet of berthing for small craft is provided at 13 finger piers within the basin, which were constructed from the 1950s through the 1980s.

Additionally, the basin is home to the Hendrix Oceanography Laboratory. The primary purpose of laboratory is to further the education of midshipmen through hands-on access to oceanographic and meteorologic equipment and the Severn River. The Hendrix Lab supports instructional labs as well as midshipman and faculty research for the Oceanography Department and other academic departments.

The Hendrix Lab consists of 4 laboratory spaces: a basic teaching lab, a microscopy lab, an AUV lab, and a swing space primarily used for maintenance and calibration of instruments, but also available for teaching labs. The Hendrix Lab also provides access to our specially outfitted Yard Patrol Craft, YP 686 and houses the Annapolis Tide Gauge.

Requirements:
An integral component of the NSAA/USNA the mission, Santee Basin and its associated assets need to continue to meet education and athletic requirements to the 2100 planning vision. The USNA Strategic Plan 2020 (USNA, 2015) requests NSAA’s support and commitment to provide athletic facilities consistent with need to offer a dynamic and challenging physical preparation program and compete in intercollegiate athletics in keeping with the Naval Service traditions of teamwork, persistence, and victory.

Unlike any other facility on the Lower Yard, Santee Basin is directly tied to water resources that threaten the installation. Although, this proximity to the Severn River provides the installation immeasurable benefits, but they also come with a cost. Coastal flooding (e.g., nuisance and storm surge), sea level rise, groundwater inundation, land subsidence, and surface water flooding from extreme weather events have and will continue to bring water in the basin and closer to mission-essential facilities and infrastructure.

NSAA/USNA is already experiencing coastal flooding and it will continue to intensify. Since 1929, relative sea level in Annapolis has risen approximately 1.06 feet, which has significantly increased the occurrences of nuisance flooding from 2-3 times per year to 30-40 times per year. These frequent flooding events are bringing flood waters into Santee Basin and the basin is unable to contain these events. Regrettfully, flood waters from Santee Basin are impacting installation operations (e.g., transportation, emergency management services) and critical infrastructure (e.g., stormwater management system). If current DRSL scenarios for NSAA/USNA are correct and an increase of 2.6 feet in relative sea level rise by 2065 and 4.4 feet by 2100 is anticipated, then these nuisance events will naturally evolve into major flooding events and Santee Basin will be a conduit for flood waters to threaten NSAA/USNA’s ability to maintain mission.
Current Situation:
Santee Basin continues to provide a productive and nurturing environment for education and athletic requirements. Its proximity and accessibility to Bancroft Hall, academic halls, and other athletic facilities cannot be undervalued. Supporting the largest athletic program at USNA, this convenient location improves academic operations. Unfortunately, all these conveniences and efficiencies come with a cost. The Santee Basin is allowing flood waters to impact more mission-critical infrastructure and assets than any other location on the Lower Yard. Recent flood events (i.e., September and October 2021) documented floodwater overtopping the existing waterfront infrastructure and dispersing along Brownson and Holloway Roads. These flood waters entered stormwater infrastructure and spread overland toward multiple assets and facilities. If current projections are correct, the frequency and intensity of these events will continue to increase.

Additionally, The Waterfront Facilities Inspections and Assessments at United States Naval Academy Annapolis, Maryland report (NAVFAC, 2017b), provided an assessment of the general physical condition of facilities, operational restrictions, and recommendations. The Santee bulkhead is 5.5 feet wide and serves as a mooring and docking location for various sailing vessels at the USNA. Consists of steel sheet piling with a concrete cap, except for the southern side, which consists of a concrete cap on timber piles with riprap protection to the channel bottom. Assessed as being in poor condition. At the time of the inspection, the report found the bulkhead exhibited increased deterioration of the steel sheet piles with corrosion holes developing below the concrete pile caps. The east side of the Santee Basin Bulkhead is currently being used as a staging area for the construction activities ongoing within the Santee Basin. There are no immediate requirements to remove the currently staged materials and equipment located in this area. It is recommended that long-term staging be phased out until repairs and improvements can be made. Improvements should consider that wave action is occasionally overtopping the hardened structures and undercutting occurring in several areas, resulting in flooding and failure of the road and parking areas in several locations behind the seawall, particularly during extreme high tides

The report also documented that several of the floats within the Santee Basin are currently under contract for repairs to reinstall the guide pile assemblies, reattach the composite fenders, and replace the carpets. While the deficient guide pile assemblies are currently scheduled for replacement at two of the seven floats within the Santee Basin, four additional floats are not scheduled for pile guide assembly replacement and thus still require repair. Damage to the floats has been noted in previous reports because of the missing and/or broken wave screens located on the Reina Mercedes and Santee Wharfs, resulting in increased wave action within the basin that damaged the floats and guide pile assemblies. The float conditions have not changed since the wave screens were replaced since the previous inspection. The gangway leading down to Float A, located along the east wall of the Santee Basin, is missing several anchor bolts securing the gangway to the concrete pile cap. The gangway could become disconnected and unsafe for use. It is recommended that the missing anchor bolts be replaced within the next three months to secure the gangway to the bulkhead.
Finally, the report found the overall deterioration at the Santee Wharf and Reina Mercedes Wharf are becoming excessive and is at a point where rehabilitation would be impractical and cost prohibitive. It is recommended that serious consideration be given to the replacement of both piers. Until the piers can be replaced, the Santee Wharf should be restricted to pedestrian and small vehicle loading only. The battered piles located along the finger pier at the outboard end of the Reina Mercedes Wharf are loose and no longer supply sufficient lateral support to the finger pier. The superstructure of the wave break finger pier exhibited excessive movement when subjected to wave action. It is recommended that access to this finger pier be prohibited.

**Impacts if not Provided:**
If the proposed actions and improvements are not implemented, the frequency and intensity of flooding through the Santee Basin to mission-essential infrastructure will continue, and sections of the existing seawalls and wharfs will continue to deteriorate over time and then fail. Both impacts will influence the resilience of installations assets and facilities, but more importantly, it will detrimentally impact on the academics and athletic programs of USNA.

**Objectives:**
NSAA/USNA proposes to repair, restore, relocate, and improve the assets and infrastructure that are within or adjacent to the Santee Basin with intention of making it more resilient to current and projected flooding. The proposed actions would address structural deficiencies on the existing seawall, wharfs, and associated infrastructure and improve the overall resilience of the basin and associated facilities to the projected impacts of extreme weather events, storm surge, sea level rise, and land subsidence.

**General Comments:**
NSAA/USNA recognizes that the Santee Basin gets flooded and is a conduit for river inundation. In addition, the NSAA/USNA has considered the need to live with some level of water inundation from flooding, and a multi-level, integrated adaptation framework is preferred as there is not a single solution that can address the threats this basin is projected to endure. This includes:

- **NSAA/USNA recommended approach is to oversheet the existing bulkhead/relieving platform and raise the bulkhead cap to between EL. 5.5’ – 6.5’ NAVD88. For the northwest portion of the bulkhead along Dewey Field and the southeast portion of the bulkhead along Brownson Road, a berm will be installed beyond the existing deadman system atop to an elevation of 9.7’ NAVD88. For the portion of the bulkhead along Santee Road, the road itself will be raised by 2 feet, and in interior flood wall will be installed at an elevation of 11.5’ NAVD88 adjacent to the Field House. A flood gate will be installed in the flood wall at Cooper Road. These measures provide additional area for water dissipation and provide a secondary crest that would need to be breached during a flood;**
- **Per the 2017 inspection report, the Santee Wharf and Reina Mercedes Wharf at the entrance to the Santee Basin are in poor and unsatisfactory condition, respectively. These structures should be reconstructed and raised to meet the new curb elevation of the adjacent bulkheads. Since wind-driven wave are not entering the basin from this area, there may be little value in adding a wave attenuator to these structures. The Robert Crown Sailing Center, Cutter Shed and Hendrix Oceanography Laboratory buildings located on the existing wharfs structures will be demolished, relocated, and be incorporated into the earthen berm network on either side of Santee Basin; and**
- **Between the hardened secondary protection of the field house flood wall and upland berms, temporary deployable barriers can be utilized when a potential flood event is forecasted to occur.**
See Figure 36 for a rendering of the described adaptation strategy. Permanent cut-off walls (magenta), upland berms (orange), raise Santee Road (purple), flood wall/gate along field house (green), reconstruct/raise wharves (cyan), relocate buildings (black) and install deployable barriers in preparation for a flood event (red).

![Figure 36. NSA Annapolis Proposed Suite of Adaptation Alternatives at Santee Basin.](image)

To accomplish these goals, a phased approach is recommended, as follows:

- Phased maintenance and repairs to bulkheads and piers to allow future adaptation alternatives to occur;
- Demolition of Hendrix Oceanography Laboratory, Robert Crown Sailing Center, and Cutter Shed;
- Demolition and reconstruction of Santee Wharf and Reina Wharf;
- Construction of new combined Sailing Center with Cutter Shed south of Santee Basin and incorporated in the earthen berm;
- Repair and improvements to Santee Basin bulkhead. This includes creation of flood wall and gates;
- Construction of new Hendrix Oceanography Laboratory; and
- Construction of new floating piers.
**Recommended Execution Timeframe:** Long-term. 2037-2057. As described, this adaptation alternative will need to be performed in several phases. Most of these phases will need to be performed concurrently to minimize adverse impacts to the USNA sailing program. Many of the phases will need to be performed between 2047-2057.

### 5.0 Repair and Raise Height of Bulkheads/Seawalls/Riprap

#### 5.1 Waterfront Infrastructure

**Current Mission:**
NSAA/USNA’s existing 19,334 linear feet of waterfront infrastructure is critical to the operations and protection of Navy property, assets, and mission-essential elements of the USNA academic programs. As a naval academy, the Severn River and Chesapeake Bay play an integral role in the mission and strategic growth of NSAA/USNA. Consequently, NSAA/USNA has planned repairs and restoration actions that would address structural deficiencies on the existing Lower Yard infrastructure (e.g., seawalls, bulkheads) and potential impacts from future extreme weather events, storm surge, sea level rise, and nuisance flooding from sustained, directional winds from the east and southeast. These proposed improvements will sustain the utility of the waterfront infrastructure for the foreseeable future.

**Requirement:**
The Lower Yard waterfront infrastructure integrally tied to the mission and strategic plans of NSAA/USNA. To ensure that this relationship is sustained NSAA/USNA will need invest in repairs and improvements that will addresses identified weaknesses and make it more resilient to projected climate-influenced changes.

Climate change, sea level rise, changing weather patterns and continued subsidence have and will continue to contribute to an increase in the number and magnitude of coastal flooding events in the near- and long-term future of the Annapolis region. These conditions will adversely impact land and infrastructure and pose significant challenges to the successful execution of the NSAA/USNA mission. Protective measures at the Lower Yard and other planning areas will be necessary to reduce damage from these events and facilitate effective mission execution.

Given the imminent threat of coastal flooding, as well as the frequency and intensity of storm events, there is increased probability of permanent inundation of some land areas over time. Consequently, every effort must be made to improve the existing NSAA waterfront infrastructure to address present-day and likely 2035, 2065 and 2100 impacts to protect mission essential assets and infrastructure. As integral component of the NSAA/USNA integrated adaptation framework, the repair and improvement of the existing waterfront is the first line of define and ensures that the installation can meet its 2100 planning vision.

**Current Situation:**
The Waterfront Facilities Inspections and Assessments at United States Naval Academy Annapolis, Maryland report (NAVFAC, 2017b), provided an assessment of the general physical condition of facilities, operational restrictions, and recommendations. At the time of the inspection, Farragut Field exhibited increased deterioration of the steel sheet piles with corrosion holes developing below the concrete pile caps. In these areas, backfill was seen escaping through the corrosion holes, with sinkholes developing behind the bulkheads. As a result, operational restrictions, and repairs for conditions for Farragut Field
bulkhead were advised. It was recommended that heavy vehicles (those with a gross vehicle weight rating exceeding 10,000 pounds) be prohibited within 15 feet of the bulkheads. In addition, it was recommended that mooring and berthing along the Farragut Field bulkhead should be restricted to mild weather conditions (which includes sustained winds of less than 35 knots and currents less than 1 knot).

Table 13 shows the engineering assessment rating, with a corresponding Engineering Management System Condition Index rating, that is given to waterfront facilities based on their condition. Facilities are given a condition index rating number that corresponds to an assessment rating and description, as shown in the table.

Table 13. Engineering Assessment Rating for Waterfront Facilities.

<table>
<thead>
<tr>
<th>Assessment Rating</th>
<th>Equivalent Condition Index Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>84–100</td>
<td>No problems or only minor problems noted. Structural elements may show some very minor deterioration, but no significant reduction in structural capacity.</td>
</tr>
<tr>
<td>Satisfactory</td>
<td>67–83</td>
<td>Minor-to-moderate defects and deterioration observed, but no significant reduction in structural capacity.</td>
</tr>
<tr>
<td>Fair</td>
<td>54–66</td>
<td>All primary structural elements are sound, but minor-to-moderate defects and deterioration observed. Localized areas of moderate-to-advanced deterioration may be present but do not significantly reduce the structural capacity.</td>
</tr>
<tr>
<td>Poor</td>
<td>37–53</td>
<td>Advanced deterioration or overstressing observed on widespread portions of the structure. Some reduction in structural capacity.</td>
</tr>
<tr>
<td>Serious</td>
<td>26–36</td>
<td>Advanced deterioration, overstressing, or breakage may have significantly affected the load-bearing capacity of primary structural components. Local failures are possible.</td>
</tr>
<tr>
<td>Critical</td>
<td>0–25</td>
<td>Very advanced deterioration, overstressing, or breakage has resulted in localized failure(s) of primary structural components. More widespread failures are possible or likely to occur.</td>
</tr>
</tbody>
</table>

Table 14 shows the assessment rating that was given to the 15 sections or reaches within the project area (NAVFAC, 2019a). Only three reaches were given the rating of good or satisfactory. Six reaches were considered fair, three were considered poor, and three were deemed serious. Those reaches considered poor or serious total 9,174 linear feet, or 47% of the assessed shoreline. Please note that two Lower Yard reaches (i.e., Turner Joy Road Revetment and Santee Basin) are not presented in this table. These reaches have been discussed in previous projects and have not been addressed in summation to remove redundancies.
Table 14. Seawall and Bulkhead Assessment Ratings and Length.

<table>
<thead>
<tr>
<th>Reach No.</th>
<th>Reach Name</th>
<th>Assessment Rating</th>
<th>Seawall Length (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>College Creek Bulkhead</td>
<td>71/Satisfactory</td>
<td>835</td>
</tr>
<tr>
<td>5</td>
<td>Rodgers Road Bulkhead</td>
<td>60/Fair</td>
<td>780</td>
</tr>
<tr>
<td>6</td>
<td>McNair Road/Nimitz Library Bulkheads</td>
<td>90/Good</td>
<td>980</td>
</tr>
<tr>
<td>7</td>
<td>Dewey Field Bulkhead</td>
<td>60/Fair</td>
<td>2,405</td>
</tr>
<tr>
<td>9</td>
<td>Farragut Field Bulkhead</td>
<td>NA/Poor</td>
<td>1,370</td>
</tr>
<tr>
<td>11</td>
<td>Halsey Fieldhouse Quaywall</td>
<td>60/Fair</td>
<td>510</td>
</tr>
<tr>
<td>12</td>
<td>Halsey Fieldhouse Quaywall 2</td>
<td>60/Fair</td>
<td>460</td>
</tr>
</tbody>
</table>

Impacts if not Provided:

If the proposed seawall and bulkhead repairs and improvements along the Lower Yard where not implemented, sections of the existing seawalls and shoreline will continue to deteriorate over time and then fail. The failure would result in continued flooding issues and undermine the reclamation land fill that supports mission-critical infrastructure (i.e., roads, athletic facilities, buildings, etc.) behind the seawall. With potential continued storm surge, sea level rise, and land subsidence, these conditions would worsen over time and result in increased frequency flooding and failure events.

Given the elevation of the installation, which ranges from sea level to 80 feet above mean sea level (NAVFAC Washington, 2011), and its location adjacent to the Chesapeake Bay, NSA Annapolis is vulnerable to localized flooding and storm surge associated with major weather events and higher water levels, particularly during high tides. Climate change would exacerbate these conditions (NAVFAC Washington, 2018a).

Storm surge occurs when there is temporary flooding and water inundation along coastlines during storm events such as tropical depressions or hurricanes. The most recent hurricane that caused major flooding damage due to storm surge at NSA Annapolis was Hurricane Isabel in 2003. This hurricane caused an immense amount of water and storm damage at the USNA, with inundation in numerous buildings. High water events like what occurred during Hurricane Isabel are expected to become more frequent, and the amount of inundation can increase over time (NAVFAC Washington, 2018a).

The Chesapeake Bay region is considered one of the nation’s most vulnerable areas to sea level rise, as data has shown that sea level rise is occurring at the highest rate on the Atlantic Coast. There are two reasons for this: the ground in the region is sinking due to natural land subsidence, and ocean levels are rising (USGS, 2013). In 2018, a record number of 41 flood events occurred at NSA Annapolis. Flooding events have increased over the past 20 years, and there is the potential for increased frequency in the future due to sea level rise. The projected increase in sea level rise varies from low to extreme scenarios. In Annapolis, this increase ranges from 1.64 feet for the low scenario to 11.15 feet for the extreme scenario in 2100 (USACE, 2017).

In addition to the factors that have already been discussed, the Proposed Action is needed to maintain the safety and function of mission-critical areas at the installation. The mission at NSA Annapolis includes seamanship and sail training; small arms weapons familiarization; and navigation and engineering professional development. Increased frequency or severity of flood events could result in loss of land or damaged facilities in these mission-critical areas and could prevent NSAA/USNA from accomplishing their missions.
Objectives:
NSAA/USNA proposes to repair and restore seawalls and bulkhead along the Lower Yard perimeter (i.e., shores of the Severn River, College Creek, and Spa Creek). The repairs, restoration, and improvements would address structural deficiencies on the existing seawall and potential impacts from future extreme weather events, storm surge, sea level rise, and land subsidence. Repairs and restoration would occur along approximately 19,334 linear feet of shoreline that is divided into 15 “reaches.”

Specific restoration and enhancement techniques could include hardened structures and log toe stabilization, where appropriate. Hardened structures include bulkhead, sheet pile seawall, riprap, or a combination of these techniques. To date, the Farragut Field Bulkhead (Reach 9) has undergone preliminary design. Construction along Farragut Field Bulkhead may be completed in phases, dependent on funding allocations, would likely begin within the next few years, and could last approximately three and a half years. Subsequent reaches would be prioritized for repair—as funding becomes available—based on condition, elevation, and mission criticality. It is assumed that construction would occur over 10 to 20 years for all 15 reaches completed by 2045.

General Comments:
The strategies summarized are based on quantitative review of risk likelihood associated with various storm intensities, generally characterized by recurrence interval, or return period, measured in years. NSAA/USNA has been in use for upwards of 170 years which factors heavily in assessing the likelihood of flood risk associated with storms. For infrastructure in use, and planned to be in use, for these durations, the likelihood of damaging events associated with flooding increases substantially. The table below provides a summary of probabilities (expressed as percentages) for each flood event defined by return period as related to facility service life, defined as 100 years, consistent with planned usage.

<table>
<thead>
<tr>
<th>Service Life (Years)</th>
<th>100</th>
<th>25</th>
<th>50</th>
<th>100</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Return Period (Years)</td>
<td>100.00%</td>
<td>99.99%</td>
<td>98%</td>
<td>87%</td>
<td>63%</td>
</tr>
</tbody>
</table>

Considering repairs and improvements to the waterfront infrastructure compose over 30% of the integrated adaptation frameworks total cost, few adaptation alternatives received as much study or investigation. Fundamentally, NSAA/USNA reviewed several strategies in response to what the table above indicates as an almost certain, potentially damaging flood event in any given year. These strategies include:
- Do Nothing: also termed ‘judicious neglect,’ this approach involves no modifications to current practices or infrastructure. Motivators to adopt a do-nothing approach include future changes that obviate the need for a particular facility or a lack of budget, manpower, or organizational resolve to implement flood risk reduction measures. This approach does nothing to minimize future risk; however, one advantage is that it enables resources that would be devoted to this cause to be deployed elsewhere. Considering the mission of NASA/USNA, coupled with planned usage into the future, it is not recommended to adopt a do-nothing response to flood risk;
- Relocation/Retreat: As the name implies, relocation involves moving critical operations and infrastructure to a location where flood risk is lower. This approach is more frequently employed where space is not at a premium or where flood risk mitigation would be prohibitively more expensive than relocation of operations and abandonment of infrastructure. Practically,
NSAA/USNA is regularly challenged with space planning requirements and the very nature of the Academy's curriculum requires waterfront locations;

- **Elevation** – typically this method of mitigation involves raising a structure in its entirety to place the finished floor elevation/critical infrastructure above the design flood elevation. At the NSAA/USNA, this can involve raising critical facilities, raising marginal (perimeter) facilities, or a combination of both. Long term, on a horizon of 50+ years, the integrated adaptation has recommended elevating critical facilities as an option to minimize flood risk; and

- **Floodproofing** – there are generally two types of floodproofing: wet and dry. Wet floodproofing involves the installation of permanent or temporary measures to reduce flood-related damage by allowing floodwater to enter the structure. Dry floodproofing similarly involves the installation of permanent or temporary measures to reduce flood-related damage by preventing floodwater from entering the structure. The benefits of these approaches, particularly in cases of unoccupied structures, is that installation of flood protection measures can be completed with less disruption and at a lower cost than relocation or elevation. However, in the long term, on a horizon of 50+ years, floodproofing measures at the waterfront facilities alone are unlikely to provide flood protection for NSAA/USNA in consideration of forecast sea level change.

NSAA/USNA recommends floodproofing that involves extensions to the existing curb/wall face to an elevation that limits the impacts of sea level rise and the amount of floodwater inundation. While this approach limits floodwater inundation, localized flooding remains possible due to wave action and partial overtopping during storm events. Thus, NSAA/USNA has chosen to leverage its integrated adaptation framework to create layers of protection and remove the likelihood of single points of failure. This framework includes earthen berms, floodproofing athletic fields, and elevation of interior roads. The combination of dry floodproofing for critical facilities, flood walls, and stormwater improvements provides a balanced mitigation approach that is not overly disruptive as compared with the other mitigation alternatives identified above.

The repair/mitigation recommendations provided herein are broken out by area and prioritized by flood risk potential considering the 2100 MHHW inundation scenario. Recommended repairs are hardened structures consisting of riprap berms or steel sheet pile bulkheads. For either of these repair types, NSAA/USNA recommends repairs and improvements to the existing stormwater system, as well as further geotechnical investigation to determine which is more of the root cause of tidal infiltration.

