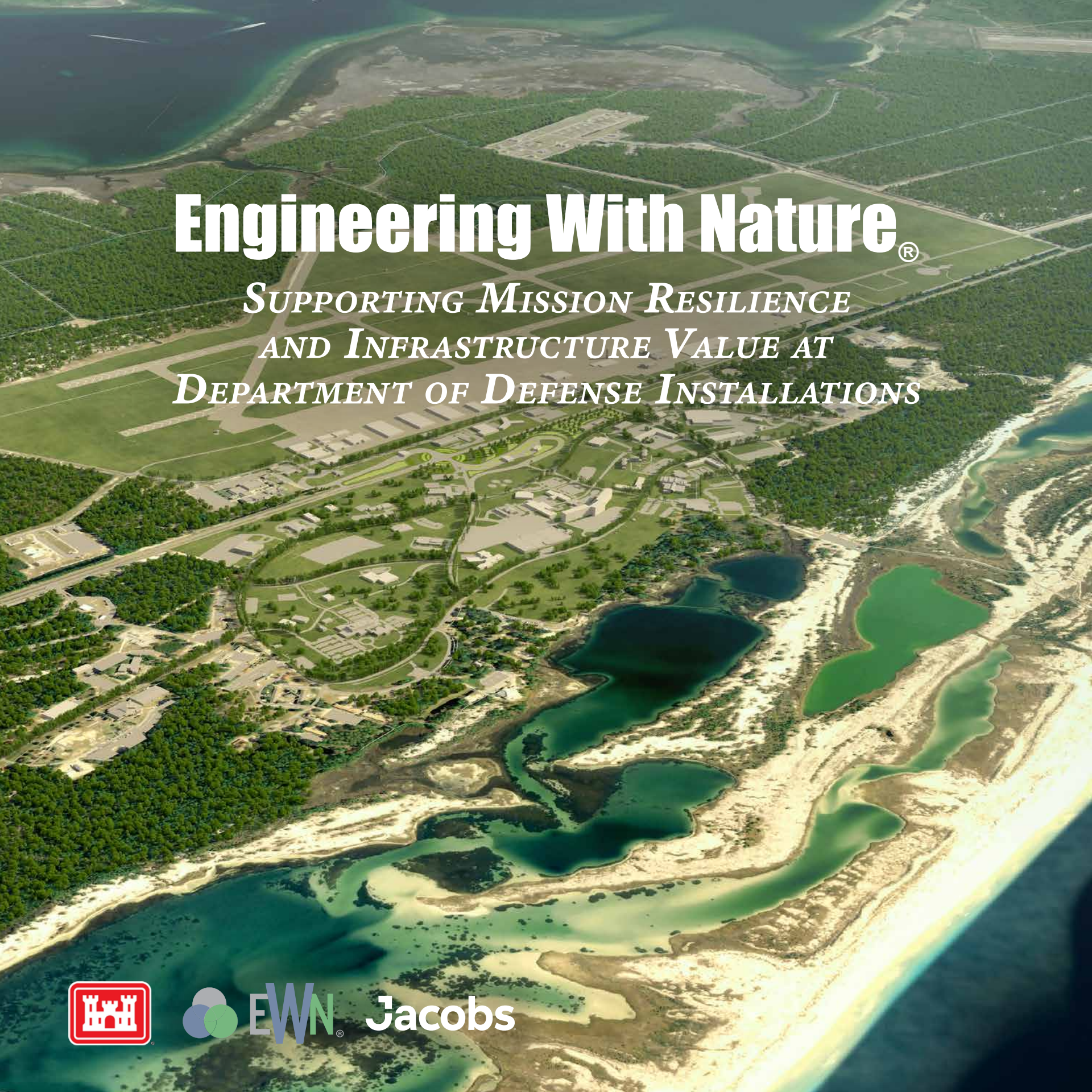

Engineering With Nature®

Supporting Mission Resilience and Infrastructure Value at Department of Defense Installations

EWN® Jacobs

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Jacobs

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Engineering With Nature® is the intentional alignment of natural and engineering processes to efficiently and sustainably deliver economic, environmental, and social benefits through collaboration.

www.engineeringwithnature.org

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Cover Photo Aerial perspective rendering for the Tyndall Air Force Base Rebuild Program. (Photo courtesy of Jacobs)

Foreword

Creating Value by Engineering With Nature

Coordinated investment in both built and natural infrastructure will be needed to sustain readiness and mission resilience across the U.S. Department of Defense (DoD) in the twenty-first century. For more than 10 years, the Engineering With Nature® (EWN®) Initiative within the U.S. Army Corps of Engineers has been working to develop and implement approaches that leverage natural systems to support critical engineering functions while also delivering a diversity of economic, environmental, and social co-benefits. The progress achieved over the last decade has been the product of numerous projects, partnerships, technical advancements, and communication investments that are accelerating innovation and delivery of nature-based solutions.

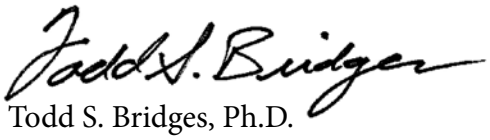
Over the last 5 years, DoD installations have experienced more than $10 billion in damage from natural hazards, such as storms and flooding. The risks produced by combinations of natural hazards, climate change, and aging infrastructure systems are increasing; and the need and demand for innovation and action to create resilient systems continues to grow. Meeting this need will require new ways of thinking about complex problems, an openness to new solutions, a willingness to change, and a commitment to adaptation.