The service life of these recommended repairs and improvements to the waterfront infrastructure is 75 – 100 years with proper maintenance and inspection program (See Table 15). In addition, NSAA/USNA recommends that all future repairs of this infrastructure include a suite of adaptations that will improve the service life of these structures. These adaptations include wave attenuation features in front of waterfront infrastructure that will incur significant wave energy, sacrificial anodes for corrosion protection of steel below water and concrete fascia for corrosion protection of steel above water. For the concrete, a durable mix design is recommended with sufficient cover to reinforcing steel. Uncoated black bar is recommended in lieu of epoxy coated bar to eliminate any holes in the epoxy that could potentially create hot spots for corrosion, leading to premature spalling of concrete.
<table>
<thead>
<tr>
<th>Facility Name</th>
<th>Description and Existing Condition</th>
<th>Recommended Repair</th>
</tr>
</thead>
<tbody>
<tr>
<td>Halsey Fieldhouse</td>
<td>Timber relieving platform consisting of timber sheet pile bulkhead, concrete cap, and timber piles</td>
<td>Oversheet with a cantilevered or anchored steel sheet pile bulkhead with a concrete cap installed to elevation between EL 5.5' and 6.5' NAVD88. Install</td>
</tr>
<tr>
<td>Quaywall 2</td>
<td>Fair condition.</td>
<td>sacrificial anodes for corrosion protection below water and a concrete fascia for corrosion protection above water. Install either an upland berm or a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>flood wall at an elevation of 11.5' NAVD88 as a secondary flood protection measure for the upland facilities. It is unknown of raising/re-grad</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ing the roadway is required in this area.</td>
</tr>
<tr>
<td>Halsey Fieldhouse</td>
<td>Steel sheet pile bulkhead, concrete cap, and curb – Fair condition.</td>
<td>Oversheet with a cantilevered or anchored steel sheet pile bulkhead with a concrete cap installed to elevation between EL 5.5’ and 6.5’ NAVD88. Install</td>
</tr>
<tr>
<td>Quaywall</td>
<td></td>
<td>sacrificial anodes for corrosion protection below water and a concrete fascia for corrosion protection above water. Install either an upland berm or</td>
</tr>
<tr>
<td></td>
<td></td>
<td>a flood wall at an elevation of 11.5’ NAVD88 as a secondary flood protection measure for the upland facilities. It is unknown of raising/re-grad</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ing the roadway is required in this area.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>If the condition of the existing structure is sufficient, extend concrete cap to elevation between EL 5.5' and 6.5' NAVD88. If not, oversheet with a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>cantilevered steel sheet pile bulkhead (or anchored steel sheet pile bulkhead if the existing tiebacks and deadman can be re-utilized) with a con</td>
</tr>
<tr>
<td></td>
<td></td>
<td>crete cap installed to elevation 9.7’ NAVD88 upland of the existing deadman system as a secondary flood protection measure for the upland facilities.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>It is unknown of raising/re-grading the roadway is required in this area.</td>
</tr>
<tr>
<td>Farragut Field</td>
<td>Steel sheet pile bulkhead with a concrete cap/parapet wall tied back to timber piles – Poor condition</td>
<td></td>
</tr>
<tr>
<td>Bulkhead</td>
<td></td>
<td>As this repair is scheduled for construction next year, it is imperative that additional geotechnical investigation be performed as soon as possible to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>identify any potential issues with the proposed repair design. Geotechnical investigations such as test pits and soil sampling should be conducted to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>determine if the existing soil has sufficient compressive strength and bearing capacity to support the weight of the berm.</td>
</tr>
<tr>
<td>Dewey Field</td>
<td>Steel sheet pile bulkhead tied back to timber piles, concrete cap, and parapet wall – Fair condition</td>
<td></td>
</tr>
<tr>
<td>Bulkhead</td>
<td></td>
<td>If the condition of the existing structure is sufficient, extend concrete cap to elevation between EL 5.5' and 6.5' NAVD88. If not, oversheet with a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>cantilevered steel sheet pile bulkhead (or anchored steel sheet pile bulkhead if the existing tiebacks and deadman can be re-utilized) with a con</td>
</tr>
<tr>
<td></td>
<td></td>
<td>crete cap installed to elevation 9.7’ NAVD88 upland of the existing deadman system as a secondary flood protection measure for the upland facilities.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>It is unknown of raising/re-grading the roadway is required in this area.</td>
</tr>
</tbody>
</table>

As this repair is scheduled for construction next year, it is imperative that additional geotechnical investigation be performed as soon as possible to identify any potential issues with the proposed repair design. Geotechnical investigations such as test pits and soil sampling should be conducted to determine if the existing soil has sufficient compressive strength and bearing capacity to support the weight of the berm.
| Rodgers Road Bulkhead | Steel sheet pile bulkhead offshore of original bulkhead, concrete cap – Fair condition. | If the condition of the existing structure is sufficient, add a concrete parapet to elevation between EL. 5.5’ and 6.5’ NAVD88. If not, oversheet with a cantilevered or anchored steel sheet pile bulkhead with a concrete cap installed to elevation between EL. 5.5’ and 6.5’ NAVD88. Install sacrificial anodes for corrosion protection below water and a concrete fascia for corrosion protection above water. Install a berm at an elevation of 9.7’ NAVD88 upland of the existing deadman system as a secondary flood protection measure for the upland facilities. It is unknown of raising/re-grading the roadway is required in this area. |
| College Creek Bulkhead | Steel sheet pile bulkhead with concrete cap – Satisfactory condition. | If the condition of the existing structure is sufficient, add a concrete parapet to elevation between EL. 5.5’ and 6.5’ NAVD88. If not, oversheet with a cantilevered or anchored steel sheet pile bulkhead with a concrete cap installed to elevation between EL. 5.5’ and 6.5’ NAVD88. Install sacrificial anodes for corrosion protection below water and a concrete fascia for corrosion protection above water. Install either an upland berm or a flood wall at an elevation of 11.5’ NAVD88 as a secondary flood protection measure for the upland facilities. It is unknown of raising/re-grading the roadway is required in this area. |

**Recommended Execution Timeframe:** Short-term. 2023-2027. The repairs and improvements to the Lower Yard infrastructure will be phased. The Farragut Field bulkhead requires immediate attention. The remaining reaches (i.e., Halsey Fieldhouse bulkhead and Turner Joy Revetment) along Spa Creek should occur upon completion of Farragut Field bulkhead). The Dewey Field Bulkhead will be the last segment to be repaired and improved and will need to be timed and sequenced other waterfront infrastructure adaptation alternatives (e.g., YP Pier and bulkhead). Currently, the Dewey Field bulkhead has been identified as a medium-term action (2027-2037).
5.2 Restoration and Enhancement of the Turner Joy Road Stone Revetment

Current Mission:
The three reaches of the Turner Joy Road stone revetment are an integral part of USNA/NSAA waterfront infrastructure. Composing 1,877 ft of the installation’s waterfront, these revetments protect mission critical assets and infrastructure located on the USNA Lower Yard from coastal flooding and erosion.

Requirement:
Climate change, sea level rise, changing weather patterns and continued subsidence have and will continue to contribute to an increase in the number and magnitude of coastal flooding events in the near- and long-term future of the Annapolis region. These conditions will adversely impact land and infrastructure and pose significant challenges to the successful execution of the NSAA/USNA mission. Protective measures at the Lower Yard and other planning areas will be necessary to reduce damage from these events and facilitate effective mission execution.

Given the imminent threat of coastal flooding, as well as the frequency and intensity of storm events has increased the probability of permanent inundation of some land areas over time. Consequently, every effort must be made to improve the existing NSAA waterfront infrastructure to address present-day and likely 2035, 2065 and 2100 impacts to protect mission critical infrastructure, facilities, and ensure the successful execution of mission critical and base support activities at the USNA. As integral component of the NSAA waterfront infrastructure, the Turner Joy Road stone revetment is in need of restoration and enhancement to ensure that it can continue to protect the installation from coastal flooding in the future.

Current Situation:
The Turner Joy Road stone revetment is located between the Farragut Field section and Halsey Field House bulkheads. Located along the western shore of Spa Creek, this shoreline was originally constructed in 1959 with subsequent repairs performed in 2000. The repairs included the placement of four new drains along the roadway, the repair of an existing drainpipe, the placement of stone rip rap along the guardrail, and the replacement of a portion of the timber and steel guardrail that was broken.

Overall, the current stone revetment is approximately 1,877 ft long by 50 ft wide. The revetment consists of large 4 ft to 6 ft sized angular riprap placed over smaller 1 in. to 3 in. diameter stone. The stone revetment is relatively stable, with a consistent configuration. No significant sloughing or settling were observed within any of the slopes. However, sea level rise, intensifying fetch, and the frequency and strength of storms are adversely impacting this shoreline. Many localized areas are seeing pronounced displacement of large armor stones due to the loss of the smaller stones in between and around the larger riprap stones. Consequently, these areas are starting to exhibit minor voids, small depressions, and causing rip rap to shift (e.g., The smaller stone at Station 74+14 washed out to an extent that the outfall...
A pipe was exposed in this area. The top course of larger riprap is missing at Station 78+59, exposing the concrete outfall pipe below.

Additionally, an approximately 0 ft to 4 ft wide area between the large riprap and Turner Joy Road is starting to exhibit some minor erosion of the smaller stones between the roadway and large riprap in several locations, with vertical differentials between the roadway and the stones typically between 6 and 12 in. high and up to a maximum of 18 in. high. The erosion caused Turner Joy Road to become undermined up to 8 in. deep in some locations. The energy that is causing this erosion is also adversely impacting curbs, bull rails, guard posts and railings. The 710 linear ft of asphalt curb this is located adjacent to the guardrail, 278 linear ft total is either missing or displaced.

The galvanized steel posts that make up the timber support guard rails are typically well-founded and exhibited freckled rust throughout; however, approximately 25% of the posts are exhibiting major corrosion at the bottom of the post with "knifing" of the bottom 6 in. of the flanges, resulting in approximately 20% section loss. The horizontal timber rails exhibit minor to moderate weathering and minor checks, splits, and shakes. There are locations where, the connection bolts and nuts for the timber rail exhibited moderate to major corrosion and five locations exhibited severe corrosion or were missing the nut. Several connection bolts had been replaced in the past, though the washers were re-used and remain corroded.

**Impact if not provided:**
Recent assessments of all three reaches of the stone revetment would indicate that it is stable and no significant sloughing is presently occurring, however it appears that the revetment is incurring more wave energy (e.g., waking from vessels, fetch) and this energy is causing armor stones to shift and filter stones to be displaced, causing voids. Additionally, the lack of a splash apron is allowing water that overtops to the revetment to further undermine slope and filter stones. If these issues to this shoreline protection are not immediately addressed, it is feared that overall integrity of the stone revetment could eventually be compromised.

At this time, the toe of stone revetment is stable and will allow the installation to restore and enhance the revetment to meet current and future changes (e.g., sea level rise). Voids can be repaired, filter and armor stones added, splash apron added, height of the revetment increased, drainage improved, and support elements (e.g., posts and guard rails restored). However, if this toe is lost and significant sloughing does occur the impacts to the installation could be profound. This includes, but not limited to...
an increased likelihood of overland flooding impacting mission critical infrastructure and the cost of repair and restoration increasing significantly due to material costs and scale of action alone.

**Background:**
Climate change, sea level rise, changing weather patterns and continued subsidence will continue to contribute to an increase in the number and magnitude of coastal flooding events in the near- and long-term future of NSAA. These conditions will continue to impact land and infrastructure and pose significant challenges to the successful execution of USNA mission. As the first line of protection against overland flooding from the Severn River, Spa Creek, and College Creek on the USNA Lower Yard, a stable and resilient waterfront infrastructure is integral to any integrated adaptation framework that NSAA/USNA will implement.

NSAA/USNA have invested significant resources to recognize how projected climate-induced changes in sea level rise and weather patterns will influence the adaptive capacity of NSAA. Recent planning and modeling efforts have confirmed the importance of the Turner Joy Road stone revetment to overall protection of the installation. The 1,877-foot-long revetment continues to take the bulk of the fetch that adversely impacts the installation when winds are from the East and Southeast. This 50-foot wide is vital to the protection of this National Historic Landmark and mission critical assets and infrastructure including academic halls (e.g., Ricketts Hall), housing facilities (e.g., Bancroft Hall), and key varsity and intramural sports facilities (e.g., Rip Miller Field). Consequently, NSAA/USNA has prioritized the restoration and enhancement of Turner Joy Road stone revetment as integral adaptation alternative in addressing current and future climate-induced overland flooding on the installation.

**Objective:**
To construct shoreline stabilization measures that restore and enhance all (3) reaches of an existing 1,877 ft long stone revetment along Turner Joy Road on NSAA. These measures will improve the installation’s resilience by further hardening one of its most exposed locations to overland flooding on the NSAA Lower Yard. Construction activities will include several measures such as installing erosion control measures, raising the height of the stone revetment 2 to 3 feet at the crest, improve function of the eight steel drainage structures located along the guard rail (4 ft long by 2 ft wide), and address improvements to the guard rails.

**General Comments:**
**Tasks:**
1) Detailed Site Assessment.
   An updated detailed terrestrial and hydrographic survey of the each of the three reaches will need to be performed. The 1,443 linear feet of the stone revetment from the Farragut Quay Wall to the bend in front of Rip Miller Field composes Reaches 1 and 2. The remaining 434 feet from the bend to the Halsey Field House bulkhead is the third Reach. Hydrographic surveys are intended to assess any scouring at the toe of the revetment and drainage outfalls. Terrestrial surveys will identify voids, armor stone displacements, locations of each outfall pipe, and accurate elevations.

2) Design of Restored and Enhanced Stone Revetment.
   Site assessments of the three reaches and associated survey data will be used to develop designs for the restoration and enhancement of the stone revetment. Designs will focus on stabilization of the stone revetment (e.g., addition of filter and armoring stones), establishment of splash apron, raising the elevation of the revetment 2 to 3 feet at the crest, improve function of the eight steel drainage structures located along the guard rail (4 ft long by 2 ft wide), and address improvements to the guard rails.
3) Obtaining Required Federal and State Permits.
The installation will need to require necessary federal, and state permits to perform these restoration and enhancement efforts. In order minimize impacts to NSAA/USNA operations, construction efforts will need to be performed from Spa Creek.

4) Construction.
Construction of all 3 reaches is expected to take 18 months to complete. Contractor will be expected to follow Navy-approved designs and maintain/comply with all Federal and State Permits.

Recommended Execution Timeframe: Short-term. 2023 – 2027.

6.0 Repairs and Improvements to Interior Roads

Current Mission:
The NSAA/USNA roadways support several mission-essential services (e.g., emergency management and anti-terrorism/force protection). Categorized either as primary, secondary, or tertiary roads, this transportation network this network is actively maintained to ensure utility and functionality. Primary roads are generally used to travel between access gates and frequent destinations within the installation. Most of the primary roads are found on Lower Yard. Most other streets at the Yards are considered secondary roads, which provide access from primary roads to buildings, housing, and athletic fields, and other installation facilities. Tertiary roads accommodate a low volume of traffic, typically providing service access or, in the case of the cemetery, site access at low speed within a designated area.

Requirement:
Most of the primary roadways on the installation were designed and constructed during the 1800s and 1900s. Relatively unchanged since they were completed, these roadway present real challenges to the installation as they are unable to adequately accommodate current traffic demands and several are subject to flooding. These deficiencies are undermining the ability of these roadways to provide critical installation services and they are expected to worsen with time. Immediate repairs and improvements of several primary roads (i.e., King George Street, Brownson Road, Santee Road, Holloway Road, McNair Road, and Decatur) are required to address these challenges.

Current Situation:
Overall, the circulation network at the installation is currently adequate. However, several vehicular circulation issues are inadequate and have a direct bearing on NSAA/USNA operations and mission:

- Public rights-of-way go through the installation allowing public vehicular access. This access is not typical of other installations and presents unique management issues with on-base circulation;
• Vehicular traffic at Lower Yard must be conscious of the number of pedestrians present, including students, faculty, employees, and tourists. A related issue is the use of vehicular roads for jogging and running paths by USNA Midshipmen since separate routes for these activities are not available;

• On the Lower Yard, several roadways are subject to flooding as they tend to be the lowest elevations on the installations. Roadways with notable flooding include sections of Brownson, McNair, Decatur, and Holloway Roads on the Lower Yard. In each of these cases, the elevations of the primary roads have not significantly changed since they were constructed; and

• The circulation system at NSA Annapolis was designed during the 1800s and 1900s when the USNA campus and support areas were planned and constructed. These roadways present real challenges in accommodating efficient and safe traffic movement in today’s age.

**Impacts if not Provided:**
If the proposed primary roadway repairs and improvements are not implemented, sections of these roadways will be unable to accommodate efficient and safe traffic movement around the installation and would cause mission-essential services to fail. Additionally, these roadways do not have the adaptive capacity to cope with current and projected flooding events. If not addressed, flooding from storm surge, sea level rise, and land subsidence will increase the frequency and intensity of flooding on installation and allow this transportation network to further exacerbate these events bringing floodwaters closer to mission-critical assets and infrastructure.

**Objectives:**
NSAA/USNA repairs and improvements of Lower Yard primary roadways will enhance traffic movements and improve the resilience of the installation. Planned improvements to primary roadways (i.e., widening and raise elevation), pedestrian sidewalk, flood retention wall, and associated stormwater infrastructure are expected to add another layer for flood defense to a multilayered integrated adaptation framework proposed by NSAA/USNA.

**General Comments:**
Recent flood events (September and October 2021) highlighted how sensitive and vulnerable these primary roads were and how this transportation network exacerbated flooding. Most of these primary roadways currently do not have the adaptive capacity to cope with nuisance flooding. NSAA/USNA analyses have determined that across the campus, a small percentage of the transportation infrastructure sits below nuisance and minor flood levels (1.1 and 6.6%, respectively). However, approximately 24% of the transportation infrastructure is below the moderate flooding level.
This proposed adaptation alternative is intended to address inadequacies in traffic movement, elevation, and resilience. Unfortunately, the same approach cannot be deployed across all the primary roadways, and two approaches will need to be employed.

1) **Approach #1:** King George Street, Brownson Road, Santee Road, Holloway Road, and Decatur Road. As Figure 40 depicts, the preferred alternative (option B) would:
   - Widen the roadways to a consistent 24 feet.
   - Elevate these roadways (no more than 2 feet).
   - Maintain a pedestrian walkway along one side of the road.
   - Improve existing stormwater infrastructure by adding new higher capacity storm drains on either side of the road that ties into new trunklines (See Stormwater Management Improvements).
   - Enhance climate resilience efforts by adding a reinforced, retention wall towards the Severn River. The improvements to roadway elevation and the addition of the retention wall would provide another line of defense from flooding. Adjacent to the athletic field, the roadway would ensure that any floodwaters that overtopped the existing waterfront and a proposed earthen berm network and overwhelmed the athletic fields would be contained before it reached mission critical infrastructure.
   - Please note that this option does propose a new utility tunnel be incorporated into this design. This would allow NSAA/USNA to update and relocate utilities to safer and more accessible location.

2) **Approach #2:** McNair Road. McNair Road has several features that will require NSAA/USNA to modify its recommendations. Specifically, NSAA/USNA recommends:
   - From Decatur Road to the McNair elevated bridge at Nimitz, the roadway will be repaired and improved as outlined in Approach #1.
   - NSAA recommends the following changes to the McNair elevated bridge and associated bulkheads.

| McNair Road/Nimitz Library Bulkheads | Precast concrete bulkhead panels, concrete pile cap, steel H-piles, timber sheet piles, concrete deck – Good condition. | If the condition of the existing structure is sufficient, add a concrete parapet to elevation between EL. 5.5’ and 6.5’ NAVD88. If not, oversheet with a cantilevered or anchored steel sheet pile bulkhead with a concrete cap installed to elevation between EL. 5.5’ and 6.5’ NAVD88. Install sacrificial anodes for corrosion protection below water and a concrete fascia for corrosion protection above water. Install a floodwall at an elevation of 9.7’ NAVD88 as a secondary flood protection measure for the upland facilities. It is unknown of raising/re-grading the roadway is required in this area. |
Recommended Execution Timeframe: Long-term. 2037 -2047.

**7.0 Implement Athletic Field Improvement**

**Current Mission:**
The Lower Yard athletic fields have supported USNA exemplary programs of athletic competition and physical challenge that foster decisive leadership, teamwork, character, and a passion for “winning” since their inception in 1959. Today, Farragut, Dewey, and the Rip Miller Fields play a pivotal role in the USNA varsity athletic programs. They continue to offer the environment and resources required to compete in intercollegiate athletics at the highest level.

**Requirement:**
To ensure that these facilities can support a key element of the NSAA/USNA mission, they will need to become more resilient to current and future flooding. Located between the existing waterfront infrastructure and mission-essential assets and infrastructure, these athletic fields will need to be integrated into the NSAA/USNA integrated adaptation framework as another line of defense from flooding. This multilayered approach will require these fields to hold and direct flood waters away from more vulnerable, critical assets and infrastructure.

**Current Situation:**
As integral components of USNA’s intercollegiate athletics, these Lower Yard fields are well maintained. Significant investment has been made to ensure fields and associated equipment are state-of-the art and able to support nationally recognized athletic programs. This has included installing artificial turf on Rip Miller Field and recently restoring the field crown on several fields.
Although, these investments have benefitted the athletic program, similar investments incorporating the athletic fields in the stormwater system or other flood resilience measures have not been made.

**Impacts if not Provided:**
NSAA/USNA is already experiencing coastal flooding and it will continue to intensify. Since 1929, relative sea level in Annapolis has risen approximately 1.06 feet, which has significantly increased the occurrences of nuisance flooding from 2-3 times per year to 30-40 times per year. These frequent flooding events are impacting installation operations (e.g., transportation, emergency management services) and critical infrastructure (e.g., waterfront infrastructure, stormwater management system). If current DRSL scenarios for NSAA/USNA are correct and an increase of 2.6 feet in relative sea level rise by 2065 and 4.4 feet by 2100 is anticipated, then these nuisance events will naturally evolve into major flooding events that will threaten NSAA/USNA’s ability to maintain mission.

Combine this increase in the frequency and intensity of nuisance flooding events with other potential sources of flooding described earlier (i.e., storm surge, ground inundation, land subsidence, and extreme precipitation events) and these natural hazards will continue to have a profound impact on the land and infrastructure and pose significant challenges to the successful execution of the NSAA/USNA mission. If the athletic fields are not included in an integrated adaptation framework for the Lower Yard, the impacts could be profound. Of the 338 acres that compose the USNA, current projections would indicate that over 95 acres will be adversely impacted by climate-induced flooding by 2100, this includes land designated as a National Historic Landmark District. Within this boundary, 139 facilities comprised of buildings and monuments, are contributing elements of the National Historic Landmark District, 42% (59 facilities) are projected to be impacted. In addition to the historical significance of USNA, there are 77 facilities categorized as critical or significant to the installation’s mission.

**Objectives:**
NSAA/USNA intends to integrate the athletic fields into a multilayered adaptation framework against current and projected flooding. As the third line of defense (behind the existing waterfront infrastructure and an earthen berm), these field will hold and direct flood water away from mission-critical infrastructure.

**General Comments:**
These athletic fields will capture floodwaters that may overtop existing waterfront infrastructure and associated earthen berms. As another line of defense, these fields will reduce the likelihood of flood water encroaching further into the installation and closer to mission-essential infrastructure.
NSAA/USNA plan to increase the elevations of Farragut, Dewey, and Rip Miller Fields by improving and maintaining their field crowns. These improvements to athletic field grades and slopes will assist in directing water to field edges where a discharge ditches on backs of the earthen berms and stormwater improvements along the elevated interior roads. These ditches and stormwater features will then direct flood waters to catchment areas that are far away from critical assets and infrastructure. On Rip Miller and Farragut Fields, the water will be directed toward the Severn River on the eastern side of the fields. Similarly, the water on Dewey Field will be directed back toward to the northeast corner of the field and closer to the Severn River.

Recommended Execution Timeframe: Long-term. 2037 - 2057. Based on current conditions, Dewey Field will need to be improved (2037 - 2047) before Farragut Field (2047 - 2057).
9.0 Implement Main Gate (Gate 1) Flood Protection

Current Mission:

Multiple pedestrian and vehicular security gates are located on NSAA/USNA, however Gates 1 and 8 are the most frequently used. Both gates are entry control/access control points that provide physical and psychological deterrent to entry and preventing unauthorized personnel from entering NSAA/USNA.

Gate 1 is the visitor entrance on the Lower Yard and is open to both pedestrians and vehicles. Gate 8 is on Bowyer Road on the Upper Yard with 24-hour access for official traffic, contractors, deliveries, and large automobiles. Consequently, Gate 1 serves as the primary entrance for most of the installation’s traffic, and the surrounding visitor-focused assets and facilities (e.g., Armel-Leftwich Visitor Center, Admissions, and short-term parking) have been aggregated near and adjacent to the Gate to create an open and welcoming environment for its visitors.

As the main access point for visitors (both pedestrian and vehicle), three entrances serve this gate: pedestrians can use the Randall Street and Barry Gate on Prince George Street, and vehicles enter at the intersection of Boundary Road and Randall Street. Pedestrians approaching from Boundary Road sometimes are unaware that there is a separate pedestrian entrance and attempt to walk in through the vehicle gate. Also, some visitors in vehicles are not aware that they must have DoD identification to drive onto the installation. When vehicles are turned away, guards at this gate instruct them where they can go to find parking, but this occurs only after the vehicle has entered the gate and must then use the rejection lane to turn around and exit.

Requirement:

As the primary access point to the installation, it is vital that this Gate 1 is able ensure safety, provide a physical and psychological deterrent, and is ultimately a representation of the installation and the community that lives and works on NSAA. To meet this goal, every effort needs be made to ensure that Gate 1 and surrounding assets and facilities are resilient and capable of supporting NSAA/USNA’s 2100 planning vision.

Current Situation:

Gate operations and associated assets and facilities are being adversely affected by coastal flooding (e.g., nuisance and storm surge), sea level rise, and surface water from precipitation. These climate-influenced threats are projected to increase both in frequency and intensity and continue to bring water closer to the Gate and associated mission-critical facilities.
To complicate this issue, most of the floodwaters that are and projected to impact this Gate are primarily from off installation. Flooding at the City of Annapolis City Dock continues to overtop existing waterfront infrastructure bring floodwaters further into the city and inundate associated roadways (e.g., Prince George Street). Since 1929, relative sea level in Annapolis has risen approximately 1.06 feet, which has significantly increased the occurrences of nuisance flooding from 2-3 times per year to 30-40 times per year. These frequent flooding events are impacting City Dock (e.g., transportation, emergency management services) and the city’s critical infrastructure (e.g., waterfront infrastructure, stormwater management system). If current DRSL scenarios for NSAA/USNA are correct and an increase of 2.6 feet in relative sea level rise by 2065 and 4.4 feet by 2100 is anticipated, then these nuisance events will naturally evolve from minor to moderate and major flooding events.

NSAA/USNA and the City of Annapolis have developed a unique partnership over the Academy’s 175-year history that has alleviated and prevented incompatible development or other activities that would likely impair NSAA/USNA operations and mission. By coordinating closely and communicating openly with community leaders whose well-being is inextricably linked to the installation, NSAA/USNA has facilitated and nurtured open engagement about their individual resilience efforts. While these engagements have been productive and beneficial, both parties have different drivers and requirements.

Although, the City of Annapolis is actively developing adaptation strategies to address these current and future constraints, their design criteria and planning vision (i.e., 2050) does not mirror NSAA/USNA’s. These differences will require NSAA/USNA to develop adaptation measures that will enhance the resilience of the installation to current and future floodwaters originating at City Dock.

Impact if not Provided:
If these flood protection measures are not implemented Gate 1, Halsey Field House, and surrounding visitor-focused assets and facilities (e.g., Armel-Leftwich Visitor Center, Admissions, and short-term parking) will be adversely impacted by the imminent threat of flooding.

Preliminary analyses would indicate that Gate 1 operations would be hindered and structural damage to associated assets and facilities would be significant.

Objective:
These proposed adaptation alternatives will align with NSAA/USNA integrated adaptation framework and reduce the flood risk to the security gates, athletic facilities, administrative facilities, and associated assets and facilities. Specifically, these adaptation alternatives will improve the resilience of assets and infrastructure and ensure limited interruptions to Gate 1 and mission-essential services from flooding.

General Comments:
Recent vulnerability assessments of Gate 1 and associated assets and facilities focused on this infrastructure’s exposure, sensitivity, and adaptive capacity to current and projected flooding from both on and off-installation. A four phased approach was developed that included:
2) Prince and King George Street Flood Wall: The installation perimeter along Prince George and King George Streets are composed of a mixture of painted brick wall, wrought iron fencing, and chain link fencing. None of these barriers were designed and constructed to retain floodwaters for an extended period (i.e., material composition or height). To ensure that the installation perimeter can provide protection to Gate 1 and the surrounding assets and facilities, NSAA/USNA is recommending a non-permeable flood wall will to be incorporated into and constructed behind the existing perimeter walls. The wall will be initiate and be incorporated into the earthen berm design near Gate 0 and extend to Gate 3 on King George Street (this includes the entire length of Prince George Street and current perimeter wall on Randall Street). This new flood wall should be built to 9.7 – 11.5’ NAVD88 depending on the location. Every effort will be made to ensure that this wall is aesthetically pleasing from the city side.

3) To maintain the both the pedestrian and vehicle entrances along the perimeter wall at Gate 1, two pedestrian entrance floodproof door and a gate one floodproof barrier will be installed at each entrance. The barrier will need to be customized to fit into the exist entrances, align with the design height of the new perimeter flood wall, and should be manually operated. This will reduce likelihood of failure.

Recommended Execution Timeframe: Short-term. 2023 -2027.
10.0 Protect and Relocate Critical Services on First Floor Elevations of Mission Critical Infrastructure

Current Mission:
Founded in 1845, USNA primary mission is to develop Midshipmen morally, mentally, and physically as future naval leaders. To accomplish this mission, NSAA/USNA fosters an educational environment that supports and encourages innovative and critical thinking, lifelong learning, and persuasive communications. On the Lower Yard several academic halls (i.e., Chauvenet, Michelson, Hopper, Rickover, Ricketts, and Luce), athletic facilities (i.e., Halsey Field House, Scott Natatorium, Alumni, and Macdonough), administrative facilities (i.e., Admissions and Armel-Leftwich Visitor Center), and Nimitz Library have been developed and maintained to provide this educational environment.

Requirement:
To provide academic, athletic, and administrative facilities consistent with the growing needs of the faculty and midshipmen and the technological advances of the 21st century, several flood adaptation measures will need to be employed to ensure that these facilities are more resilient to current and future flooding.

Current Situation:
Located at the confluence of the Severn River and Chesapeake Bay, NSAA/USNA is extremely vulnerable to major localized flooding, resulting from high tides, and sustained easterly or southerly winds. Since 1929, relative sea level in Annapolis has risen approximately 1.06 feet, which has significantly increased the occurrences of nuisance flooding from 2-3 times per year to 30-40 times per year. These frequent flooding events are impacting installation operations (e.g., transportation, emergency management services) and critical infrastructure (e.g., waterfront infrastructure, stormwater management system). If current DRSL scenarios for NSAA/USNA are correct and an increase of 2.6 feet in relative sea level rise by 2065 and 4.4 feet by 2100 is anticipated, then these nuisance events will naturally evolve into major flooding events that will threaten NSAA/USNA’s ability to maintain mission. Combine these projections with associated changes in groundwater inundation, land subsidence, and precipitation, the need for an integrated adaptation framework for NSAA/USNA is both timely and vital.

A recent vulnerability assessment undertaken by NSAA/USNA has identify that several academic halls (i.e., Chauvenet, Michelson, Hopper, Rickover, Ricketts, and Luce), athletic facilities (i.e., Halsey Field House, Scott Natatorium, Alumni, and Macdonough), administrative facilities (i.e., Admissions and Armel-Leftwich Visitor Center), and Nimitz Library are being adversely impacted by intermittent flooding.

Given the imminent threat of extreme flooding events, as well as probable permanent inundation of some land adjacent to these facilities over time. The installation will need to combine a variety of wet and dry flood protection features to address present-day and future constraints that these facilities will incur and ensure the successful execution of mission.

Figure 46. Michaelson academic hall.
Impact if not Provided:
If these wet and dry flood protection features are not implemented, several academic halls (i.e., Chauvenet, Michelson, Hopper, Rickover, Ricketts, and Luce), athletic facilities (i.e., Halsey Field House, Scott Natatorium, Alumni, and Macdonough), administrative facilities (i.e., Admissions and Armel-Leftwich Visitor Center), and Nimitz Library will be adversely impacted by the imminent threat of flooding. Preliminary analyses would indicate that the structural damage to these facilities would be significant, but more importantly, the destruction and potential loss of teaching and research laboratories, equipment, instrumentation, collections, and athletic resources that currently reside on the first floors of these facilities would be extremely difficult to overcome and will have a profound impact on mission.

Objective:
These proposed adaptation alternatives will build on existing wet and dry flood proofing efforts undertaken by NSAA/USNA by reducing the flood risk to academic halls, athletic facilities, administrative facilities, and the library. Specifically, these adaptation alternatives will:

- Risk reduction for vulnerable areas (e.g., laboratories, research facilities, multimedia classrooms);
- Ensure limited interruptions to core curriculum from flooding; and
- Provide a safe and health educational environment.

General Comments:
In September 2003, Hurricane Isabel impacted the Mid-Atlantic region with high winds and a significant storm surge that flooded low lying areas of the coast in Virginia, Maryland, and North Carolina. At NSAA/USNA, the storm surge caused over $120 million (2003 costs) in damage to buildings, fields, and equipment. Flooding was prevalent on the Lower Yard and on the perimeter athletic fields of the Upper Yard.

Following the storm, NSAA/USNA in partnership with the Army Corps of Engineers, developed mitigation strategies, such as wet and dry flood proofing, that were designed to address major storms and stormwater surge (USACE, 2006). Consequently, NSAA/USNA has made substantial investment in deploying a variety adaptation measures across this installation.

For example, a deployable door dam system was installed on several buildings. The door dams are deployed when significant rainstorms or high tide events are predicted. These door dams are effective in holding surface runoff out of buildings until the storm system can process the water through normal conveyance piping. They can withstand water sitting against them for several hours before leaking into the building. For that reason, they are not effective during a prolonged flood event or in the case of perpetual flooding from sea level rise.
Additionally, NSAA/USNA have adopted wet and dry flood proofing practices in the construction of new facilities (e.g., Wesley Brown Field House and Hopper Hall) as well as upgrades to existing facilities (e.g., Rickover Hall). Some strategies adopted to mitigate the effects of water intrusion in facilities include:

- Raising ground floor elevations on new construction;
- Locating mechanical and electrical equipment above the floodplain elevation or on roofs;
- Raising electrical outlets on ground floors of buildings;
- Use of flood proof building materials on ground floors; and
- Instituting operational protocol of moving lab and classroom equipment out of ground floor spaces in preparation for major storms.

These efforts have made a profound difference in the resilience of the facilities as a recent flood event in October 2021 illustrated. However, additional interior adaptation measures are warranted if these facilities are going to be resilient to the increased frequency and intensity of flooding that is currently projected. Additional, adaptations measures may include:

- Wet Floodproofing Methods for Shallow Flooding.
  - Reduction of wicking damage.
    - Reduction of wicking damage from shallow floods is typically not confined to the area that was touched by floodwater but includes areas that were wet by water wicking up sheetrock and other porous building materials. Efforts should be made to reduce the damage from shallow flooding by creating gaps in the sheetrock and other materials so wicking stops at the gap and would need to replace only the wallboard or insulation below the gap. The sheetrock gap can be disguised by decorative trim such as a chair rail. The gap can be filled with waterproof caulk or a gasket material. Similarly, use of non-wicking waterproof material to separate insulation in the upper wall from that in the lower wall creating the smallest possible gap in the insulation.
    - For very shallow flooding, efforts can be made to avoid damage by trimming the bottom, so it ends several inches above the floor. These gaps can be covered with extra-wide baseboards to cover the gap.
    - In both cases, these upgrades provide opportunity created by re-doing the walls to raise the electrical wiring, switches, and outlets, ideally moving them to a location above the wicking gaps;
  - Create Flood-hardy Walls.
    - A flood-hardy wall is one that can stay in place during the flood and require only cosmetic restoration - cleaning and painting, not replacement of materials. A flood-hardy wall (or flood-hardy lower wall section) consists of materials that are flood-damage resistant. It is designed so flood water enters and drains freely from the wall. Gaps at the top and bottom of the floodable section of the wall must be wide enough
to allow flushing (to remove silt and contaminants) and air circulation (to dry the materials before harmful fungi and bacteria take hold).

- Interior walls - and the inside face of exterior walls - can be made more flood-resistant with some simple interior finish alternatives including use of paperless drywall (fiberglass mat gypsum) or create wainscoting with plywood or fiber-cement panels; and use only latex paint to finish the wall;

  o Compartmentalize First Floors.

  o Several of these facilities have long, unobstructed hallways that run the entire length of the building and in some cases connect multiple buildings together. These hallways were designed this way and are intended to provide faculty and midshipmen interior pathways that would allow them to walk across campus without stepping outside during inclement weather.

  o This design also makes them ideal conduits for transporting flood waters across buildings and into other buildings.

  o Recommendation is to construct or deploy waterproof doors and dams that would compartmentalize these hallways during flood and fire. There are a variety of normal-use swing door, specifically engineered for interior and exterior openings requiring watertight flood protection and a 90-minute fire rating (e.g., PS Flood Barriers Hydro1). Always in place, this dual-defense door provides unmatched flood and fire protection while allowing pedestrian access to these facilities. These products are typically 100% customizable in single or paired configurations and have been tested to 3' and 8' water protection heights with 50% less leakage than the ANSI/FM Approvals 2510-2020 4.3.3 standard.

  o In areas where waterproof flood doors cannot be installed, the deployment of interior water barriers or dams are recommended. These devices can be deployed whenever threats arise. Again, there are several manufactures that can provide customizable solutions for these facilities; however, these will take time and resources to deploy. Therefore, the waterproof flood doors are preferred for compartmentalization.

11.0 Repair and Expansion of Hill Bridge and Associated College Creek Shorelines

Current Mission:
NSAA/USNA’s Hill Bridge (Bridge 641) is one of the primary means of ingress to and egress from the Lower Yard of the Naval Academy. The bridge serves Gate 8 and traffic entering the Upper Yard from Route 450
and spans College Creek to the Lower Yard. Consequently, it is vital to the daily operations and emergency management services of the installation.

The bridge and associated waterfront infrastructure along the College Creek (e.g., adjacent to Ramsay, McNair, and Rodgers Road) are critical to the operations and protection of Navy property, assets, and mission-essential elements of the USNA academic programs. A few of these associated waterfront infrastructure reaches will be addressed in under this proposed adaptation project, but most of the proposed waterfront infrastructure adaptation are addressed earlier under Project 5.0 ‘Repair and Raise Height of Bulkheads/Seawalls/Riprap’.

**Requirement:**

In the early 2022, NSAA/USNA solicited a request for construction support services to extend the lifespan of Hill Bridge by a minimum of an additional 30 years by providing the necessary repairs and upgrades, while maintaining the bridge’s historic appearance. While this acquisition will address identified deficiencies in the superstructure and electrical systems, they do address intermittent flooding that tends to occur on either side of the bridge (i.e., Decatur and Bowyer Roads) (See Figure 49). Flooding from precipitation and tidal flooding is already having an impact on the access and utility of Gate 8 and is projected to become significantly worse in these locations and along the adjacent waterfront infrastructure.

Climate change, sea level rise, changing weather patterns and continued subsidence have and will continue to contribute to an increase in the number and magnitude of coastal flooding events in the near- and long-term future of the Annapolis region. These conditions will adversely impact land and infrastructure and pose significant challenges to the successful execution of the NSAA/USNA mission. Protective measures at the Lower Yard, Upper Yard, and other planning areas will be necessary to reduce damage from these events and facilitate effective mission execution.

Given the imminent threat of coastal flooding, as well as the frequency and intensity of storm events, there is increased probability of permanent inundation of some land areas over time. Consequently, every effort must be made to improve Bridge 641 and associated waterfront infrastructure to address present-day and likely 2035, 2065 and 2100 impacts to protect mission essential assets and infrastructure. As integral component of the NSAA/USNA integrated adaptation framework, the repair and improvement of the existing waterfront is the first line of defense and ensures that the installation can meet its 2100 planning vision.
Current Situation:
Hill Bridge was built in 1983 and carries Decatur Road over College Creek at NSAA/USNA. Bridge 641, also known as the Hill Bridge, carries Decatur Road over Dorsey Creek at the U.S. Naval Academy in Annapolis, Maryland. The bridge's location is approximately 0.3 miles southeast of Route 450. The bridge serves as the main crossing over College Creek for the USNA. The bridge consists of eight equal spans with overall dimensions of roughly 500’ long by 36’ wide. The bridge's substructure consists of two abutments and seven intermediate pile foundations; each is constructed of three 36”-diameter concrete piles with concrete pile cap. The superstructure consists of five prestressed concrete beams for each span supporting an 8” thick concrete deck.

A 2019 and 2021 EXWC Inspection Report for Bridge 641 (Hill Bridge) determined the bridge to be in “fair” condition overall (NAVFAC 2019, 2021). This inspection report provides a detailed view of the bridge conditions as of the summer of 2019 and provides a comprehensive list of conditions and deficiencies to be addressed to extend the life of the bridge and to maintain a safe structure. The inspection report emphasizes several structural-related repairs which are of the highest priority.

Additionally, a Federal Highway Administration selected NAVFAC EXWC’s Navy Bridge Inspection program to be a pilot program for the Resilience and Durability to Extreme Weather. The goal was to use the administration vulnerability assessment framework to assess the vulnerability and risk of transportation system to extreme weather impacts or other current and future environmental conditions. NAVFAC EXWC assessed approximately 60 Navy and USMC vehicular bridges on the east coast focusing on sea level rise and storms surge stressors. This assessment used several indicators relating to exposure, sensitivity, and adaptive capacity of each asset to assess vulnerability. Of 20 vehicular bridges assessed in 2020, Hill Bridge analyses found it to be 19 out of 20 with a ‘fair’ assessment score of 2.43 of 4.

The adjacent waterfront infrastructure along Ramsay Road and adjacent to Hubbard Hall are also in ‘fair’ condition and will require attention to meet current sea level rise and storm surge projections.

Impacts if not Provided:
Segments of the Decatur and Bowyer Roads are subject to nuisance flooding and in some cases, these events have restricted use of these roads and access to Gate 8. Projected changes in sea level rise and storm surge indicate that flooding frequency and intensity will only get worse limited the utility of Gate 8 as ingress to and egress from the Lower Yard.

Objective:
Hill Bridge will need to be raised and extended to ensure that this mission critical asset is able to provide future traffic, security, and emergency services requirements for the installation. Additionally, the adjacent waterfront will need to be repaired and raised to protect the bridge and associated assets and infrastructure.

General Comments:
The strategies summarized are based on quantitative review of risk likelihood associated with various storm intensities, generally characterized by recurrence interval, or return period, measured in years. NSAA/USNA has been in use for upwards of 170 years which factors heavily in assessing the likelihood of flood risk associated with storms. For infrastructure in use, and planned to be in use, for these durations, the likelihood of damaging events associated with flooding increases substantially. The table below provides a summary of probabilities (expressed as percentages) for each flood event defined by return
period as related to facility service life, defined as 100 years, consistent with planned usage. Fundamentally, NSAA/USNA reviewed several strategies in response to what the table above indicates as an almost certain, potentially damaging flood event in any given year. These strategies include:

1) Hill Bridge (Bridge 641):
   a. Repairs outlined in the NAVFAC EXWC inspection should be undertaken immediately to ensure that deficiencies are addressed. NAVFAC began their acquisition strategy in the spring of 2022.
   b. NSAA/USNA should consider contracting an architecture/engineering firm to redesign the bridge to meet current and future sea level rise and storm surge projections. This should include elevating (~6 ft) and extending (from 500 ft to 1,200 ft) the bridge (See Figure 50). The bridge should be width should be expanded to support three lanes of traffic and pedestrian walkway/running track. These proposed changes would ensure that the bridge continues to be an integral part of the installation traffic, security, and emergency management posture.

2) Ramsay Road and Columbarium:
   a. NSAA/USNA should implement several strategies outlined in the AECOM Columbarium Flood Mitigation Engineering Strategy (AECOM, 2019) to protect both Ramsay Road and the Columbarium in the near-term. Alternative 1 outlined in the study is a cost-effective solution that should be provide adequate protection until 2035.
   b. To meet the NSAA/USNA planning vision the Columbarium will need to be relocated to an elevated position on Hospital Point. Ramsay Road and all other manmade structure should be removed between Pythian Road and Sherman Field. This area (~3.28 acres) should be ecologically restored to living shoreline. This green infrastructure would have several ecological benefits and provide the installation TMDL credits for future construction efforts (See Appendix D).
   c. An elevated pedestrian walkway/bridge should be created that follows the old Ramsay Road segment from Pythian Road to Sherman Field. It would connect the new earthen berm at the field to the redesigned Hill Bridge.

3) Firehouse, Hubbard Hall, and Waterfront Infrastructure:
   a. NSAA/USNA proposes to restore the creek bed and wetland in front of the Firehouse (i.e., aircraft memorial). This will require the parking lot in adjacent to Hubbard Hall to be altered to allow natural water flow from the wetland to College Creek. The Firehouse will need be relocated closer to Gate 8.
   b. Wet and dry protections will need to be deployed at Hubbard Hall to make it more resilient to flooding.
   c. Waterfront infrastructure near and adjacent to Hill Bridge, Hubbard Hall, and Bishop Stadium will need to be repaired and raised to provide these facilities.

Figure 50. Rendering of the Proposed Hill Bridge Expansion to Gate 8 on Naval Support Activity Annapolis.
Recommended Execution Timeframe: Mid-term. 2028 – 2037.
B. Upper Yard Project Portfolio

1.0 Design and Construction of Wave Attenuation Features

Current Mission:
NSAA/USNA’s existing 19,334 linear feet of waterfront infrastructure are critical to reducing the vulnerability of Navy property, assets, and mission-essential elements of the USNA academic programs from flooding. Consequently, NSAA/USNA has planned repairs and restoration actions that would address structural deficiencies on the existing Upper Yard infrastructure (e.g., seawalls, bulkheads, revetments) and potential impacts from future extreme weather events, storm surge, sea level rise, and land subsidence. While a concerted effort has been made to ensure that these repairs and restoration will address the changes in sea level rise elevation, wave energy, and associated forces at the entrance of College Creek, additional efforts need will need to be made to improve the design life of this waterfront infrastructure (Figure 51).

Requirement:
The proposed installation of wave attenuation features is built on the educated assumption that planned repairs and restoration of the Upper Yard waterfront infrastructure will be a significant financial investment by the Navy. Every effort should be made to ensure that the planned design life of this infrastructure is met or exceeded. The proposed wave attenuation features would alter the perceived hydrodynamics at the mouth of College Creek thereby reducing the likelihood of degradation to the waterfront infrastructure. Any protection to the waterfront infrastructure at the entrance of College Creek and along the creek shoreline to the Dorsey Creek Bridge is expected to reduce flood risk to assets.
and infrastructure (e.g., underground utility tunnel) and extend the design life of the waterfront infrastructure.

**Current Situation:**
Located at the confluence of the Severn River and Chesapeake Bay, NSAA/USNA is vulnerable to storm surge associated with major weather events and localized, high-tide flooding that is exacerbated by sustained easterly or southerly winds. Recent studies by USNA have suggested that that three-, six-, and twelve-hour sustained, prevailing winds significantly influences these flooding events in Annapolis. Sustained wind forcing out of the northeast, east, southeast and south is associated with positive nuisance flooding events, and sustained wind forcing out of the northwest and north is associated with negative or negligible flooding (Davies et al., 2022). While these results suggest a relationship, it must be understood that in geomorphological complex coastal systems like the Chesapeake Bay and Severn River, this relationship can be influenced and complicated by other factors (Lyddon et al., 2018). Specifically, shallow-water, channel convergence, fetch length, along with the wind speed (wind strength), and duration, determines the size of waves produced. If the wind direction is constant, the longer the fetch and the greater the wind speed, the more wind energy is transferred to the water surface and the larger the resulting wave size will be. Wave size will increase over time until local energy dissipation balances energy transfer to the water from the wind and a fully developed wave is achieved. The resulting wave will amplify high-tide flooding and can adversely impact existing waterfront infrastructure in a variety of ways (e.g., power and energy impacting the structure, overtopping).

Current projections would indicate that the frequency and intensity of these wind driven impacts will increase with sea level rise. Since 1929, the relative sea level in Annapolis has risen slightly more than one foot, which has significantly increased the occurrences of nuisance flooding from 2-3 times per year to over 40 times per year and left the installation more vulnerable to major storms. If this trend continues, impacts from high-tide flooding, and sustained, prevailing winds will affect daily operations through closures of roads, sidewalks, building entry points, and flooding of buildings.

In College Creek these threats are amplified as current infrastructure and assets are near and most cases, adjacent to this water body. While College Creek and the watershed that supports it has not received a lot of investigation, the entrance of College Creek appears to have undergone some significant hydrodynamic and sediment transport changes after the creation of Dewey Field through land reclamation. Historically, the ebb tide appeared to have created an eddy when it meets the waterfront infrastructure, and this eddy appears to have generated some significant scouring that has altered its depth by 18 feet in some locations (note: compared to historic navigation charts). It is unknown if significant changes to the bathymetry in this location is still occurring but there are concerns that the site might become more unstable and unable to support planned adaptations to the waterfront infrastructure if causes of this scouring is not addressed.

**Impacts if not Provided:**
Recent hydrographic surveys at the entrance to College Creek indicate that this area has undergone some significant changes in the last 80 years. Reclamation efforts on either side of College Creek (e.g., creation of Sherman Field in 1941, McNair Road in 1942, and Dewey Field in 1959) had some profound changes the hydrodynamics and sediment transport at the entrance of this creek. Most notably is the scouring that has occurred since the reclamation efforts were undertaken. Preliminary surveys would indicate that the Sherman Field bulkhead is directing currents and wave energy into the bulkheads on the Lower Yard on the ebb tide. The resulting deflection had created an eddy and an associated scouring event.
these preliminary findings need further investigation, there are concerns that this energy could adversely impact future repairs of the waterfront infrastructure along College Creek and with projected changes in sea level rise reduce the infrastructures service life.

**Objective:**
Installation of wave attenuation features at the upstream entrance of College Creek would dissipate and reduce the amount of wave and tidal energy impacting the Dewey Field Bulkhead, McNair Raised Road Bridge, and other associated waterfront infrastructure. This should alter any scouring occurring at the entrance of College Creek and assisting the existing waterfront infrastructure be more resilient to the intensity, frequency, and duration of wave energy that will arise with sea level rise.

**General Comments:**
Recent hydrographic surveys at the entrance of College Creek would indicate that stone breakwaters would be expensive and adversely impact navigable waters if constructed, due to water depth and substrate composition. Consequently, any wave attenuation features employed would need to consider a suite of innovative, manmade engineering solutions. USACE ERDC has tested and extensively evaluated a new family of prefabricated concrete elements as Reefmaker, URGEBREAKER offshore reef system, BEACHSAVER reef, WAVEblock, T-sill elements and others that have been developed and applied.

Recommendations are based on the Reefmaker technology that was originally developed and upgraded for the wave environment found along the Atlantic coastline. The Reefmaker technology is a pile-based wave attenuation system. This system allows water to flow through it while providing improved wave protection characterized by a traditional breakwater system. The system consists of concrete ‘eco-disks’ individually stacked on top of one another. The eco-disks are perched above the benthic substrate by a mechanical support system. The product is an octagonal shape to create additional surface area to reduce wave energy, accommodate irregular shorelines and reduce structure weight. The eco-disks are designed to direct and dissipate wave energy.

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**Recommended Execution Timeframe:** Long-term. 2047 – 2057. This proposed action should not be undertaken until all the adaptations along College Creek have been completed and a hydrodynamic study of the creek entrance can be performed.

### 2.0 Implement Integrated Stormwater Management Program

**Current Mission:**
The Upper Yard is composed of several drainage basins and subbasins that support a variety of mission-critical assets and facilities. The stormwater infrastructure contained within these basins continue to support a wide range of climate conditions while ensuring that base operations are continued to be maintained.
Requirement:
The repairs and improvements will reduce flooding risk around Gate 8 and along Bowyer Road, minimize long term operational costs, and provide a better opportunity for that system to adapt to future climate changes. Considering Gate 8 and Bowyer are mission essential assets and infrastructure, a concerted needs to ensure that they continue to support force protection and emergency management requirements. Consequently, these recommendations are built on the educated assumption that current climate projections indicate that the frequency and intensity of coastal and precipitation-based overland flooding will increase. Repairs and improvements to the existing stormwater infrastructure within the Upper Yard are expected to address present-day stormwater requirements and provide a foundation for the installation to meet its 2100 planning vision.

To meet these challenges, the proposed repairs improvements are focused on enhancing stormwater network that appear to fall within historic creek beds and are viewed as components of broader integrated adaptation framework. This framework presents a holistic method intends to restore natural function (i.e., ecological restoration of historic creek beds and wetlands) and thereby addressing flood risks across the installation and consists of four complementary flood protection layers. Each layer presents a specific approach to flood risk management—working through the lenses of natural engineered defenses, adapted structures, natural mitigations, and prepared communities. These layers are designed to support each other, integrating structural and non-structural measures to ensure comprehensive flood protection across a range of environmental conditions. Additionally, these efforts will reduce anticipated O&M investment by returning some areas into natural features (e.g., wetlands, living shorelines), relocating mission critical and culturally important facilities (e.g., fire station and Columbarium), and removal of other infrastructure (e.g., segment of Ramsay Rd.).

The stormwater improvement recommendations and associated changes to assets and infrastructure presented in this adaptation have been built on several underlining assumptions. Specifically, repairs and improvements of infrastructure will enhance protection of mission critical infrastructure, proposed pipe improvements and upgrades will occur in the same locations as existing network components and associated planned pump stations will be in areas that are currently open land. Consequently, no utility conflicts have been identified based on current layout.

Current Situation:
The Upper Yard has the highest elevations with the installation boundaries on southern side of the Severn River. This high vantage point is well documented in the historic literature and two creek beds were present. The first creek was located on the southern side of Hospital Point and meander down on the west of side of Pythian Rd and entered College Creek where the current Hubbard Hall parking lot is located. The second creek was on the northern side of Hospital Point and ran down the hill, across the current track field (i.e., shotput and discus) and entered directly into the Severn River near the Naval
Academy Bridge. Both locations are prone to flooding and the stormwater infrastructure in these areas bring little relief to the Upper Yard. Like most of the Upper Yard, the stormwater systems are old and antiquated. Consequently, it has generated some unique challenges.

Inlet capacities within the drainage that cause inefficient collection pathways for stormwater runoff, several of roads in the drainage have been present since 18th century and are acting as runoff conduits (e.g., Ramsay and Bowyer Roads), and undersized pipes and/or varying pipe sizes on the same line is causing inadequate conveyance pathways resulting in localized overland flooding. Localized ponding is also caused by and amplified due to surcharge of structures, negative slopes in pipe, and tidal mean high water covering existing outfalls. High peak tidal condition impedes gravity drainage into receiving waters and some locations allow tidal waters to enter the drainage basin by way of the stormwater system. Unfortunately, these deficiencies are allowing flood waters to adversely impact installation transportation, security, and emergency services.

**Impact if not provided:**
Vulnerability assessments of current and future flooding from sea level rise, storm surge, and precipitation will continue to adversely impact Bowyer Road and Ramsay Roads. Specifically, these assessments would indicate that the Upper Yard will observe an increase in the frequency and the severity of flooding if repairs and improvements are not made. These impacts will have a profound impact on installation operations and damage mission essential assets and infrastructure if not addressed.

**Objective:**
The proposed repairs and improvements to the stormwater management system within the Upper Yard will reduce flood risk and improve stormwater conveyance by:

- Reducing the amount of nuisance flooding and damage;
- Restore several areas around Bowyer and Ramsay Roads back to native wetlands, living shorelines, and creeks;
- Leverage green infrastructure solutions to improve water balance, reduce heat island effect, and capture and direct surface water flow to more appropriate locations (Appendix D);
- Relocate mission critical and culturally important infrastructure (e.g., Fire Station, Columbarium) to areas that are above the 500-year flood plain;
- Enhance stormwater function around Hubbard Hall, Bishop Stadium, and Hill Bridge to complement proposed wet and dry adaptations around these facilities and infrastructure.
- Providing a foundation for other adaptation alternatives by providing relief from recurring flooding; increasing storage volumes and detention times within the system to reduce peak flows during all storm events; and
- Increasing water quality and protect natural resources in surrounding water bodies.

**General Comments:**
A phased approach to this proposed design build will address gaps and needs before committing to 95% design: The proposed phases of the MILCON project would include:

1) Identify and predict changing groundwater elevations over the planning horizon (influence of precipitation and tides).
2) Determine if existing stormwater system is working efficiently and is not in disrepair.
   a) Assessment should focus on negative slopes and how tide cycles impede gravity drainage.
b) CCTV and diver investigations of the existing stormwater system is inclusive. Recommend deployment an integrated, turnkey solution like Stormsensor (https://www.stormsensor.io/) to assess function and monitor changes concurrently with groundwater monitoring wells.

3) Build on existing digital elevation models to evaluate overland flooding and how alterations to slope and grade.
   a) Efforts should be made to direct overland runoff away from critical infrastructure to areas that can retain water.
   b) This should include removal of a segment of Ramsay Road and restore it to a living shoreline, relocation of firehouse and restore creek and wetlands in that location, closure of the track field and restore the creek and wetland to the Naval Academy bridge, and elevating and extending Hill Bridge to Gate 8.
   c) New retention areas should be planted with native wetland grasses and trees that can reduce soil erosion and increase soil absorption capacity.
   d) Every effort should be made to leverage green infrastructure on the Upper Yard. This includes native trees around athletic fields, near and adjacent to Hubbard Hall, and around base housing. These natural features will provide multiple benefits and reduce O&M expenses (See Appendix D).

4) Phases 1-3 should be performed while preliminary designs to the drainage stormwater system is being developed.

5) Final designs for Improvement of stormwater system infrastructure.
   a) Design should consider splitting existing drainage network into three subnetworks to address pipe capacity constraints and leverage gravity drainage toward main outfall. This would divide the current drainage into high and low elevation networks. Low elevation networks would be on the north and south sides of Hospital Point.
   b) This will consist of larger diameter pipes (trunk lines) necessary to convey runoff and manage localized overland flooding. Drainage gradient will be positive towards the outfall. A large portion of the pipes will continue to be below tide levels under both existing and future conditions.
   c) Install tidal gates at outfalls in the drainage.
   d) Wet wells and pump stations (with 100 cfs peak pumping capacity) along Bowyer and Ramsay Road. The subsurface storage system sizes for each wet well will be contingent on previous studies.
   e) Note: No other adaptation alternatives will be performed in this drainage until these stormwater improvements are successfully completed.

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Recommended Execution Timeframe: Medium-term. 2027-2037.
3.0 Repair and Raise Height of Bulkhead along Sherman Field

Current Mission:
NSAA/USNA’s existing 19,334 linear feet of waterfront infrastructure is critical to the operations and protection of Navy property, assets, and mission-essential elements of the USNA academic programs. As a naval academy, the Severn River and Chesapeake Bay play an integral role in the mission and strategic growth of NSAA/USNA. Consequently, NSAA/USNA has planned repairs and restoration actions that would address structural deficiencies to the existing Sherman Field bulkhead and potential impacts from future extreme weather events, storm surge, sea level rise, and nuisance flooding from sustained, directional winds from the east and southeast. These proposed improvements will sustain the utility of the waterfront infrastructure for the foreseeable future.

Requirement:
The Upper Yard waterfront infrastructure is integrally tied to the mission and strategic plans of NSAA/USNA. To ensure that this relationship is sustained NSAA/USNA will need to invest in repairs and improvements that will address identified weaknesses and make it more resilient to projected climate-influenced changes.

Climate change, sea level rise, changing weather patterns and continued subsidence have and will continue to contribute to an increase in the number and magnitude of coastal flooding events in the near- and long-term future of the Annapolis region. These conditions will adversely impact land and infrastructure and pose significant challenges to the successful execution of the NSAA/USNA mission. Protective measures at the Upper Yard and other planning areas will be necessary to reduce damage from these events and facilitate effective mission execution.

Given the imminent threat of coastal flooding, as well as the frequency and intensity of storm events, there is increased probability of permanent inundation of some land areas over time. Consequently, every effort must be made to improve the existing NSAA waterfront infrastructure to address present-day and likely 2035, 2065 and 2100 impacts to protect mission essential assets and infrastructure. As integral component of the NSAA/USNA integrated adaptation framework, the repair and improvement of the existing waterfront is the first line of define and ensures that the installation can meet its 2100 planning vision.

Current Situation:
The Waterfront Facilities Inspections and Assessments at United States Naval Academy Annapolis, Maryland report (NAVFAC, 2017b), provided an assessment of the general physical condition of facilities, operational restrictions, and recommendations. At the time of the inspection, the Sherman Field bulkhead exhibited increased deterioration of the steel sheet piles with corrosion holes developing below the concrete pile caps. In these areas, backfill was seen escaping through the corrosion holes, with sinkholes developing behind the bulkheads. As a result, it was found to be in poor condition. The Columbarium seawall and Upper Yard riprap were found to be in fair condition.
Impacts if not Provided:
If repairs are not provided for the Sherman Field Bulkhead steel sheet piling, an increase in the number of sinkholes behind the bulkhead will likely result from the progressive deterioration and anticipated loss of backfill material through the corrosion holes in the sheets. The inspection report further states that the anticipated loss of backfill material would further compromise the integrity of the site and adversely impact other adaptation strategies along the waterfront. Until further analysis is performed, it is recommended that mooring and berthing along the Sherman Field Bulkhead not be allowed during weather conditions more than Type I conditions, as defined by UFC-4-159-03, which covers sustained winds of less than 35 knots and currents less than 1 knot. It is also recommended that vertical loading be limited to pedestrian only. The formation of sinkholes will ultimately yield unsafe conditions for pedestrian traffic behind the bulkhead.

Consequently, the proposed seawall and bulkhead repairs and improvements along the Upper Yard where not implemented, sections of the existing seawalls and shoreline will continue to deteriorate over time and then fail. The failure would result in continued flooding issues and undermine the reclamation land fill that supports mission-critical infrastructure (i.e., roads, athletic facilities, buildings, etc.) behind the seawall. With potential continued storm surge, sea level rise, and land subsidence, these conditions would worsen over time and result in increased frequency flooding and failure events.

Given the elevation of the installation, which ranges from sea level to 80 feet above mean sea level (NAVFAC Washington, 2011), and its location adjacent to the Chesapeake Bay, NSA Annapolis is vulnerable to localized flooding and storm surge associated with major weather events and higher water levels, particularly during high tides. Climate change would exacerbate these conditions (NAVFAC Washington, 2018a).

Storm surge occurs when there is temporary flooding and water inundation along coastlines during storm events such as tropical depressions or hurricanes. The most recent hurricane that caused major flooding damage due to storm surge at NSA Annapolis was Hurricane Isabel in 2003. This hurricane caused an immense amount of water and storm damage at the USNA, with inundation in numerous buildings. High water events like what occurred during Hurricane Isabel are expected to become more frequent, and the amount of inundation can increase over time (NAVFAC Washington, 2018a).

The Chesapeake Bay region is considered one of the nation’s most vulnerable areas to sea level rise, as data have shown that sea level rise is occurring at the highest rate on the Atlantic Coast. There are two reasons for this: the ground in the region is sinking due to natural land subsidence, and ocean levels are rising (USGS, 2013). In 2018, a record number of 41 flood events occurred at NSA Annapolis. Flooding events have increased over the past 20 years, and there is the potential for increased frequency in the future due to sea level rise. The projected increase in sea level rise varies from low to extreme scenarios. In Annapolis, this increase ranges from 1.6 feet for the low scenario to 8.2 feet for the extreme scenario in 2100 (Hall et al, 2016).
In addition to the factors that have already been discussed, the Proposed Action is needed to maintain the safety and function of mission-critical areas at the installation. The mission at NSA Annapolis includes seamanship and sail training; small arms weapons familiarization; and navigation and engineering professional development. Increased frequency or severity of flood events could result in loss of land or damaged facilities in these mission-critical areas and could prevent either NSA Annapolis or the USNA from accomplishing their missions.

Objectives:
NSAA/USNA proposes to repair and restore seawalls and bulkhead along Upper Yard (i.e., Sherman Field bulkhead, Columbarium seawall, and Upper Yard riprap). The repairs, restoration, and improvements would address structural deficiencies on the existing seawall and potential impacts from future extreme weather events, storm surge, sea level rise, and land subsidence.

Specific restoration and enhancement techniques could include hardened structures and log toe stabilization, where appropriate. Hardened structures include bulkhead, sheet pile seawall, riprap, or a combination of these techniques.

General Comments:
The service life of these recommended repairs and improvements to the waterfront infrastructure is 75 – 100 years with proper maintenance and inspection program (See Table 19). In addition, NSAA/USNA recommends that all future repairs of this infrastructure include a suite of adaptations that will improve the service life of these structures. These adaptations include wave attenuation features in front of waterfront infrastructure that will incur significant wave energy, sacrificial anodes for corrosion protection of steel below water and concrete fascia for corrosion protection of steel above water. For the concrete, a durable mix design is recommended with sufficient cover to reinforcing steel. Uncoated black bar is recommended in lieu of epoxy coated bar to eliminate any holidays in the epoxy that could potentially create hot spots for corrosion, leading to premature spalling of concrete.
### Table 19. Medium Priority – Upper Yard Structures (recommend addressing repairs within 10 years).

<table>
<thead>
<tr>
<th>Facility Name</th>
<th>Description and Existing Condition</th>
<th>Recommended Repair</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sherman Field Bulkhead</td>
<td>Steel sheet pile bulkhead, tied to timber piles with a concrete cap - Poor condition.</td>
<td>Oversheet with an anchored or cantilevered steel sheet pile bulkhead with a concrete cap installed to EL. 6.1’ NAVD88; sacrificial anodes for corrosion protection below water and a concrete fascia for corrosion protection above water.</td>
</tr>
<tr>
<td>Columbarium Seawall</td>
<td>Riprap with a stone cap – Fair condition.</td>
<td>Near-term: The Columbarium seawall along Ramsay Rd. is fair condition but is vulnerable to nuisance flooding. These flooding events are increasing in frequency and intensity and are having impacts on the utility of the road and regretfully, some impacts on the Columbarium. Recommendation is to further evaluate and implement adaptations outlined in the AECOM Feasibility Study (2019). These measures will allow NSAA/USNA time to develop an appropriate course of action for the relocation of the Columbarium. Long-term: NSAA/USNA will need to relocate the Columbarium and remove the segment of Ramsay Rd. from Bowyer Rd. intersection to Sherman Field. Recommendation is to return this tidal area into a living shoreline that will enhance water quality in College Creek, protect the existing bluff from erosion, and allow NSAA to obtain TMDL credits for future resilience efforts. Additionally, an elevated pedestrian bridge/walkway that will be constructed above this ecological restoration site. This will provide midshipman a safe walk and running path that would connect the walkway on the Sherman Field earthen berm to the sidewalk on Hill Bridge.</td>
</tr>
<tr>
<td>Upper Yard Riprap</td>
<td>Riprap – Fair condition</td>
<td>Located west of Hill Bridge, the existing rip rap along College Creek well be repaired and restored to an elevation of 6.1’ NAVD88. To meet this elevation on a 3:1 slope, some additional earthworks (like the earthen berm) will need to be created.</td>
</tr>
</tbody>
</table>

**Recommended Execution Timeframe:** Medium-term. 2027 – 2037.
4.0 Improve Elevation of Interior Road Implement Sherman Resilience Measures

Current Mission:
The NSAA/USNA roadways support several mission-essential services (e.g., emergency management and anti-terrorism/force protection). Categorized either as primary, secondary, or tertiary roads, this transportation network is actively maintained to ensure utility and functionality. Primary roads are generally used to travel between access gates and frequent destinations within the installation. Most other streets at the Yards are considered secondary roads, which provide access from primary roads to buildings, housing, and athletic fields, and other installation facilities. Tertiary roads accommodate a low volume of traffic, typically providing service access or, in the case of the cemetery, site access at low speed within a designated area.

Requirement:
Most of the primary roadways on the installation were designed and constructed during the 1800s and 1900s. Relatively unchanged since they were completed, these roadway present real challenges to the installation as they are unable to adequately accommodate current traffic demands and several are subject to flooding. These deficiencies are undermining the ability of these roadways to provide critical installation services and they are expected to worsen with time. Immediate repairs and improvements of several primary, Upper Yard roads (i.e., Bowyer, Pythian and Ramsay Roads) are required to address these challenges.

Current Situation:
Overall, the circulation network at the installation is currently adequate. However, several vehicular circulation issues are inadequate and have a direct bearing on NSAA/USNA operations and mission:

- Public rights-of-way go through the installation allowing public vehicular access. This access is not typical of other installations and presents unique management issues with on-base circulation;
- Vehicular traffic at the Upper Yard must be conscious of the number of pedestrians present, including students, faculty, employees, and tourists. A related issue is the use of vehicular roads for jogging and running paths by USNA Midshipmen since separate routes for these activities are not available;
- On the Upper Yard, several roadways are subject to flooding as they tend to be the lowest elevations on the installations. Roadways with notable flooding are Bowyer and Ramsay Road on the Upper Yard. In each of these cases, the elevations of the primary roads have not significantly changed since they were constructed; and
- The current circulation system was designed during the 1800s and 1900s when the USNA campus and support areas were planned and constructed. These roadways present real challenges in accommodating efficient and safe traffic movement in today’s age. In particular, the Upper Yard has a few one-way and under-sized roadways that make reuse of vacant facilities at the Upper Yard particularly challenging.

Impacts if not Provided:
If the proposed primary roadway repairs and improvements are not implemented, overtime, sections of these roadways will be unable to accommodate efficient and safe traffic movement around the installation and would cause mission-essential services to fail. Additionally, these roadways do not have the adaptive capacity to cope with current and projected flooding events. If not addressed, flooding from storm surge, sea level rise, and land subsidence will increase the frequency and intensity of flooding on
installation and allow this transportation network to further exacerbate these events bringing floodwaters closer to mission-critical assets and infrastructure.

**Objectives:**
Repairs and improvements of the Upper Yard primary roadways will enhance traffic movements and improve the resilience of the installation. Planned improvements to primary roadways (i.e., widening and raise elevation), pedestrian sidewalk, flood retention wall, and associated stormwater infrastructure are expected to add another layer for flood defense to the proposed multilayered integrated adaptation framework.

**General Comments:**
Recent flood events (September and October 2021) highlighted how sensitive and vulnerable these primary roads were and how this transportation network exacerbated flooding. Most of these primary roadways currently do not have the adaptive capacity to cope with nuisance flooding. The Vulnerability Assessment determined that across the campus, a small percentage of the transportation infrastructure sits below nuisance and minor flood levels (1.1 and 6.6%, respectively). However, 27% of the transportation infrastructure would have partial flooding in the 2100 intermediate SLR scenario.

This proposed adaptation alternative is intended to address inadequacies in traffic movement, elevation, and resilience. Unfortunately, the same approach cannot be deployed across all the primary roadways, and two approaches will need to be employed.

3) **Approach #1:** Ramsay and Bowyer Roads
   As Figure 55 depicts, the preferred alternative (option B) would:
   - Widen the roadways to a consistent 24 feet;
   - Elevate these roadways (no more than 2 feet);
   - Maintain a pedestrian walkway along one side of the road;
   - Improve existing stormwater infrastructure by adding new higher capacity storm drains on either side of the road that ties into new trunklines (See Stormwater Management Improvements); and
   - Enhance climate resilience efforts by adding a reinforced, retention wall towards the Severn River. The improvements to roadway elevation and the addition of the retention wall would provide another line of defense from flooding. Adjacent to the athletic field, the roadway would ensure that any floodwaters that overtopped the existing waterfront and a proposed earthen berm network and overwhelmed the athletic fields would be contained before it reached mission critical infrastructure.

   Please note that this option does propose a new utility tunnel be incorporated into this design. This would allow NSAA/USNA to update and relocate utilities to safer and more accessible location.

4) **Approach #2:** Pythian Road
   - Pythian Road has several features that will require modification to this recommendation. Widen the roadway to a consistent 24 feet;
   - Elevate these roadways (no more than 2 feet) at the intersections of Bowyer and Ramsay Road. Specifically, on the downward slopes;
   - Add a pedestrian walkway along one side of the road; and
- Improve existing stormwater infrastructure on the downward slopes by adding new higher capacity storm drains on either side of the road that ties into new trunklines (See Stormwater Management Improvements).

Please note that this option still proposes a new utility tunnel be incorporated into this design. This would allow NSAA/USNA to update and relocate utilities to safer and more accessible location.

**Recommended Execution Timeframe:** Long-term. 2037 -2047. Any improvements to the transportation network on the Upper Yard should not be addressed until the Hill Bridge improvements have been designed. The length and elevation of Hill Bridge will need to change significantly, and it will alter security and emergency management services.

*Figure 55. New Elevated Road, Option B.*
C. North Severn Project Portfolio

1.0 Design and Construction of Wave Attenuation Features

Current Mission:
NSAA/USNA’s existing waterfront infrastructure are critical to reducing the vulnerability of Navy property, assets, and mission-essential elements of the USNA academic programs from flooding. Consequently, NSAA/USNA has planned repairs and restoration actions that would address structural deficiencies on the existing North Severn infrastructure (e.g., seawalls, bulkheads) and potential impacts from future extreme weather events, storm surge, sea level rise, and land subsidence. Current designs for the YP Pier restoration currently include wave attenuation features that will sufficiently address the energy that this mission critical waterfront infrastructure will endure the next 40 years, however these adaptations are unlikely to support the climate induced hazards it will tolerate during its full design life cycle. Projected changes in hydrodynamics, fetch, and sediment transport due to sea level rise will have a dramatic impact on the energy this pier will be incurring. The addition of wave attenuation features in front of the pier will assist in the dissipation of this energy and extend the design life of this waterfront infrastructure (Figure 56).

Requirement:
The proposed installation of wave attenuation features is built on the educated assumption that planned repairs and restoration of the North Severn waterfront infrastructure will be a significant financial investment by the Navy. Every effort should be made to ensure that the planned design life of this infrastructure is met or exceeded. The proposed wave attenuation features would provide reduce wave height and energy prior to it reaching the infrastructure and other adaptation alternatives and thereby
reducing the likelihood of degradation to the waterfront infrastructure. Any protection to the waterfront infrastructure is expected to extend the design life to meet the installation’s 2100 planning vision.

**Current Situation:**
Located at the confluence of the Severn River and Chesapeake Bay, NSAA/USNA is vulnerable to storm surge associated with major weather events and localized, high-tide flooding that is exacerbated by sustained easterly or southerly winds. Recent studies by USNA have suggested that three-, six-, nine-, and twelve-hour sustained, prevailing winds significantly influences these flooding events in Annapolis. Sustained wind forcing out of the northeast, east, southeast and south is associated with positive nuisance flooding events, and sustained wind forcing out of the northwest and north is associated with negative or negligible flooding (Davies et al., 2022). While these results suggest a relationship, it must be understood that in geomorphological complex coastal systems like the Chesapeake Bay and Severn River, this relationship can be influenced and complicated by other factors (Lyddon et al., 2018). Specifically, shallow-water, channel convergence, fetch length, along with the wind speed (wind strength), and duration, determines the size of waves produced. If the wind direction is constant, the longer the fetch and the greater the wind speed, the more wind energy is transferred to the water surface and the larger the resulting wave size will be. Wave size will increase over time until local energy dissipation balances energy transfer to the water from the wind and a fully developed wave is achieved. The resulting wave will amplify high-tide flooding and can adversely impact existing waterfront infrastructure in a variety of ways (e.g., power and energy impacting the structure, overtopping).

Current projections would indicate that the frequency and intensity of these wind driven impacts will increase with sea level rise. Since 1929, the relative sea level in Annapolis has risen slightly more than one foot, which has significantly increased the occurrences of nuisance flooding from 2-3 times per year to over 40 times per year and left the NSAA more vulnerable to major storms. If this trend continues, impacts from high-tide flooding, and sustained, prevailing winds will affect daily operations of NSAA/USNA through closures of roads, sidewalks, building entry points, and flooding of buildings.

**Impacts if not Provided:**
The most recent Waterfront Facilities Inspections and Assessments at United States Naval Academy Annapolis, Maryland report (NAVFAC, 2017b), provided an assessment of the general physical condition of the facilities, operational restrictions, and recommendations. At the time of the inspection, Yard Patrol Relieving Platform, Basin Sheet Pile Bulkhead, and Basin Concrete Encased Bulkhead were found to be in serious and poor condition. While this infrastructure has exceeded its design life, it is starting exhibit the degradation expected with >80-year-old facilities and are incurring significant wave energy. The repair and reconstruction of wave dampeners in this location are generating significant annual maintenance costs (>$300K per year). These costs will only continue to increase with projected changes in sea level rise and extreme level water events and reduce the design the life of any future repairs and improvements to the waterfront infrastructure unless this adaptation is implemented.

**Objective:**
Installation of wave attenuation features in front of waterfront infrastructure that will assist repaired and restored waterfront infrastructure receive projected changes in the intensity, frequency, and duration of wave energy that will arise with sea level rise.

**General Comments:**
Preliminary modeling efforts indicate that Yard Patrol Basin is incurring most of the fetch and wave energy currently and projected to impact the North Severn. Unfortunately, recent hydrographic surveys along this waterfront infrastructure would indicate that stone breakwaters would be expensive and adversely impact navigable waters if constructed, due to water depth and substrate composition. Consequently, in any wave attenuation features employed would need to consider a suite of innovative, manmade engineering solutions. USACE ERDC has tested and extensively evaluated a new family of prefabricated concrete elements as Reefmaker, URGEBREAKER offshore reef system, BEACHSAVER reef, WAVEblock, T-sill elements and others that have been developed and applied.

Recommendations are based on the Reefmaker technology that was originally developed and upgraded for the wave environment found along the Atlantic coastline. The Reefmaker technology is a pile-based wave attenuation system. This system allows water to flow through it while providing improved wave protection characterized by a traditional breakwater system. The system consists of concrete ‘eco-disks’ individually stacked on top of one another. The eco-disks are perched above the benthic substrate by a mechanical support system. The product is an octagonal shape to create additional surface area to reduce wave energy, accommodate irregular shorelines and reduce structure weight. The eco-disks are designed to direct and dissipate wave energy.

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### 2.0 Repair and Raise Height of Bulkhead along North Severn

**Current Mission:**
NSAA/USNA’s existing 19,334 linear feet of waterfront infrastructure is critical to the operations and protection of Navy property, assets, and mission-essential elements of the USNA academic programs. As a naval academy, the Severn River and Chesapeake Bay play an integral role in the mission and strategic growth of NSAA/USNA. Consequently, NSAA/USNA has planned repairs and restoration actions that would address structural deficiencies on the existing North Severn infrastructure (e.g., seawalls, bulkheads) and potential impacts from future extreme weather events, storm surge, sea level rise, and nuisance flooding from sustained, directional winds from the east and southeast. These proposed improvements will sustain the utility of the waterfront infrastructure for the foreseeable future.
Requirement:
The North Severn waterfront infrastructure is integrally tied to the mission and strategic plans of NSAA/USNA as it provides berthing and maintenance to the Yard Patrol (YP) Boats. The Midshipmen-run Yard Patrol Squadron provides opportunities for Midshipmen to enhance their leadership, seamanship, and navigation skills in a safe and controlled learning environment that mimics that of the Fleet. To ensure that this relationship is sustained, NSAA/USNA will need to invest in repairs and improvements that will address identified weaknesses and make it more resilient to projected climate-influenced changes.

Climate change, sea level rise, changing weather patterns and continued subsidence have and will continue to contribute to an increase in the number and magnitude of coastal flooding events in the near- and long-term future of the Annapolis region. These conditions will adversely impact land and infrastructure and pose significant challenges to the successful execution of the NSAA/USNA mission. Protective measures at the North Severn and other planning areas will be necessary to reduce damage from these events and facilitate effective mission execution.

Given the imminent threat of coastal flooding, as well as the frequency and intensity of storm events, there is increased probability of permanent inundation of some land areas over time. Consequently, every effort must be made to improve the existing NSAA waterfront infrastructure to address present-day and likely 2035, 2065 and 2100 impacts to protect mission essential assets and infrastructure. As an integral component of the NSAA/USNA integrated adaptation framework, the repair and improvement of the existing waterfront is the first line of defense and ensures that the installation can meet its 2100 planning vision.

Current Situation:
The NAVFAC Engineering and Expeditionary Warfare Center’s Waterfront Facilities Inspections and Assessments at United States Naval Academy Annapolis, Maryland report (NAVFAC 2017b, 2020), provided an assessment of the general physical condition of facilities, operational restrictions, and recommendations. At the time of the inspection, all the North Severn reaches exhibited increased deterioration. The existing waterfront infrastructure (YP Pier associated dolphins, Marine Railway/Boat Ramp, and Quay Wall- both reaches A & B) have exceeded their service life and require replacement to meet current codes, accommodate 21 Yard Patrol craft, and to be resilient to projected climate induced changes in wave action, storm energy, and fetch from the North Severn.

Table 20 shows the engineering assessment rating, with a corresponding Engineering Management System Condition Index rating, that is given to waterfront facilities based on their condition. Facilities are given a condition index rating number that corresponds to an assessment rating and description, as shown in the table. Table 21 (below) shows the assessment rating that was given to the three (3) reaches on the North Severn (NAVFAC, 2020). All three reaches were given serious assessment ratings.
Table 20. Engineering Assessment Rating for Waterfront Facilities.

<table>
<thead>
<tr>
<th>Assessment Rating</th>
<th>Equivalent Condition Index Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>84–100</td>
<td>No problems or only minor problems noted. Structural elements may show some very minor deterioration, but no significant reduction in structural capacity.</td>
</tr>
<tr>
<td>Satisfactory</td>
<td>67–83</td>
<td>Minor-to-moderate defects and deterioration observed, but no significant reduction in structural capacity.</td>
</tr>
<tr>
<td>Fair</td>
<td>54–66</td>
<td>All primary structural elements are sound, but minor-to-moderate defects and deterioration observed. Localized areas of moderate- to-advanced deterioration may be present but do not significantly reduce the structural capacity.</td>
</tr>
<tr>
<td>Poor</td>
<td>37–53</td>
<td>Advanced deterioration or over stressing observed on widespread portions of the structure. Some reduction in structural capacity.</td>
</tr>
<tr>
<td>Serious</td>
<td>26–36</td>
<td>Advanced deterioration, over stressing, or breakage may have significantly affected the load-bearing capacity of primary structural components. Local failures are possible.</td>
</tr>
<tr>
<td>Critical</td>
<td>0–25</td>
<td>Very advanced deterioration, over stressing, or breakage has resulted in localized failure(s) of primary structural components. More widespread failures are possible or likely to occur.</td>
</tr>
</tbody>
</table>

**Impacts if not Provided:**

If the proposed seawall and bulkhead repairs and improvements along the North Severn were not implemented, sections of the existing seawalls and shoreline will continue to deteriorate over time and then fail. The failure would result in continued flooding issues and undermine the reclamation land fill that supports mission-critical infrastructure (i.e., maintenance and repair shops, buildings, road, utilities etc.) behind the seawall. With potential continued storm surge, sea level rise, and land subsidence, these conditions would worsen over time and result in increased frequency flooding and failure events.
Given the elevation of the installation, which ranges from sea level to 80 feet above mean sea level (NAVFAC Washington, 2011), and its location adjacent to the Chesapeake Bay, NSA Annapolis is vulnerable to localized flooding and storm surge associated with major weather events and higher water levels, particularly during high tides. Climate change would exacerbate these conditions (NAVFAC Washington, 2018a).

Storm surge occurs when there is temporary flooding and water inundation along coastlines during storm events such as tropical depressions or hurricanes. The most recent hurricane that caused major flooding damage due to storm surge at NSA Annapolis was Hurricane Isabel in 2003. This hurricane caused an immense amount of water and storm damage at the USNA, with inundation in numerous buildings. High water events like what occurred during Hurricane Isabel are expected to become more frequent, and the amount of inundation can increase over time (NAVFAC Washington, 2018a).

The Chesapeake Bay region is considered one of the nation’s most vulnerable areas to sea level rise, as data have shown that sea level rise is occurring at the highest rate on the Atlantic Coast. There are two reasons for this: the ground in the region is sinking due to natural land subsidence, and ocean levels are rising (USGS, 2013). In 2018, a record number of 41 flood events occurred at NSA Annapolis. Flooding events have increased over the past 20 years, and there is the potential for increased frequency in the future due to sea level rise. The projected increase in sea level rise varies from low to extreme scenarios. In Annapolis, this increase ranges from 1.6 feet for the low scenario to 8.2 feet for the extreme scenario in 2100 (Hall et al., 2016).

In addition to the factors that have already been discussed, the Proposed Action is needed to maintain the safety and function of mission-critical areas at the installation. The USNA mission includes seamanship and sail training; small arms weapons familiarization; and navigation and engineering professional development. Increased frequency or severity of flood events could result in loss of land or damaged to mission-critical facilities.

Objectives:
Repair and restore the waterfront infrastructure along the North Severn perimeter. The repairs, restoration, and improvements would address structural deficiencies on the existing seawall and potential impacts from future extreme weather events, storm surge, sea level rise, and land subsidence.

Specific restoration and enhancement techniques could include hardened structures and log toe stabilization, where appropriate. Hardened structures include bulkhead, sheet pile seawall, or a combination of these techniques.
General Comments:
Floodproofing that involves extensions to the existing curb/wall face to an elevation that limits the impacts of sea level rise, and the amount of floodwater inundation is recommended. While this approach limits floodwater inundation, localized flooding remains possible due to wave action and partial overtopping during storm events. Thus, NSAA/USNA has chosen to leverage its integrated adaptation framework to create layers of protection and remove the likelihood of single points of failure. This framework includes earthen berms, floodproofing athletic fields, elevation interior roads, combination of dry floodproofing for critical facilities, flood walls, and stormwater improvements provides a balanced mitigation approach that is not overly disruptive as compared with the other mitigation alternatives identified above.

The repair/mitigation recommendations provided herein are broken out by area and prioritized by flood risk potential considering the DRSL sea level rise 2100 scenario. Recommended repairs are hardened structures consisting of riprap berms or steel sheet pile bulkheads. For either of these repair types, NSAA/USNA recommends repairs and improvements to the existing stormwater system, as well as further geotechnical investigation to determine which is more of the root cause of tidal infiltration.

The service life of these recommended repairs and improvements to the waterfront infrastructure is 75 – 100 years with proper maintenance and inspection program (See Table 22). In addition, NSAA/USNA recommends that all future repairs of this infrastructure include a suite of adaptations that will improve the service life of these structures.

Table 22. Low Priority – Upper Yard Structures (recommend addressing repairs within 10 years).

<table>
<thead>
<tr>
<th>Facility Name</th>
<th>Description and Existing Condition</th>
<th>Recommended Repair</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yard Patrol Basin Relieving Platform</td>
<td>Timber sheet pile bulkhead, timber piles and timber deck - Serious condition.</td>
<td>Oversheet with an anchored steel sheet pile bulkhead or an open cell sheet pile wall with a concrete cap installed to EL. 8.5-9.7' NAVD88 depending on the location. Install sacrificial anodes for corrosion protection below water and a concrete fascia for corrosion protection above water. Both recommendations will include permanent fill material below the existing relieving platform which may result in mitigation efforts.</td>
</tr>
<tr>
<td>Yard Patrol Basin Steel Sheet Pile Bulkhead</td>
<td>Steel sheet pile bulkhead with concrete cap - Serious condition.</td>
<td>Oversheet with an anchored steel sheet pile bulkhead with a concrete cap installed to EL. 8.5-9.7' NAVD88 depending on the location. Install sacrificial anodes for corrosion protection below water and a concrete fascia for corrosion protection above water. If the existing deadman system is non-existent or cannot be re-utilized, a new deadman and tieback system will be required.</td>
</tr>
<tr>
<td>Yard Patrol Basin Concrete Encased Bulkhead</td>
<td>Timber sheet pile bulkhead with concrete backfill and cap - Serious condition.</td>
<td>Oversheet with an anchored steel sheet pile bulkhead or an open cell sheet pile wall with a concrete cap installed to EL. 8.5-9.7′ NAVD88 depending on the location. Install sacrificial anodes for corrosion protection below water and a concrete fascia for corrosion protection above water.</td>
</tr>
</tbody>
</table>
These adaptations include wave attenuation features in front of waterfront infrastructure that will incur significant wave energy, sacrificial anodes for corrosion protection of steel below water and concrete fascia for corrosion protection of steel above water. For the concrete, a durable mix design is recommended with sufficient cover to reinforcing steel. Uncoated black bar is recommended in lieu of epoxy coated bar to eliminate any holidays in the epoxy that could potentially create hot spots for corrosion, leading to premature spalling of concrete.

The existing waterfront infrastructure (YP Pier associated dolphins, Marine Railway/Boat Ramp, and Quay Wall- both reaches A & B) have exceeded their service life and require replacement in order meet current codes, accommodate 21 Yard Patrol craft, and resilient to projected climate induced changes in wave action, storm energy, and fetch from the North Severn. More specifically, the following recommendations should be considered:

- Full replacement of the approximately 800' YP Pier at the North Severn YP Basin. The new YP Pier shall be designed to meet the code requirements of UFC 4-152-01, Piers and Wharves. The new pier is intended to accommodate 20 703-class YP boats in a configuration like the existing pier and requires capabilities for Type IIB mooring requirements as specified in UFC 4-149-03, Moorings. The top deck elevation of NAVD88 8.5'. It shall incorporate a structurally independent wave screen;
- Remove equipment and appurtenances that supported the obsolete marine railway ramp; Infill of the approximately 4300SF; Top with concrete and reconstruct/elevate sidewalls to NAVD 88 8.5' to convert the area to a standard boat ramp while maintaining the existing width; Repave and restore the immediate surrounding area;
- Repair Quay Wall Reach “A” (Northern segment) to approximately 670 LF of the quay wall between the existing marine railway ramp and the corner adjacent to the Lift Piers; Relieving platform: backfill the subgrade underneath, repair, and resurface the relieving platform; Reconstruct the Fuel Pier; Repair/reconstruct the covered pier; Design of this segment of the quay wall is preferred to be an iteration of the recent design developed for the USNA Farragut Seawall repairs. This preferred solution provides a concrete faced steel sheet pile wall outboard of the existing bulkhead, attached via tie rods to the addition of a pile-supported deadman system;
- Repair Quay Wall Reach “B”, (Southern segment) to approximately 840 LF of the quay walls covering the length from the Travel Lift Pier to a location of the old airplane ramp. This reach has experienced observable differential settlement and known void development. Design to repair this section of the quay wall will require additional subsurface investigation and the preferred design solution may differ from the northern segment. Design will require modification to or accommodation of the existing Travel Lift Pier and will incorporate / accommodate the reconstructed YP Pier."; and
- The pier is requiring annual maintenance to repair wave damage (~$850K). The reconstruction of the YP Pier and associated infrastructure is expensive and other restoration actions on the installation are priorities. Interviews with NSAA subject matter experts indicated that these annual repairs can currently sustain North Severn operations until other existing waterfront infrastructure repairs and reconstruction efforts have been successfully completed (e.g., Farragut Seawall). Any repairs to the YP Pier and associated basin would require the relocation and mooring of the YP boats until construction is completed. This will include the mooring of YP boats on the Lower Yard for extended periods of time (i.e., Farragut Seawall). The JV agreed the YP
Pier/shoreline restoration could be delayed, and other wave attenuation strategies could be employed.

**Recommended Execution Timeframe:** Medium-term. 2027 – 2037. These waterfront infrastructure improvements should not be undertaken until the waterfront infrastructure on the Lower Yard have been completed. The Lower Yard and most likely Baltimore Harbor will need to actively support the YP Boats while these repairs and improvements are undertaken.

**D. Greenbury Point Project Portfolio**

1.0 **Greenbury Point Shoreline Protection**

**Current Mission:**
The five reaches of the Greenbury Point shoreline are composed of a mixture of revetment (rip rap) and living shoreline. These features protect and stabilize the shoreline from the effects of wave action (e.g., tidal, boat wakes), storm surge, and fetch. The loss of this protection would lead to extensive erosion that will result in loss of land.

**Requirement:**
Located at the confluence of the Severn River and the Chesapeake Bay, NSAA must remain compliant with current federal and state laws governing water resources. This includes compliance with the Chesapeake Bay Total Maximum Daily Load (TMDL). This cleanup plan under the U.S. Clean Water Act (CWA) is a multi-state agreement that sets limits on nitrogen, phosphorus, and sediment pollution necessary to meet water quality standards in the Bay and its tidal rivers. To meet this requirement and assist the installation comply with permits for the discharge of stormwater (MS4), the reduction of shoreline erosion along Greenbury Point would allow NSAA to obtain TMDL credits and be good stewards of these watersheds.

**Current Situation:**
The North Severn Complex of NSAA is located on the north shore of the Severn River and its confluence with the Chesapeake Bay, across from the USNA and the City of Annapolis in Anne Arundel County, Maryland. The North Severn Complex encompasses approximately 850 acres and includes Greenbury Point. The complex is integral to the NSAA/USNA mission as several facilities are located on it including the Navy Exchange, Commissary, Medical Center, Child Development Center, Family Service Center, USNA athletic resources (e.g., USNA Golf Course, Brigade Sports Complex, athletic fields) and USNA Outdoor
Range Facilities. The area is also undergoing development to improve its morale, welfare, and recreation benefits to provide high quality recreation facilities for active duty and veterans.

The North Severn Complex was purchased by the Navy in 1909 for use as a dairy farm. From 1918 to 1996, the Naval Radio Transmitter Facility operated on Greenbury Point. During the Cold War, Greenbury Point was a key communications center for the Navy’s submarine fleet. The antennas at Greenbury Point transmitted signal capable of penetrating the ocean, allowing communications with the submarines. By the early 1990’s, advances in satellite communications made the antennas obsolete. After demolition, only 3 of the 19 antennas remain. The undeveloped land at Greenbury Point is now managed by NSA Annapolis as a resource conservation area with contiguous forest, tidal and nontidal wetlands resources and the surface danger zone (SDZ) for the USNA Outdoor Range Facilities.

Since the 1930’s extensive shoreline protection efforts, including revetments, wooden bulkheads, and earthen berms have resulted in only 12,500 linear feet of shoreline left remaining in natural condition. The remaining shoreline (+20,000 linear feet) are indifferent levels of disrepair and extensive erosion is being observed. To stabilize and restore these areas, NSAA has developed a shoreline restoration management plan that divides the Greenbury Point shoreline into distinct longshore segment of a shoreline where influences and impacts, such as wind direction, wave energy (Reach). Five reaches were selected (i.e., A, B, D, E, and G) for stabilization and restoration (See Figure 59).

Each of the seven reaches are seeing levels of wave action, storm energy, and fetch that is resulting in shoreline erosion. Reach C* is not listed as it is being addressed under stabilization of Greenbury Point berm. Table 23 provides a brief summation of five reaches and the findings of recent observations.

With most of these sites, the primary reasons for shoreline instability and erosion are:
- Erosion from wave action and runoff;
- Instability due to shoreline face being steeper than the natural angle of repose;
- Erosion and weathering of the cliff face due to the lack of vegetation on the steep sections; and
- A 4.2-mile fetch from the Chesapeake Bay.

In addition, there are also several minor causes for cliff erosion and instability at this site. These are:
- Falling trees dislodging chunks of soils within the root mass as they fall;
- Erosion from loss of vegetation from deer foot traffic; and
- Burrowing animals.
Figure 59. NSA Annapolis Shoreline Reaches on Greenbury Point.
Table 23. Description of Individual Reaches on Greenbury Point on NSA Annapolis.

<table>
<thead>
<tr>
<th>Reach</th>
<th>Length (linear feet)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>9,1 60</td>
<td>Reach A includes most of the eastern and southern areas of Greenbury Point and is subject to some of the highest wave action, storm energy, and fetch in the project area, leading to extensive erosion. Portions of the eastern side of Greenbury Point included in Reach A have had some armoring placed at the toe of slope.</td>
</tr>
<tr>
<td>B</td>
<td>1,1 60</td>
<td>Reach B is located on the southwestern portion of Greenbury Point, which also exhibits extensive erosion; however, the wave energy and fetch is not as great as Reach A.</td>
</tr>
<tr>
<td>D</td>
<td>D1 7,5 30</td>
<td>Reach D includes the shoreline of Carr Creek and has been divided into D1 and D2. Reach D1 was the subject of the Carr Creek Shoreline Survey, Riparian Habitat Conceptual Restoration Design Report in 2013, and Reach D2 includes the remainder of the Carr Creek shoreline adjacent and like D1, but not included in the survey. Carr Creek areas are experiencing erosion due to wave and storm energy and slope saturation.</td>
</tr>
<tr>
<td>D</td>
<td>D2 1,6 00</td>
<td>Reach D includes the shoreline of Carr Creek and has been divided into D1 and D2. Reach D1 was the subject of the Carr Creek Shoreline Survey, Riparian Habitat Conceptual Restoration Design Report in 2013, and Reach D2 includes the remainder of the Carr Creek shoreline adjacent and like D1, but not included in the survey. Carr Creek areas are experiencing erosion due to wave and storm energy and slope saturation.</td>
</tr>
<tr>
<td>E</td>
<td>1,4 00</td>
<td>Reach E includes the area on the east side of the Carr Creek Marina and is also subject to high wave action, storm energy, and fetch.</td>
</tr>
<tr>
<td>G</td>
<td>2,5 00</td>
<td>Reach G includes the remainder of the Mill Creek shoreline areas, which is experiencing erosion of the banks.</td>
</tr>
</tbody>
</table>

*Reach C is not listed as it is being addressed under stabilization of Greenbury Point berm.

Impacts if not Provided:
The impacts to the mission of NSA Annapolis if not implemented include further degradation of soils that could lead to stabilization impacts to surrounding structures and the potential for a large block failure resulting in nonpoint source pollution. In addition, soil failures over time accumulate and could adversely impact the Chesapeake Bay with sediment runoff. This effort supports the requirement of the Sikes Act and the NSAA Integrated Natural Resources Management Plan (INRMP) to mitigate soil erosion and conserve property. INRMPs offer a coordinated approach for incorporating ecosystem management efforts into the management of natural resources at DoD installations.

Objective:
The purpose is to design and construct shoreline stabilization measures using low impact shoreline restoration using log toe, log sill, rock sill, and marsh creation techniques. Specifically, the work shall create structural stability along the indicated shoreline. Native plantings shall be used in the marsh creation areas as appropriate for shoreline stabilization. This will also involve a wetland verification using the new CWA definitions.

General Comments:
The goal for shoreline stabilization, is to design and obtain the permits for shoreline restoration and stabilization measures for the five reaches. These restoration and stabilization techniques should utilize the preferred methods of log toe, log sills, rock sills and marsh creation to provide structural repair and
erosion prevention measures to restore and stabilize the shoreline. A summation of these alternatives is provided below in Table 24.

Table 24. Description of Repair and Restoration Methods on Greenbury Point on NSA Annapolis.

<table>
<thead>
<tr>
<th>Reach</th>
<th>Repair and Restoration Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaches A and E</td>
<td>Hardened Structure/Revetment - The hardened structure/revetment includes 1) armoring of the lower portions of the slope utilizing riprap (or similar) of appropriate size; 2) a geotextile fabric underlay for stabilization and erosion control; and 3) grading of the upper portions of the embankment to a less erosive slope. The work for the hardened structure/revetment would be accomplished either from on land, in the water, or a combination of the two depending on the land and water constraints in the various work areas.</td>
</tr>
<tr>
<td>Reaches B, D, and G</td>
<td>Living Shoreline - Living shoreline techniques include the use of sills, groins, or breakwaters in combination with sand, and other natural materials. Living shoreline restoration includes the installation of marsh and riparian plants for stabilization and to create/improve upland and wetland habitat. A breakwater may be installed, consisting of a trapezoidal stone structure, for the purpose of dissipating wave energy before waves reach the shore. This alternative would be utilized in areas with lower wave energy where installation of this type of restoration measure would be most successful. This technique would also include potential grading of the upper portions of the embankment to a less erosive slope, where appropriate. This work would be accomplished either from on land, in the water, or a combination of the two depending on the land and water constraints in the various work areas.</td>
</tr>
</tbody>
</table>

Recommended Execution Timeframe: Medium-term. 2027 – 2037. Several reaches have been restored and there is active construction planned of another reach. Only those reaches that have not been completed will need to be addressed.

2.0 Stabilization of Greenbury Point Berm

Current Mission:
The Greenbury Point berm was established to capture and store dredge disposal materials that were generated from the 25-year dredge maintenance program at U.S. Naval Air Facility Annapolis. Located on the west side of the Greenbury Point peninsula, near Carr Creek and the mouth of the Severn River this
berm ensures that these dredge disposal materials do not discharge into Carr Creek, the Severn River, and Chesapeake Bay.

Requirement:
In order maintain flight operation at the facility, several maintenance dredges were performed near and adjacent to the facility and the dredge disposal materials were stored on Greenbury Point behind a berm. Since these dredge activities were performed around an active seaplane base the resulting dredge disposal materials have been found to be contaminated with high levels of heavy metals. To ensure that there is not a potential release of heavy metal contaminated lagoon sediments into Carr Creek, Severn River from current and projected flooding events (e.g., storm surge, sea level rise) an immediate environmental restoration action is being recommended (e.g., reconstruction of the berm or relocation of the dredge disposal materials to an approved site).

Current Situation:
The North Severn Complex of NSAA is located on the north shore of the Severn River and its confluence with the Chesapeake Bay, across from the USNA and the City of Annapolis in Anne Arundel County, Maryland. The North Severn Complex encompasses approximately 850 acres and includes Greenbury Point. The complex is integral to the NSAA/USNA mission as several facilities are located on it including the Navy Exchange, Commissary, Medical Center, Child Development Center, Family Service Center, USNA athletic resources (e.g., USNA Golf Course, Brigade Sports Complex, athletic fields) and USNA Outdoor Range Facilities. The area is also undergoing development to improve its morale, welfare, and recreation benefits to provide high quality recreation facilities for active duty and veterans.

The North Severn Complex was purchased by the Navy in 1909 and became of the first naval aviation base in 1911. Responsible for training and experimentation of seaplanes, this aviation facility only remained open for a few years and was transferred to Pensacola, Florida in 1914. In 1927, a naval aviation program was reestablished at a dock at USNA so that Midshipmen could begin obtaining flight instructions as part of their academic program. These education efforts were further expanded in 1937 when a 16 acres site near the 1911 site was constructed at Greenbury Point becoming the U.S. Naval Air Facility Annapolis. Active until January 17, 1962, this facility maintained several different squadrons of seaplanes over its 25 years of operation (e.g., 5 large twin-engine PBM Mariner seaplanes, 19 smaller twin-engine JRF Goose seaplane, and 35 N3N "Yellow Peril" biplane floatplanes).

In order maintain flight operation at the facility, several maintenance dredges were performed near and adjacent to the facility and the dredge disposal materials were stored on Greenbury Point behind a berm. The Greenbury Point berm is located on the west side of the Greenbury Point peninsula, near Carr Creek and the mouth of the Severn River. The berm is constructed of soil and fortified with large concrete debris and other disposed material. There is vegetation that covers most of the berm where soils are exposed, and rubble is not present. Urgent stabilization measures have been implemented to prevent the outer berm wall failing by removing mature trees along the berm, installing berm armoring, and resetting the existing water control structure to a lower invert elevation.

Impacts if not Provided:
An urgent environmental restoration measure is required to prevent the potential release of heavy metal contaminated lagoon sediments into Carr Creek, Severn River, and Chesapeake Bay. The potential release of these sediments into these water bodies would be extremely detrimental to these water bodies and
have long-term environmental impacts. The U.S. Navy would be liable for any associated environmental damages to these water bodies, their socio-economic impacts on fisheries, and potential impacts to public health.

**Objective:**
To undertake an environmental restoration action that contaminated dredge disposal material are not discharged into Carr Creek, Severn River, and Chesapeake Bay. The resulting actions could include:

1) Rehabilitation of the existing berm by installing a water control structure to relieve head pressure within the spoil area during storm events and construct a small breakwater along portions of the berm.
2) Undertake an environmental remediation action to remove all contaminated dredge disposal materials from behind the berm and relocate them to an EPA approved site.

**General Comments:**
On 31 August 2016, NAVFAC Washington released a solicitation for the stabilization of the Greenbury Point berm but chose not to award this contract. The proposed action required the implementation of a government approved design that would use a combination of vinyl sheeting and porous cellular concrete as backfill to reconstruct the existing berm. Current sea level rise and extreme water level events project that the Greenbury Point is highly susceptible to flooding and it that will be extremely difficult for NSAA to continue to contain these dredge disposal materials even if the proposed 2016 reconstruction efforts were performed. Hardening the berm will only delay climate-induced impacts to the berm and associated shoreline stabilization actions on the segment of shoreline. It is recommended that the installation should consider this environmental remediation action and remove the contaminated dredge disposal materials from this location. The associated ROM cost estimate was developed assuming that NSAA would follow this recommendation and that environmental remediation would be performed. A cost benefit analysis indicated that this remediation action was significantly less than the cost of restoration if a discharge of the contaminated soils occurred. However, it is not cheaper than the proposed 2016 berm reconstructions which was less than $2.5 million in 2016.

**Recommended Execution Timeframe:** Short-term. 2023 – 2027.
Execution Plan
XIII. EXECUTION PLAN

In the previous section a concerted effort was made to further evaluate the merits of the proposed project portfolio and integrated adaptation framework. NSAA/USNA invested time and resources to perform a BCA, refine its original technical feasibility assessment, evaluate appropriateness of the portfolio, and clarify the installation’s risks. Following the methodology outlined in this plan (and Stage III of the Handbook) this exercise allowed NSAA/USNA to gain additional insights into the portfolio, but more importantly, it validated the integrated adaptation framework and provided the installation the assurances it required.

As NSAA/USN was beginning to finalize this project portfolio, an insightful question arose:

“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 repairs and improvements to the NSAA waterfront infrastructure near the City of Annapolis, City Dock will require complicated permitting, community involvement, and significant financial investment, is it feasible that this adaptation alternative cannot be built before unacceptable impacts occur.”

While the response to this question was – ‘yes’, NSAA/USNA leadership realized that it required more visibility into implementation of these adaptation alternatives and the interdependencies that occurred with the integrated adaptation framework.

As the methodology conveys, NSAA/USNA understood that the first three Stages of the Handbook and their associated examinations would assist in the down selection of the final set of adaptation action alternatives to be included in the “portfolio” of adaptations. In this, the fourth and final Stage, the twenty-eight (28) preferred adaptation action alternatives have been selected after further analysis. NSAA/USNA has obtained a better appreciate of the life cycle cost and cost-effectiveness of the adaptation alternative as a component of a broader integrated adaptation framework. Specifically, this Stage IV is expected to assess future variables and formally compile action alternatives into a Portfolio Summary that will be captured in the Stage IV worksheet.

Inherently, the completion of Portfolio Summary is invaluable to the installation, but NSAA/USNA need a product that was more actionable. The installation needed the Portfolio Summary and this comprehensive resilience plan to quickly evolve into an execution plan. PWD Annapolis required a tool that would allow them to plan, design, and execute this integrated framework logically and efficiently. The climate-induced threats to the installation are imminent.

NSAA/USNA chose to leverage and maximize a tool that was already at their disposal and is frequently used by NSAA subject matter experts to support large MILCON actions on the installation. They chose to capture the Portfolio Summary in Microsoft Projects. This decision to use this Microsoft Office 365 program were as follows:

- What Is Microsoft Project? Microsoft Project is a project and work management solution that enables all professionals who manage projects to stay on top of the changing requirements of their day-to-day jobs. It provides tools that are simple for anyone to use, flexible for any project type, powerful for initiatives of any size, and transparent for visibility across the organization. The
software offers a simple and intuitive interface where users can switch between grids, boards, or Gantt charts to track progress. It integrates with Microsoft Teams to support collaboration where team members can share files, chat, or hold meetings. Distributed teams can coauthor or edit tasks simultaneously. Automated scheduling based on effort, duration, and resources help teams stay on track;

- **Project Management.** Microsoft Project software comes with familiar scheduling tools where users can list tasks, assign them to team members, and set details such as duration and due date. It includes different views like grid view, board view, and timeline/Gantt chart view where project managers can oversee schedules. As a collaborative software, it allows co-authoring so project teams can work together with other stakeholders to edit and update task lists, project schedules, dependencies, and priorities. Teams can use it also for timesheet submission as it captures project and non-project time and linked to payroll or invoicing;

- **Portfolio Management.** Project allows users to manage multiple projects and programs of a company and provide information as to which initiatives should have priority. Modern features such as business intelligence can model different scenarios and help organizations determine the best path and the higher value. It has features to help evaluate and weigh project proposals against business goals and drivers. Companies can also use Microsoft Project management software for demand management as a tool to capture ideas across departments and check them against a standard process;

- **Resource Management.** Microsoft Project lets teams forecast resource needs, predict bottlenecks early, manage utilization, and ensure timely project delivery. Users can define the project team, know when to request resources for the project, and assign tasks to resources. Additionally, they can view and compare resource utilization across projects. Pre-built reports can help them track progress on resources and on projects, programs, and portfolios;

- **Integration.** Project integrates with the ubiquitous Microsoft 365 Office suite. The project management software also works seamlessly with Microsoft Teams, Skype, Power BI, and Sharepoint, with easier integration to Azure and other Microsoft platforms. The ribbon interface is like various Microsoft products, such as Excel;

- **Dependability.** Microsoft Project software is a pioneer among project management tools. Commercially released in 1984, it is a stable software that continually gets enhanced for more relevant features that suit the needs of its users;

- **Customer Support.** Microsoft as a reputable software company provides reliable support to its users. Partners, consultants, and third-party support services are available for this software; and

- **Flexibility.** Microsoft Project management software is flexible enough for other purposes such as a road mapping tool or for financial management. The deployment options as on-premises or cloud-based solution also provides teams and companies more choices to fit user requirements.
As described above, this program can be an invaluable resource to NSAA/USNA. The capabilities and associated benefits align with the Stage IV goals outlined in the methodology outlined in this plan. Microsoft Project allows NSAA/USNA to:

- Consider how future events and trends can influence decision making;
- Consider finance and funding options (and most importantly when funding needs to be programmed);
- Build in climate change data reviews, triggers, and signals that may help inform when action should be taken;
- Identify potential timeframes for implementation and key decision points; and
- Most importantly, the execution timeframes were developed to provide NSAA/USNA a “must be installed date” based on date a project must in in ground to mitigate risk and backing the date out from there to allow for planning and design components to take place. Specifically, the execution timeframes are “requirements” that will need to be met to ensure mission is not impacted.

The resulting Portfolio Summary in Microsoft Project summarizes all identified strategic approaches and reflect NSAA/USNA leadership’s risk management priorities. More importantly, the Portfolio Summary created recommendations for combining action alternatives for how alternatives should be phased (i.e., creation of an execution plan), where interdependencies between alternatives occurred, and how this portfolio of projects and the integrated adaptation framework will mitigate risk from all flood sources (land subsidence, sea level rise, coastal flooding/storm surge, stormwater) to 2100.
Figure 60. Execution Plan (Present to 2065).

Figure 61. Execution Plan (Present to 2065).
Benefit Cost Analysis
XIV. BENEFIT COST ANALYSIS

The analysis of costs and benefits can significantly assist DoD, Navy, and NSAA/USNA leadership in working out the best strategy for using scarce economic resources for the most effective adaptation approach and help prioritize and time resilience investments. Cost–benefit assessments are often used to appraise the desirability of a given action or investment. The analysis can help to predict whether the benefits of a measure outweigh its costs in relation to other alternatives (i.e., it allows to rank alternative measures in terms of the cost–benefit ratio).

Adaptation costs are understood to be the "costs of planning, preparing for, facilitating, and implementing adaptation measures, including transition costs" (IPCC, 2021) and the benefits are "the avoided damage costs or the accrued benefits following the adoption and implementation of adaptation measures" (IPCC, 2021). Because almost no adaptation action can fully eliminate a climate change impact and the associated risk, the costs of the residual risk (the remaining impacts after the implementation of the adaptation action) also need to be considered.

Assessing the costs and benefits of adaptation options can be undertaken more narrowly considering financial budgetary costs and benefits only or more comprehensively considering the wider costs and benefits to the operations and maintenance of NSAA. In addition, community and environmental costs and benefits may also be included in cost-benefit assessments. NSAA/USNA recognizes it is especially important to include non-monetized costs and benefits, in the assessments of adaptation options to realistically account for the full range of benefits and costs, even though they are more difficult to express in monetary terms.

For these reasons, NSAA/USNA decide a full benefit cost analysis (BCA) may not be beneficial. Because of NSAA/USNA’s unique education mission and cultural heritage it would be extremely difficult to accurately capture non-monetized cost and benefits. How do you value of intercollegiate sports, a sailing program, or a National Historic Landmark? Consequently, NSAA/USNA chose to perform a preliminary BCA following guidance provided in the Stage III of the Handbook with intention of obtains measures of merit for adaptation alternatives defined in Stage II. These measures of merit included benefit cost ratios (BCR), net present values (NPV), and internal rates of return (IRR) provided monetized metrics that were used to preliminarily rank each of the adaptation alternatives outlined in the previous section of this comprehensive resilience plan.

NSAA/USNA has chosen to align this summation to the steps outlined in Stage III of the Handbook. Associating the narrative of the overall analysis, methodologies used, assumptions, results, and conclusions to the steps in the Handbook should create transparency and support for future analyses. The steps were:

**Step 1: Defining Adaptation Action Alternatives:**

Following NSAA/USNA’s application of Stage II of the Handbook, an initial list of 28 Adaptation Action Alternatives were provided to carry forward to Stage III (note that certain actions were to remain in the project portfolio; however, further analysis would not be conducted). These alternatives were proposed using an integrated adaptation framework and were assigned to the four defined areas of concern –
including the Lower Yard (11 alternatives), Upper Yard (10 alternatives), North Severn (5 alternatives), and Greenbury Point (2 alternatives).

Step 2: Assigning Geospatial Area to Alternatives

NSAA/USNA understood that the adaptation alternatives needed to be grouped and/or allocated to certain geospatial areas to quantify benefits and “performance metrics” as part of Stage III. This was a necessary step to not only consider what assets on the installation were being protected because of the adaptation alternatives – but also, this allowed a better temporal awareness of when adaptation alternatives needed to be constructed (in place) for protection, and when related benefits (or damage avoidance) could be captured in the analysis.

It was determined that the most appropriate geospatial allocation of the adaptation alternatives would be by drainage basin, which had a natural linkage to water movement and flooding issues experienced at the installation. Therefore, the 28 adaptation alternatives for the four areas of concern were allocated into twelve drainage basin areas noted in the table below (Table 25).

### Table 25. Geospatial Allocation of the Stage II Adaptation Alternative by Drainage Basin on NSA Annapolis.

<table>
<thead>
<tr>
<th>Area</th>
<th>Drainage Basin</th>
<th>Planning Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area 1</td>
<td>Lejeune Hall</td>
<td>Lower Yard</td>
</tr>
<tr>
<td>Area 1b</td>
<td>Halsey Field House</td>
<td>Lower Yard</td>
</tr>
<tr>
<td>Area 2</td>
<td>Ingram Field</td>
<td>Lower Yard</td>
</tr>
<tr>
<td>Area 2b</td>
<td>Santee Basin</td>
<td>Lower Yard</td>
</tr>
<tr>
<td>Area 3</td>
<td>Brownson Road</td>
<td>Lower Yard</td>
</tr>
<tr>
<td>Area 4</td>
<td>Alumni Hall</td>
<td>Lower Yard</td>
</tr>
<tr>
<td>Area 5</td>
<td>College Creek</td>
<td>Lower Yard</td>
</tr>
<tr>
<td>Area 6</td>
<td>Price Memorial</td>
<td>Upper Yard</td>
</tr>
<tr>
<td>Area 7</td>
<td>Hubbard Hall</td>
<td>Upper Yard</td>
</tr>
<tr>
<td>Area 8</td>
<td>Upper College Creek</td>
<td>Upper Yard</td>
</tr>
<tr>
<td>Area 9</td>
<td>North Severn Waterfront</td>
<td>North Severn</td>
</tr>
<tr>
<td>Area 10</td>
<td>Greenbury Point</td>
<td>Greenbury Point</td>
</tr>
</tbody>
</table>

Step 3: Defining Life Cycle Costs and Performance Metrics

Using Worksheet III.1 (Appendix E) – LCCA Grouping of the Stage III worksheets, the grouped adaptation alternatives were assigned an estimated cost. Certain adaptation alternatives in a particular area of concern crossed into two or more drainage basins (i.e., the earthen berm) and the costs were allocated based upon the proportion of the adaptation alternative in the drainage basin. The ROM costs was developed using professional experience, other similar projects where the contracting team had experience, and researching similar projects elsewhere in the U.S. A 15% contingency was added to all ROM cost estimates, and all amounts at this step are in present day dollar values.

In addition, the geospatial allocation of the alternatives to the various drainage basins on the installation allowed for the NSAA/USNA to use the “NSAA/USNA Sea Level Rise and Vulnerability Exposure Analysis Viewer (SRVEAV)” online modeling tool to estimate both the level of inundation and the point at which
that asset is impacted using their 2035, 2065 and 2100 year and the sea level rise/extreme water level event scenarios developed.

Using the GIS layers for building footprints in the drainage basins, an intersect analysis was performed to capture the square footage of buildings protected (i.e., the performance metric) within the drainage basins to use in the Cost Effectiveness Analysis (CEA) – Worksheet III.2 (Appendix E) - CEA. This information, combined with the life cycle costs of the adaptation alternatives within that drainage basin, provided the cost per unit to protect assets in that area – and allowed for the ability to compare the protections offered in the areas. The table below (Table 26) presents the results of the CEA, which is Step 2 of Stage III.

**Step 4: Benefit Estimations**

Below are different benefits categories that were captured as part of the Stage III analysis, including damage avoidance to buildings, damage avoidance to building contents, damage avoidance to non-building assets, and other categories. These benefit estimates were then populated in Worksheet III.4.2 (Appendix E) – Benefits for each drainage basin area – and then rolled up into the integrated worksheet for the entire installation - Worksheet III.3 – Benefits Grouping.

- **Damage Avoidance – Buildings:** Tiering off the building square footage estimates for the performance metric under the CEA, the team applied the replacement value of buildings impacted from the iNFADS database. These benefits were captured in the Excel workbook and had a worksheet for each of the twelve drainage basins that listed the adaptation alternatives for that area, the building details, as well as the replacement value and percentage within the drainage basin (when a building was in more than one basin).

  The buildings throughout NSAA/USNA have various first floor elevations, various numbers of stories, and other attributes that would affect the amount of damage if would incur if inundated. To estimate these specifics for each of the buildings throughout the entire installation was beyond the scope of this analysis; therefore, an installation-wide percentage was assumed at 30% damage if the building was inundated;
The next step was to use the SRVEAV model to capture what year (2035, 2065, or 2100) the building would be impacted and under which scenario (SLR or EWL), which would dictate how the damages would be discounted over time. These figures are also captured in the Full BCA Metric workbook. It was decided that for 2035, the SLR water levels would be used to assess avoided building damage, and for the 2065 and 2100 years, the EWL event levels would be used.

These damage avoidance figures from the Full BCA Metric workbook were then transferred to the Stage III worksheets for each drainage basin/area (Worksheets III.4.2 – Benefits) and assigned to the year in which the benefit of protecting that building asset would be realized (i.e., 2035, 2065, or 2100);

- **Damage Avoidance – Building Contents:** A second benefit captured is the avoided damage to building contents, where 25% of the building damage avoided was also applied with the assumption that furniture, equipment, supplies, etc. would be damaged should the building be inundated;

- **Damage Avoidance – Other Non-Building Assets:** In conducting this analysis utilizing the iNFADS dataset and capturing avoided damage to buildings, it was quickly identified that there are many other assets at NSAA/USNA that are valuable assets that could be protected through the implementation of the adaptation alternatives; however, they were not buildings and there was no assigned value or entry in iNFADS. Therefore, this analysis included the incorporation of several of the more significant non-building assets, including 1) athletic fields, 2) Santee Basin Marina, 3) North Severn Marina, 4) various roadways. These were quantified and allocated to the drainage basin where they are located.

For Greenbury Point, due to it inherently having more greenspace and far less buildings than the other areas, the analysis was adjusted to capture the number of acres protected from erosion instead of protection of building assets. To do this, the number of acres were calculated using GIS and a price per acre of $100K was applied; and

- **Other Benefits Not Captured:** There were other benefits that were not able to be quantified in the Stage III analysis due to various reasons, which if captured and monetized, they could serve to improve the overall benefit-cost ratio metrics. These included such benefits as the lost academic days for students at the USNA, cleanup efforts associated with significant storm events, potential damages to vehicles and other equipment and damage to the underground utility tunnel system, among others.
Step 5: Stage III Metrics

As noted previously, to allow for an examination of each drainage basin individually as well as an evaluation of the overall integrated approach, separate worksheets were developed for the Benefit Cost Ratio - Net Present Value (BCR-NPV) calculations. For each drainage basin, these worksheets include Worksheets III.4.2 (Appendix E) – BCR NPV, and for the entire installation, this is captured in Worksheet III.4.1 BCR NPV Grouping.

Worksheet III.4.1 BCR NPV Grouping, which rolls up all the individual worksheets, captures both the life cycle costs and the benefit values by year for all drainage basins, and adaptation alternatives. A Discount Rate of 7% was applied to future years to arrive at a cumulative present value for all costs and benefits (noted at the bottom of the table [Row 88]). These figures were then used to calculate three metrics – 1) the Benefit Cost Ratio (BCR), 2) the Internal Rate of Return (IRR), and 3) the Net Present Value (NPV). These were also calculated by drainage basin in the individual, separate worksheets.

Overall, Worksheet III.4.1 BCR NPV Grouping shows that the integrated adaptation alternatives as currently constructed and using the benefits that were able to be captured would have a BCR of 0.18, with the different drainage areas ranging from 0.03 to 1.08. The CCPH notes that a BCR of greater than 1 means the project is “economically feasible,” meaning there are more benefits than costs. In the case of the proposed adaptation alternatives using the integrated, installation-wide approach, the BCR is less than 1 as are most of the individual drainage basin areas, which are presented in the table below (Table 27).

Step 6: Conclusions and Observations

Although the BRC, IRR and NPV of the adaptation alternatives for the drainage basins primarily do not show that the benefits would outweigh the costs of these climate change resiliency projects, there are several factors that could greatly impact the analysis and BRC. Two prominent factors are the discount rate utilized and the benefits captured.
This analysis utilized a discount rate of 7% per Circular No. A-94 — “Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs.” However, a lower discount rate closer to 5% may be warranted and more reasonable. Since by the nature of the adaptation alternative needing to be constructed in some period before the associated benefit would be realized, the period between the cost and the benefit is greatly affected by the discount rate.

As noted earlier in this summation, there are certain benefits that were not monetized in this analysis for various reasons. The inclusion of those benefits would also impact the BCR and other Stage III metrics. In addition, it was noted that the iNFADS database is replacement of assets at the lowest cost, and therefore may not represent the actual value of building assets at NSAA/USNA. However, this was the best data source available and there was not consensus on if or how these values should be adjusted. In addition, there are many historically significant assets at NSAA/USNA and intrinsic values to the layout of the facility with the connection of academic buildings, waterfront/marinas, athletic fields, etc., which would be extremely challenging to recreate or replace.

In conclusion, this preliminary BCA was productive and beneficial. It allowed NSAA/USNA to have confidence in the preliminary portfolio of action alternatives that have been developed and provided invaluable insights into merits of the integrated adaptation framework that has been established. Although, several factors greatly impacted NSAA/USNA this analysis and BRC, it provided the assurances NSAA/USNA required to further evaluate the technical feasibility, appropriateness, and risks associated with this project portfolio.

**XV. TECHNICAL FEASIBILITY, APPROPRIATENESS, AND RISK**

Although not outlined in Stage III of the Handbook, NSAA/USNA chose to circle back to Stage II and further evaluate the technical feasibility, appropriateness, and risk associated with each of adaptation alternatives in the project portfolio after the BCA was completed. The objectives were to further evaluate whether the installation had the adaptive capacity to support the proposed integration adaptation network, ensure that this propose framework would improve the resilience of the installation, and characterize the risks NSAA/USNA will be undertaking.

To accomplish these objectives NSAA/USNA worked closely with the SLRAC, NSAA subject matter experts, and vested stakeholders to address several pertinent questions. Questions were divided into three categories (i.e., technical feasibility, appropriateness, and risk) and responses were obtained using several mechanisms (e.g., on-site charrette-like meeting, virtual meetings, focal group discussions, and in-person interviews). Every effort was made to ensure that questions were provided to a large, multidisciplinary audience that could provide different thoughts and perspectives. The ultimate goals were to ensure that this new evaluation met the objectives set forth and
that the responses would assist NSAA/USNA refine adaptation alternatives, the project portfolio, and the integrated adaptation framework, if appropriate.

1.0 Further Evaluation of Technical Feasibility

NSAA/USNA evaluation began with a thorough review of each adaptation alternative. To structure this review NSAA/USNA leadership refined its technical feasibility criteria to ask SLRAC, NSAA subject matter experts, and vested stakeholders the following questions:

- 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?
- Are there a current NSAA Installation Development Plan that includes programmed projects that cannot be relocated?
- Do any legal or regulatory plans, policies, regulations, or design standards impede use of the action alternative?

It is important to note that questions presented here are meant to provide examples and illustrate how NSAA/USNA facilitated the decision-making process by identifying existing enabling conditions and how effort could improve adaptation alternatives and the integrated adaptation framework. Additionally, the audience was asked to assess conceptual designs. Unless a design had been previously contracted by NSAA, the audience was asked to review and provide responses on new concepts or vet similar actions performed by federal, state, or municipal agencies.

Every effort was made to leverage these interactions to evaluate and refine ROM cost, engineering feasibility, risk reduction, and historical/cultural, regulatory, and environmental and hydrologic considerations for each adaptation alternative. Consequently, this exercise identified several data gaps (e.g., geotechnical surveys, hydrodynamic models, space utilization data) that will need to be obtained if the project portfolio were to be finalized.

1.1 Relevant Laws and Regulations

Of particular interest were the legal and regulatory issues that may need to be navigated if the proposed integrated adaptation framework was implemented. As shared earlier in this comprehensive resilience plan, a concerted effort has been made to ensure this comprehensive resilience plan and associated deliverables are compliant with all primary federal, DoD and Navy requirements relating to climate change. For this technical feasibility assessment, NSAA/USNA needed to ensure that the proposed action alternatives that composed the project portfolio aligned with current Executive, Federal and State laws, statutes, regulations, and policies pertinent to the implementation of the Proposed Action, including the following:

- NEPA (42 U.S. Code [U.S.C.] sections 4321–4370h), which requires an environmental analysis for major federal actions that have the potential to significantly impact the quality of the human environment;
- CEQ Regulations for Implementing the Procedural Provisions of NEPA (40 Code of Federal Regulations [CFR] parts 1500–1508);
Navy regulations for implementing NEPA (32 CFR part 775), which provides Navy policy for implementing CEQ regulations and NEPA;
- Clean Air Act (42 U.S.C. section 7401 et seq.);
- Clean Water Act (33 U.S.C. section 1251 et seq.);
- Rivers and Harbors Act (33 U.S.C. section 407);
- Coastal Zone Management Act (16 U.S.C. section 1451 et seq.);
- National Historic Preservation Act (54 U.S.C. section 306108 et seq.);
- Endangered Species Act (16 U.S.C. section 1531 et seq.);
- Magnuson-Stevens Fishery Conservation and Management Act (16 U.S.C. section 1801 et seq.);
- Marine Mammal Protection Act (16 U.S.C. section 1361 et seq.);
- Migratory Bird Treaty Act (16 U.S.C. section 703–712);
- Bald and Golden Eagle Protection Act (16 U.S.C. section 668–668d);
- Comprehensive Environmental Response, Compensation, and Liability Act (42 U.S.C. section 9601 et seq.);
- Emergency Planning and Community Right-to-Know Act (42 U.S.C. sections 11001–11050);
- Federal Insecticide, Fungicide, and Rodenticide Act (7 U.S.C. section 136 et seq.);
- Resource Conservation and Recovery Act (42 U.S.C. section 6901 et seq.);
- Toxic Substances Control Act (15 U.S.C. sections 2601–2629);
- Executive Order (EO) 11988, Floodplain Management;
- EO 12088, Federal Compliance with Pollution Control Standards;
- EO 12898, Federal Actions to Address Environmental Justice in Minority Populations and Low-income Populations;
- EO 13045, Protection of Children from Environmental Health Risks and Safety Risks;
- EO 13175, Consultation and Coordination with Indian Tribal Governments;
- EO 13834, Efficient Federal Operations;
- National Defense Authorization Act for Fiscal Year 2019, section 2805; and
- Maryland Living Shoreline Protection Act (Maryland House Bill 973).

Once the legal, regulatory, and technical feasibility questions were addressed, an effort was made to ask about and obtain responses associated with appropriateness of the project portfolio.

2.0 Further Evaluation of Appropriateness

Appropriateness reflects how well the solution fits into the overall planning context of NSAA/USNA. At this point, NSAA/USNA felt it should be possible to eliminate some obvious “poor fit” adaptation alternatives. An example of an obvious poor fit is an offshore breakwater across a boat basin access route. The alternatives in the project portfolio will be, to the greatest extent possible, consistent with NSAA/USNA 2100 planning vision. NSAA/USNA understood adaptation measures and the entire integrated adaptation framework will change and evolve. Fundamentally, a technically feasible adaptation alternative that aligns well with integrated adaptation framework should not be considered inappropriate unless the action would contradict many or most of the installation’s future planning goals. Consequently, NSAA/USNA asked the following questions:

- 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?
- Will the adaptation require the involvement of the City of Annapolis or multiple organizations to implement the approach?
- Would the approach generate controversy or inconvenience to others?

The responses to these questions tended to be a lot more subjective. It was difficult for the audience to assess and comprehend the spatial and temporal constraints the installation is projected to endure or how the NSAA/USNA mission may evolve in the future (i.e., 2035, 2065, 2100). However, the information garnered from it was beneficial.

### 3.0 Characterize Risk Approach

Finally, efforts were made to better characterize any perceived risks associated with project portfolio and the integrated adaptation framework. Unlike the previous efforts, these questions tended to be directed at NSAA/USNA leadership, and a more structured approach was employed to facilitate these discussions. Specifically, four general strategies were leveraged to reflect different levels and approaches to risk management (adapted from Sheehan, 2010). The strategies were:

- **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 for NSAA/USNA to assume the risk and continue with current workarounds (e.g., sandbagging and door dams), rather than implementing adaptation actions. Current design standards may already have sufficient safety margins to account for climate change impacts (e.g., Hopper Hall). 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 for NSAA/USNA to either rely on another entity to address the risk or to share responsibility for the adaptation action with other stakeholders. For example, are there opportunities for the City of Annapolis to share an interest in undertaking adaptation projects and can share the cost and implementation responsibilities for some types of adaptation actions along Prince George, Randall, and King George Streets? 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 for NSAA/USNA to control the exposure of the installation to the hazard. It may be necessary to revise development plans and land use designs 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 an additional line of defense (e.g., wave attenuation features); and
- Avoid risk: If the impact magnitude is expected to be catastrophic (with permanent damage and loss of infrastructure service), it may be necessary for NSAA/USNA to avoid the risk entirely by implementing adaptation actions that eliminate exposure to the hazard or minimize the severity of the impact from the hazard.

This structured approach assisted NSAA/USNA to drive to four pertinent questions.

- Is NSAA/USNA willing to assume risk?
- Are there opportunities for NSAA to transfer or share risk?
- Is NSAA/USNA able to control risk?
- Where are there opportunity able to avoid risk?

NSAA/USNA’s thorough assessment of technical feasibility, appropriateness, and risk was time consuming and required several large and small group engagements and in-person interviews to complete. To NSAA/USNA’s satisfaction, this discussion did not result in substantive changes to the portfolio of projects referenced in the previous section or the integrated adaptation framework. More importantly, these engagements appeared to validate the framework that NSAA/USNA had proposed.

However, these technical feasibility efforts did highlight several regulatory drivers, sociopolitical constraints, and cultural heritage issues that will need to be further evaluated for several projects within the portfolio. For example:

1) Environmental - NSAA/USNA has worked to closely with NAVFAC Washington, State of Maryland, and USACE to ensure that current and planned (i.e., in the Program Objective Memorandum Cycle) resilience efforts have met all regulatory requirements (e.g., NEPA, permitting). However, several proposed adaptations (e.g., wave attenuation, earthen berms) have not and will need to be addressed.

2) Sociopolitical – The resilience efforts of the City of Annapolis and surrounding communities do not share the same planning vision of NSAA/USNA (e.g., 2100). Several proposed projects (e.g., flood wall along Prince George Street) may be received by the community with some trepidation. Every effort must be made to ensure that the community continues engaged in future resilience efforts.

3) Cultural Heritage - USNA is steeped in tradition. It is more than a nationally recognized institution of higher education. It is a National Historic Landmark. Any planned adaptations must be respectful of the institution cultural heritage and its existing architecture.

That said, the installation recognizes that assessing resilience is an iterative process, and these types of discussions will need to continue to occur. This comprehensive resilience plan will provide foundation for future efforts but must be considered a living document that will need to be refined and improved as new information becomes available and this planning process evolves into the implementation phase.
Conclusion/Path Forward
XVI. Conclusion/Path Forward

Future Data and Information Needs

As stated in earlier in this document, this comprehensive resilience plan and associated products were developed with the purpose of synthesizing and building upon the extensive research, studies, planning efforts, and implementation of resilience measures performed by NSAA, USNA SLRAC, USACE, and DoD SERDP with the goal of achieving several objectives, including but not limited to:

- Assess the impacts of current and future climate-hazards on mission-critical assets and infrastructure for each installation planning area;
- Gain a comprehensive awareness of existing, designed adaptation alternatives and implemented resilience measures;
- Work with NSAA subject matter experts and USNA SLRAC members to develop and evaluate new adaptation alternatives;
- Establish an integrated adaptation framework that improves installation resilience, creates functional redundancies, aesthetically aligns with this national historic landmark, considers operations and management costs, respectful of community and regional partners, and evolves to meet future constraints; and
- Identification of any data gaps that will be needed to support the planning, design, and implementation of the proposed adaptation alternatives.

By building on over a decade of assessments and analyses, these review and integrated efforts provided NSAA/USNA an extensive documentation of the present-day and future constraints (i.e., 2035, 2065 and 2100) imposed on the installation and ensure the successful execution of mission critical and base support activities. They also highlighted a few data gaps that would better inform the planning, design, and implementation of proposed adaptation alternatives and the associated integrated framework. These data gaps included:

- Groundwater Inundation:
  The threat of groundwater inundation is unique for each coastal installation, hinging largely on the vertical extent of unsaturated space between built infrastructure and tidally influenced coastal groundwater. As sea level rises, this space will narrow and, in some places, will be lost altogether. This will produce groundwater inundation in the form of increasingly severe periodic localized flooding that will be exacerbated during periods of extreme high tide. Heavy rainfall is also likely to cause more extensive flooding owing to reduced unsaturated space available for infiltration and reduced surface drainage pathways. Thus, groundwater inundation requires a more complex assessment of adaptation tools and strategies than marine inundation alone.

To meet these challenges, the installation of ten (10) additional groundwater monitoring wells on the USNA Lower Yard is recommended. Coupled with existing monitoring wells, these wells will be used to assess groundwater table elevation and associated hydrologic data for all the historical land reclamation sites on Lower Yard. This groundwater monitoring data will be analyzed (i.e., quarterly, annually) compared with tidal gauge, meteorological station, and stormwater diagnostic instrumentation to compare and identify potential influences on the USNA Lower Yard groundwater elevation (note: if tide is influencing water table elevation, water quality and salinity in the wells should also be undertaken);
Lower Yard Water Balance:
Water balance estimation is an important tool to assess the status and trends in water resource availability in an area over a specific period. Furthermore, water balance estimates strengthen water management decision-making, by assessing and improving the validity of visions, scenarios, and strategies.

Once the measurements of the components of the hydrological cycle are complete, the analysis of the hydrology of the Lower Yard is best approached through the water balance estimation. This simply expresses the fact that, over any period, water input to the Yard must equal output and changes in storage. Input is likely to be rainfall, river inflow, and groundwater inflow; output will include evaporation, river outflow and groundwater outflow, while storage changes include increases in soil moisture and groundwater storage;

Geotechnical Data:
Associated with the groundwater efforts and water balance estimation, geotechnical investigations to acquire information regarding the physical characteristics of all the land reclamation areas on the installation are recommended. These data collections should be performed in areas where adaptations are currently planned (e.g., along the waterfront infrastructure, earthen berm and raised road locations). The purpose of these geotechnical investigations is to design earthworks and foundations for structures, and to execute earthwork repairs necessitated due to changes in the subsurface environment. These proposed geotechnical examinations include surface and subsurface exploration, soil sampling, and laboratory analysis. Geotechnical investigations are also known as foundation analysis, soil analysis, soil testing, soil mechanics, and subsurface investigation;

College Creek Watershed:
Watersheds are the basic land unit for water resource management and their delineation, importance, and variation with the Chesapeake Bay have received considerable attention. The hydrologic cycle and its components (precipitation, evaporation, transpiration, soil water, groundwater, and streamflow) which collectively provide a foundation for how landscapes and water interact are need prior to any significant changes to a watershed.

Several engineered adaptations (e.g., lock and dam) at the mouth of College Creek may need to be further evaluated if future projected sea level rise and extreme level water scenarios are worse than currently projected. Prior to considering these adaptation alternatives, as assessment and evaluation of College Creek watershed is warranted. It is recommended that a watershed assessment of College Creek be performed and impacts to water quality and TMDL requirements identified;

Installation Energy Plan:
It is recommended that an installation energy plan to be performed. An installation energy plan is an integration of applicable installation- and higher-level strategic guidance, plans and policies into a holistic roadmap that enables the installation to work constructively towards its goals in
energy efficiency, renewable energy, and energy resilience. Energy availability and reliability are necessary for executing mission essential operations, so improving the ability to avoid, prepare for, minimize, and adapt to energy disruptions and future demands is imperative.

The installation energy demands have increased significantly since 2005 with the construction of new assets (e.g., chill water plant), and facilities (e.g., Hopper Hall). These investments in mission critical assets and facilities have placed increased demands on the installations antiquated energy infrastructure. NSAA has made a concerted effort to the efficient use of energy resources to ensure optimal mission readiness. Unfortunately, these measures will probably not be efficient to meet future demands. The integrated adaptation framework outlined in this document will require significant alterations to existing stormwater system, adaptations to mission critical facilities, and other measures to address climate-induced constraints on the installation. Unfortunately, these energy requirements were not assessed for this report, but it is understood a detailed study is warranted prior to implementing any of the proposed adaptation alternatives that will place new demands on the existing energy infrastructure;

- **Space Utilization:**
  As stated earlier in this plan, if these wet and dry flood protection features are not implemented, several academic halls (i.e., Chauvenet, Michelson, Hopper, Rickover, Ricketts, and Luce), athletic facilities (i.e., Halsey Field House, Scott Natatorium, Alumni, and Macdonough), administrative facilities (i.e., Admissions and Armel-Leftwich Visitor Center), and Nimitz Library will be adversely impacted by the imminent threat of flooding. Preliminary analyses would indicate that the structural damage to these facilities would be significant, but more importantly, the destruction and potential loss of teaching and research laboratories, equipment, instrumentation, collections, and athletic resources that currently reside on the first floors of these facilities would be extremely difficult to overcome and will have a profound impact on mission.
  To address this imminent threat, a space utilization study of the Lower Yard should be performed. This study would assist the Architect of the USNA and NSAA Public Works Officer in space planning and management to maximize the efficient use of land, facilities, and space to support assigned missions. The objectives of space planning and management are to:
  
  - use existing facilities property and space in an efficient manner to reduce the need to existing facilities, property, and space in an efficient manner;
  - ensure that these academic halls, athletic facilities, and the Nimitz are more resilient to flooding of first floor elevations and mission critical assets (e.g., laboratories, equipment, instrumentation, etc.);
  - reduce the need to construct, rent, lease, or otherwise acquire land and facilities by using existing NSAA controlled facilities;
  - determine any shortfalls or excesses of assigned land, facilities, and space consistent with the brigade needs and the installation mission; and
  - inform future IDP updates so that actions are undertaken to deal with shortfalls or excesses, and to dispose of land, facilities, or space excess to NSAA/USNA needs;
• Traffic Control and Parking:
  An assessment the overall functionality of installation roadways and associated parking be undertaken. The results of this effort will inform and provide solutions for roadway design, traffic control, and parking on NSAA/USNA;

• Hydrodynamic Modeling:
  Hydrodynamic modeling of the Severn River and associated creeks (i.e., Spa, College, and Carr) is recommended to evaluate the current and future impacts of these water bodies will have on the existing waterfront infrastructure, athletic programs (e.g., Santee Basin), and installation operations (e.g., YP pier and basin).

Hydrodynamic modelling is the study of fluids in motion. Fluid motion can be generated by many forces acting alone or in combination. These include forces generated by tide, wind, and waves as well as gradient, and masses of fluid meeting (e.g., Chesapeake Bay and Severn Rivers). Hydrodynamic movement generates forces that act on solid bodies immersed in fluid (e.g., bulkheads, piers), which in turn affects the behavior of the fluid. Recognizing and quantifying this complex interaction is essential for effective and responsible development of adaptation alternatives that are intended to reduce frequency and intensity of flooding on NSAA/USNA.
References
XVII. References


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Appendices
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APPENDIX A
NAVFAC CLIMATE CHANGE PLANNING HANDBOOK - PILOT STUDY FINDING
Appendix A - Summation of Naval Support Activity Annapolis / United States Naval Academy Use of NAVFAC Climate Adaptation Planning Handbook

1.0 Background

Around the world, climate change is a destabilizing force, demanding the Navy and Marine Corps installation commands to develop new and innovative processes and tools to meet this challenge. Every effort must be made to ensure climate-related extreme weather does not continue to adversely affect military readiness and drain limited resources. In just the past few years, wildfires have forced evacuations at bases in the western United States, while hurricanes on the East Coast have inflicted billions of dollars of damage on facilities that are home to key warfighting capabilities.

On January 27, 2021, President Biden issued Executive Order (EO) 14008, ‘Tackling the Climate Crisis at Home and Abroad’, making it administration policy that climate considerations will be an essential element of United States foreign policy and national security. The EO calls on federal agencies, including the DOD, to prioritize climate change in all our activities and incorporate its security implications into analyses as well as key strategy, planning, and programming documents. The Navy, Commander Navy Installations Command (CNIC), and Naval Facilities Engineering Systems Command (NAVFAC) have embraced this charge from the administration and have developed a Navy Climate Adaptation Plan (2022), updated Unified Facilities Criteria (UFC), and other guidance and tools to proactively meet this policy.

This Navy Climate Adaptation Plan provides a roadmap to ensure the Department maintains the ability to operate under changing climate conditions while preserving operational capability and protecting systems essential to our success. The Department has included the security implications of climate change in all our risk analyses, strategy development, and planning. It charges the installation commands to incorporate climate risk into planning, into modeling, simulation, and into key documents like the Navy Installation Development Plan (IDP).

Fundamentally, climate change constitutes more than natural disasters. UFC 3-201-01, “Civil Engineering with Change 5,” incorporates sea level change to increase accuracy in flood projections used in the planning and design phases. Current guidance aligns with recent National Defense Authorization Act stipulations for establishing design flood elevations for facilities by using a comparison approach of freeboard instead of DOD Regional Sea Level database requirements coupled with facility mission criticality.

Changes to UFC 2-100-01, “Installation Master Planning,” address climate change and sea level rise. Specific updates instituted the use of the DOD Regional Sea Level database for sea level change and include the use of the DOD Climate Vulnerability Assessment Tool. Additionally, the NAVFAC Climate Change Planning Handbook (Handbook)(2017) – Installation Adaptation and Resilience provides the analytical framework and methodology to help Navy master development planners consider climate change in their plans and projects. The handbook is a desktop reference and serves as a companion tool throughout planning, especially the analysis phase of the IDP process.
To better understand how these UFCs, planning tools, and associated resources and databases will support installation climate resilience planning activities and inform the IDP process, NAVFAC chose to perform pilot study at Naval Support Activity Annapolis (NSAA), home of the U.S. Naval Academy (USNA). Contracted in September of 2020, the purpose was to use the Handbook to develop a comprehensive plan with a specific integrated adaptation framework and year-by-year execution strategy that would cohesively address and mitigate the combined effects of land subsidence, sea level rise, groundwater changes, coastal flooding/storm surge, and inadequate stormwater management on NSAA. This was not the first undertaken by the Department of Navy, a similar study was performed on Marine Corps Recruit Depot (MRCD) Parris Island, but there were significant differences at the inception:

- MCRD Parris Island had not tracked climate-induced impacts to assets, infrastructure, and/or mission. Nor had they made significant investments in plans, studies, and adaptations that may mitigate these adverse impacts. NSAA/USNA had made significant investments in the development of various products (e.g., plans, studies, reports, and designs) since 2003, and were able to compile numerous resources (i.e., over 22 deliverables) at the inception of this study.
- Scientific instrumentation (e.g., tidal gauge, meteorological station, groundwater monitoring wells) had not been deployed on MCRD Parris Island and remote sensing data (e.g., aerial LiDAR) was limited for installation. For example, the nearest NOAA tidal gauge to MCRD Parris Island was over 20 miles away. Conversely, the NSAA/USNA had a wealth of historic and recent collected datasets to support this study (e.g., NOAA tidal gauge one of the oldest active gauges in the U.S.).
- NSAA/USNA had made a concerted effort to get installation and local community engaged and involved in climate-related planning actions and studies. (e.g., USNA Sea Level Rise Advisory Council). MCRD Parris Island was beginning to identify mechanisms to facilitate these types of interactions at the inception of their project, but it was going to require time to develop the investment that NSAA/USNA has achieved.

There are the notable differences between the two studies, but the intent in highlighting this dichotomy is to illustrate that the Handbook provide very different value propositions to each installation. By requiring both installations to perform each stage of the Handbook (i.e., Stage I – IV) allowed the Navy and Marine Corps to assess and validate the Handbook. More importantly, it provided unique opportunities to capture lessons learned from these climate resilience exercises and determine how they would inform and assist in the development of planning guidance that would benefit the enterprise (and ideally could be self-performed by the enterprise without contractor support).

2.0 Methodology

This summation will not focus on the methodologies NSAA/USNA employed to perform the military installation resilience plan they developed. A detailed description of the methodologies is presented in the Technical Report (2022). Rather this summation is focused on lessons learned.

3.0 Lesson Learned:

MCRD Parris Island and NSAA/USNA both found the Handbook to be a useful desktop reference and tool. The Handbook provided an intuitive and assisted each installation in shaping their integrated adaptation
frameworks, developing adaptation alternatives, and generating recommendations that would support various planning activities (e.g., Integrated Natural Resources Management Plan, Integrated Cultural Resources Management Plan, Range Complex Management Plan, Land Use Compatibility Planning), and most importantly, the IDP.

These efforts also highlighted some reoccurring items that continued to arise and have been captured for future consideration. These items have been categorized to align with the Scope of Work, Government Furnished Information, and Stages of Handbook (i.e., I – IV). They are:

**Scope of Work**

- The intent of the handbook is quite clear. It has been developed to inform and support the IDP process. However, this distinction is not embraced by installation leadership. The leadership continues to stress that more important than the assets and infrastructure themselves, are the functions that they enable. Putting this in a familiar lexicon: assets work together in systems to create function; function enables capability; and capability supports city services and military mission. Importantly, it is not the assets themselves that we care about it is the missions they ultimately support. In general, a key challenge for installation owners is understanding the relationship between asset and mission and that is before we start to consider the rise in potential threats caused by climate-related or nature hazards. This recognition that mission impacts should be captured in the SOWs and are a critical part of the prioritization even if not presented in the Handbook.

- The importance of GIS deliverables (and standards) continues to be under-represented in the SOWs. These deliverables are invaluable for several reasons including performing vulnerability analyses, establishing a common operation picture, facilitate discussions during each Stage of the Handbook, evaluating adaptation alternatives, creation of an integrated adaptation framework, and other services (e.g., modeling recent flood events). Considering how valuable these products are to other plans, every effort should be made to ensure that this data is effortlessly transferred to the GeoReadiness and GeoFidelis centers.

- If there are expectations that contractor will need to collaborate with other contractors (e.g., designers, planners, construction) then this needs to be accounted for in the SOW

**Government furnished information:**

- Recent interest to capture climate-related information in the INSIPP and the future development of Resilience Summary for each IDP, it may be beneficial to integrate elements of worksheet I.1 and I.2 in these deliverables. This would streamline future efforts and bring link the Handbook to these efforts.

- Regrettfully, much of the dataset that is required to support these planning actions are disparate and most do not reside in the enterprise. In a rush to drive this type of planning, diligence does not tend to occur. Fundamentally, this is causing issues and there appears to be a lack of understanding of the differences in the datum.

- It would be beneficial to add an appendix to the Handbook that would list all the datasets that installations should acquire and maintain to provide a baseline for future installation climate resilience planning actions.
Stage I

- Ensure schedules are structured to provide adequate time to develop constraint/inundation maps prior to any site visits or preliminary engagements about Stage II elements.
- Communication is essential to the success of these planning actions. They require continuous engagement between the government and the contractor. This engagement does not need to be on-site, but this engagement with stakeholders for information gathering to understand and document current and future impacts to both infrastructure, operations, and mission is essential. This is particularly the case if a reference storm event defines what they’ve seen on-site as their worst-case scenario (thus far). Would be helpful to gather all those stories at one time to ensure we’ve covered impacts and their workarounds from “x storm” to infrastructure, operations, and mission.

Stage II

- Validate and prioritize the impacts with leadership to develop problem statements. There could be problem statements for each prioritized impact, perhaps some overarching ones with then specific ones for impacts. As part of process, need to clarify NAVFAC vs. Installation priorities, for example in the development of problem statements.
- Brainstorm strategies in smaller settings with contractor and installation subject matter experts (e.g., planners, engineers, etc.) to address each prioritized impact / problem statement; go through the Handbook screening/filtering process. Agree that the process to identify action alternatives deserves more attention from on-site people who really understand use/layout of infrastructure and engineers/planners who understand what may be possible.

Stage III

- The implementation of Stage III of the Handbook at NSAA/USNA as a pilot test went well in many respects and had challenges in some areas. The following captures a review of the Stage III process and worksheets along with recommendations or considerations for improvements to the process and what pitfalls one may encounter when applying the worksheets.
- As outlined in the Handbook, the goal of Stage III is to further screen adaptation action alternatives that were developed in Stages I and II and provide additional metrics to carry forward into the portfolio summary for Stage IV. Stage III as designed in the Handbook does provide the process and framework to accomplish this task; however, due to the high level of variation from installation-to-installation, there are components of Stage III that may not be applicable or be more challenging to capture effectively at specific installations.
- The worksheets associated with the Handbook allow for those less familiar or comfortable with Excel to still utilize the formulas and analysis to complete Stage III and produce metrics and results. In addition, the Handbook is useful for comparing different alternatives to protect a given asset(s) at an installation.
- The drawbacks of the Handbook in terms of Stage III mostly relate to being able to capture benefits, accounting for the criticality of assets, and comparing alternatives to each other in terms of how well or cost effectively they provide climate change resilience. It is understood that the Handbook has several “on and off ramps” where you could apply a particular facet of the analysis or utilize certain worksheets during installation planning processes; however, when looking at an
integrated framework for installation-wide planning, there are challenges to differentiate projects from each other and where funding should best be allocated.

- For instance, from a BCR, IRR, or NPV standpoint, implementing an adaptation alternative in a particular area may look best on paper at the conclusion of Stage III; however, it may be overlooking a much more critical asset that is mission essential. Therefore, all results would need to be looked at through the lens of mission sustainment and addressing the Problem Statement established in Stage I. This comparison and evaluation is addressed in Stage IV where the portfolio summary can account for some of these intrinsic values and non-monetized benefits to allow decision-makers the full complement of information.

Additional observations for Stage III are noted below:

- **Individual adaptation alternatives vs. integrated approach**
  The Handbook is a great resource outlining the overall process for working through the identification of adaptation alternatives, screening the alternatives, applying a cost-benefit analysis to the alternatives, and developing a portfolio to carry forward. However, applying the Handbook to an installation-wide plan to protect such a vast array of areas and assets provided challenging. To be able to identify performance metrics, the adaptation alternatives were assigned to geographic drainage basins that they would provide protection to; however, oftentimes there were five or more adaptation alternatives working in concert to provide that protection. The analysis assumed that all the adaptation alternatives would be necessary and implemented to provide the resiliency required to protect those assets, but each individual adaptation alternative could not be evaluated for its own merit because they were grouped in this manner.

- **Quantifying Benefits**
  Assessing the benefits related to the implementation of adaptation alternatives is obviously an essential component of the analysis. This is inherently heavily dependent on the availability of, and quality of, data. Although the approach and/or methodology may vary slightly from case-to-case, quantifying damage avoidance to buildings is traditionally a benefit that can be captured reasonably. Tiering off that calculation, the analyst can also estimate the potential damage to building contents.

Besides these calculations, quantifying benefits presents some challenges as noted below:

- Vehicles/Equipment – Depending on the climate change impact that may be present, there may be sufficient lead time for most vehicles and equipment to be relocated (i.e., if there is an incoming hurricane, vehicles can be moved to higher ground or protected areas). Therefore, this damage avoidance figure was not included in the analysis as it was challenging to determine how realistic it was in the future with the variety of projects being proposed.

- Training (Academic) Days – USNA/NSAA has a unique mission unlike most other Navy installations, where its primary purpose is to develop Midshipmen. Because of this academic pursuit, there are not the traditional measures of how a storm event or SLR
may impact the installation (i.e., lost flying days at an air installation). A storm event or SLR does have an impact on the Academy’s ability to develop Midshipmen; however, this was not specifically quantified or monetized.

- Record-keeping and Historic Data – For installations with a history of storm events and flooding issues, it would be valuable to be able to reference historic data to either include within the analysis, or to provide a baseline/sanity check for certain assumptions being applied. Oftentimes there are large dollar figures that are memorialized as the damage or cost incurred from a storm event; however, there is not a level of detail that went into calculating that number that could then be utilized for the Handbook analysis. Installations should be encouraged to track damages from storm events and keep good records for future use and justification.

- Discount rate and timing between

  Applying a discount rate to future year costs and benefits has a significant impact on the overall Handbook Stage III analysis. Both the discount rate used (i.e., 5-percent or 7-percent) will impact the cumulative present value of the costs and benefits, but also the timing of when an adaptation alternative is implemented versus realizing the overall benefits base on SLR modeling. If basing inundation on EWL events, this can be done by applying the probability of storms temporally after the installation of an adaptation alternative. Using both SLR and EWL water models provided more data and useful information but created challenges on determining when the benefit for an action alternative would be realized.

Stage IV

- The Handbook Stage IV does a commendable job of outlining how the installation should begin to consider decision trajectories, pivot points, risks, and other key elements that the installation should consider in developing an integrated adaptation framework. This framework generates a portfolio project that can seamlessly be added to the IDP update. However, installation leadership have not been interested in waiting on updated IDPs for near-term (5-year) priority actions. They are driven to shift near-term portfolios of projects into actionable actions. They want to evolve into DD-1391s and roll into their POM cycles; while committing to bringing individual projects for specific Installation Planning Areas forward for consideration within the standard five-year execution planning, design and execution cycle.

- Tiering off the last bullet, the Handbook does not discuss the development of an execution plan and rightfully so. However, all the Navy and Marine Corps installations are incurring some climate-induced impact. Outlining a process that can inform and support the development of an execution plan would be beneficial.

3.0 Path Forward

These planning actions clarified strengths and weaknesses of these Handbook planning actions. While the investments in the MCRD Parris Island and NSAA/USNA were beneficial, these types of full Handbook exercises should only be performed on installations that have broad national security importance and/or have unique climate-induced vulnerabilities. Recent institutional investment in developing a Resilience
Component to the Master Plan (i.e., Resilience Summary) template and iNSIPPs guidance have begun to establish deliverables that will allow the installations to identify data gaps, risks and threats, impacts to mission critical assets/infrastructure, lessons learned, ongoing and planned mitigation projects, outside the installation threats, public/private agreements, and potential adaptation alternatives in a concise, matrix driven format. This new guidance will meet all DoD requirements and drivers.

All this said, it must be understood that these climate-related threats are dynamic and complex. The enterprise needs to understand that these future planning documents are living documents, they will need to be continually updated. Every climate-induced hazard that has damaged an asset or facility, or even worse, impact mission should be captured. Fundamentally, this is going to require a paradigm shift in the enterprise. We are no longer developing these plans to check a box; we are trying to understand how this destabilizing force is going to continue impact each installation and place constraints on mission readiness.
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APPENDIX B
EVALUATION OF 3-DIMENSIONAL VIRTUAL ENVIRONMENTS TO IMPROVE RESILIENCE - PILOT STUDY
Appendix B - Summation of Naval Support Activity Annapolis / United States Naval Academy 3D Virtual Environment Pilot Study
1

2
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APPENDIX C
ADDITIONAL VUNERABILITY INFORMATION
Appendix C – Additional Vulnerability Information

Number of buildings impacted by scenario (total number of buildings analyzed on the Upper and Lower Yards of the USNA and NSAA is 403).

<table>
<thead>
<tr>
<th>Water Level</th>
<th>Current</th>
<th>2035</th>
<th>2050</th>
<th>2065</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Higher High Water</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>13</td>
<td>68</td>
</tr>
<tr>
<td>Nuisance Flood Level</td>
<td>4</td>
<td>13</td>
<td>43</td>
<td>73</td>
<td>90</td>
</tr>
<tr>
<td>5-yr Storm Surge</td>
<td>21</td>
<td>49</td>
<td>77</td>
<td>94</td>
<td>112</td>
</tr>
<tr>
<td>20-yr Storm Surge</td>
<td>52</td>
<td>73</td>
<td>95</td>
<td>101</td>
<td>120</td>
</tr>
<tr>
<td>100-yr Storm Surge</td>
<td>77</td>
<td>102</td>
<td>111</td>
<td>121</td>
<td>133</td>
</tr>
</tbody>
</table>

Miles of road inundated by scenario (total road network analyzed on the Upper and Lower Yards of the USNA and NSAA is 27 miles).

<table>
<thead>
<tr>
<th>Water Level</th>
<th>Current</th>
<th>2035</th>
<th>2050</th>
<th>2065</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Higher High Water</td>
<td>0</td>
<td>0.3</td>
<td>0.5</td>
<td>1.9</td>
<td>4.6</td>
</tr>
<tr>
<td>Nuisance Flood Level</td>
<td>0.1</td>
<td>1.8</td>
<td>3.3</td>
<td>4.8</td>
<td>5.4</td>
</tr>
<tr>
<td>5-yr Storm Surge</td>
<td>2.7</td>
<td>3.8</td>
<td>4.9</td>
<td>5.2</td>
<td>6.2</td>
</tr>
<tr>
<td>20-yr Storm Surge</td>
<td>4.1</td>
<td>4.7</td>
<td>5.3</td>
<td>5.7</td>
<td>6.6</td>
</tr>
<tr>
<td>100-yr Storm Surge</td>
<td>5.3</td>
<td>5.9</td>
<td>6.2</td>
<td>6.6</td>
<td>7.1</td>
</tr>
</tbody>
</table>

Percent of Athletic Fields inundated by scenario.

<table>
<thead>
<tr>
<th>Water Level</th>
<th>Current</th>
<th>2035</th>
<th>2050</th>
<th>2065</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Higher High Water</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Nuisance Flood Level</td>
<td>0%</td>
<td>0%</td>
<td>7%</td>
<td>14%</td>
<td>30%</td>
</tr>
<tr>
<td>5-yr Storm Surge</td>
<td>0%</td>
<td>10%</td>
<td>20%</td>
<td>35%</td>
<td>49%</td>
</tr>
<tr>
<td>20-yr Storm Surge</td>
<td>3%</td>
<td>20%</td>
<td>36%</td>
<td>46%</td>
<td>52%</td>
</tr>
<tr>
<td>100-yr Storm Surge</td>
<td>30%</td>
<td>48%</td>
<td>50%</td>
<td>52%</td>
<td>54%</td>
</tr>
</tbody>
</table>
Part II – October 29, 2021 Flood Event Models

On October 29th 2021 the installation experienced an abnormal high tide event. To prepare for potential adverse effects, the predicted flood level, and additional scenarios at varying heights, were modeled in the days leading up to the event. After the event, the final measured high tide was also modeled to compare model results with observations.

<table>
<thead>
<tr>
<th>Potential Flood Level</th>
<th>Above MHHW</th>
<th>Above MSL</th>
<th>Above MLLW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projected High Tide 10/28</td>
<td>3.7 feet</td>
<td>4.4 feet</td>
<td>5.1 feet</td>
</tr>
<tr>
<td>Projected High Tide plus 2 Inches</td>
<td>3.9 feet</td>
<td>4.6 feet</td>
<td>5.3 feet</td>
</tr>
<tr>
<td>Projected High Tide plus 4 Inches</td>
<td>4.03 feet</td>
<td>4.74 feet</td>
<td>5.46 feet</td>
</tr>
<tr>
<td>Actual High Tide</td>
<td>3.4 feet</td>
<td>4.1 feet</td>
<td>4.8 feet</td>
</tr>
</tbody>
</table>
Figure 63. The flood water level for October 29th was expected to be approximately 3.7 feet above Mean Higher High Water.
Figure 64. Modeled projected flood water level above Mean Higher High Water, plus 2 inches.
Figure 65. The projected flood water level above Mean Higher High Water, plus 4 inches.
Figure 66. The actual water level was determined to be 3.4 feet above Mean Higher High Water.
APPENDIX D
GREEN INFRASTRUCTURE
Appendix D – Green Infrastructure

Green infrastructure is made up of the interconnected network of waterways, wetlands, woodlands, wildlife habitats, and other natural areas; greenways, parks, and other open spaces that support native species, maintain natural ecological processes, sustain air, and water resources on an installation that contribute to health and quality of life (McDonald, Benedict, and O’Connor, 2005). Green infrastructure assets contribute to health and quality of life, such as forests that clean the air and filter, absorb stormwater, reduce heat island effects, and assist with stabilization of the water table. Just as we plan for “grey infrastructure” we also need to plan for and conserve green infrastructure to improve the resilience of NSAA/USNA.

What is Green Infrastructure Planning?

The science community describes natural resources as “green infrastructure” because they provide vital community functions. As described above green infrastructure provides numerous non-monetized benefits to the installation that will enhance resilience, but it also supports cultural resources by providing scenic views and settings that enhance our enjoyment of the landscape. Consequently, NSAA/USNA made a concerted to capture green infrastructure into this planning effort this included identifying locations on the installation that provided ecological value and how it should be conserved or restored.

In short, green infrastructure planning on NSAA/USNA entailed:

- Inventorizing green assets and connections,
- Identifying opportunities for their protection and/or restoration, and
- Developing a coordinated strategy to channel development and re-development to the most appropriate locations.

Green Infrastructure Planning Elements Identified

NSAA/USNA spent considerable time evaluating different green infrastructure strategies and several became integral components of the integrated adaptation framework that has been developed:

- Lower Yard: The framework recommends native grasses and trees to plant in several locations. Most of these plantings are being recommended to support the installations stormwater management system. They will be deployed in the hopes of slowing, directing, and containing surface water flow, as well as absorb soil moisture in low lying areas. However, every effort has been made to consider changes in ambient temperature (i.e., increases) and heat island effects especially around the athletic fields.

- Upper Yard: On the Upper Yard an effort was made to mirror the Lower Yard strategies, but additional efforts were made to identify where we can restore ecological function leveraging green infrastructure. This includes recommending ecological restoration efforts that would restore creek beds and wetlands that were historically present. This includes areas near Gate 8 and the track field on either side of Hospital Point.
Greenbury Point: The framework highlights the importance of Greenbury Point to NSAA/USNA. The project portfolio highlights two ecological restoration efforts that should be undertaken. These green infrastructure solutions provide multiple non-monetized benefits to the installation.

Most importantly, the framework highlighted the importance of this large, wooded track of land to the installation and most importantly, the academy’s education programs (e.g., training, recreation, research & development activity). The ecological value of this large track in an urban setting is difficult to quantify and can be potentially leveraged in a number in the future (i.e., mitigation offsets, carbon sequestration credits, etc.). Every effort should be made to maintain this resource in perpetuity.

The figures below depict potential sites where conversion from impervious surfaces and open spaces to areas with native plantings suited to future conditions are possible.
Figure 67. USNA Lower Yard. Above - current conditions. Below - potential planting areas.
Figure 68. USNA Upper Yard. Above - current conditions. Below - potential planting areas.
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APPENDIX E

PROJECT BIBLIOGRAPHY
Appendix E – Project Bibliography


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APPENDIX F

LIST OF DIGITAL PROJECTS
APPENDIX G

CLIMATE CHANGE PLANNING HANDBOOK WORKSHEETS STAGE I-IV
Appendix G is redacted in its entirety due to being an internal working document.