The people and physical assets of the DoD operate on more than 25 million acres of land at DoD sites, facilities, and installations around the world. The natural landscapes, features, and processes operating on that land (and water) represent 25 million acres of natural infrastructure potential—potential that science, engineering, and investment can focus to create nature-based solutions that support DoD readiness and resilience.

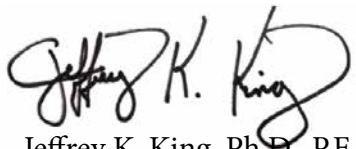
We developed this book to spark thought and conversation about opportunities to engineer with nature across the DoD. The example projects presented here, from across DoD, illustrate the potential to leverage nature as infrastructure. The scope and size of the risks, challenges, and opportunities the DoD faces now and in the remainder of the twenty-first century argues strongly for the need to "think big" about expanding and scaling up applications to reduce risks while increasing environmental benefits and social value for the more than 3 million active duty, National Guard and Reserve forces, and civilians who live and work on DoD installations.

It is our sincere hope that this book will increase interest and enthusiasm within DoD to "see" opportunities for increasing resilience with a fresh set of eyes, to reimagine landscapes and diverse systems that also include nature-based solutions, and to embrace a multidimensional approach to reducing risk that includes the a broad array of engineering and environmental benefits.

The EWN Initiative looks forward to engaging, collaborating, and partnering across the DoD and all sectors to develop natural-based solutions that support readiness and resilience for the DoD and its missions.



Todd S. Bridges, Ph.D.
Senior Research Scientist, Environmental Science
National Lead for Engineering With Nature
U.S. Army Corps of Engineers



Jeffrey K. King, Ph.D., P.E.
Deputy National Lead for Engineering With Nature
U.S. Army Corps of Engineers

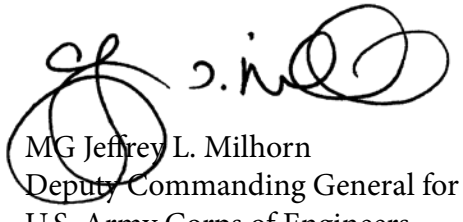
Modernizing, Innovating, and Partnering with Nature

Modernization and innovation are dual levers for achieving installation resilience. Modernizing the built infrastructure that supports DoD's missions will enable our ability to execute our missions around the world. Innovating to develop and implement new approaches to sustain and adapt infrastructure systems, including the use of natural infrastructure, will provide the foundation for enduring resilience. Working intentionally to expand our business, technical, and engineering practices is a necessary component of meeting the challenges before us in the twenty-first century. Developing and integrating the natural infrastructure associated with DoD's 25 million acres of land and water, as a part of our strategies and systems, will enable us to reduce risks, build resilience, and support the well-being of DoD service members and civilians.

With our partners, the U.S. Army Corps of Engineers (USACE) is pursuing nature-based solutions through the Engineering With Nature (EWN) Initiative. Nature-based solutions have been implemented in the United States and around the world for decades, supporting civil works functions and infrastructure. This book highlights seven examples of this practice on DoD installations, supporting conversation about the potential to "engineer with nature" across the DoD to develop broadly based resilience.

Relationships and partnerships are fundamental elements of innovation and progress. The diverse projects, contexts, and contributing organizations evident in these highlighted projects illustrate the interest and need for nature-based solutions and the progress achieved through partnership. The examples here are just a glimpse of a much larger potential within DoD. Advancing the use of natural infrastructure in combination with built infrastructure will involve the coordinated efforts of many organizations. Building these relationships across the boundaries of organization, mandate, and mission is the foundation of future resilience.

I invite you to join the conversation and the work of building resilience for our installations and communities. There is important work to do and value to be created as we modernize, innovate, and partner with nature.



MG Jeffrey L. Milhorn
Deputy Commanding General for Military and International Operations
U.S. Army Corps of Engineers

Resilience and Sustainability through Partnership

Increasing threats, such as climate change, and other operational challenges are driving an immediate need to improve the resiliency of our military installations, both at home and around the globe. The importance of creating the right balance between the built environment and the natural environment has never been stronger. As an industry, we must be prepared to advocate for, develop, and deliver nature-based solutions that will help prepare our installations for the growing vulnerabilities they face.

As we look to the future of sustainable and resilient solutions, we must consider more innovative, proven approaches to modernizing Department of Defense (DoD) installations that intentionally align natural and engineering processes. Through this Engineering With Nature collaboration, we are committed to partnering in the pursuit of nature-based solutions and pushing the limits of what is possible.

Our installations must provide protection and life support while remaining resilient and ready for Multi-Domain Operations. Working in partnership alongside the Engineering With Nature Program, we are leveraging our global capabilities in a focused effort to restore the operational effectiveness of Tyndall Air Force Base, incorporating natural processes in engineering design to achieve maximum benefits. The successful integration of coastal and flood risk management strategies provides enormous economic, environmental, and social benefits for the region. At Tyndall, the collective leadership team of the DoD, local communities, private intergovernmental offices, and industry is proving that the best solutions come through successful collaboration across a diverse group of stakeholders and partners.

Jacobs is proud to partner with the U.S. Army Corps of Engineers, Engineer Research and Development Center, for the publication of *Engineering with Nature: Supporting Mission Resilience and Infrastructure Value at Department of Defense Installations*. I urge you to read and study these case studies as they provide a vital collection of successful solutions for some of the most pressing issues facing our nation's defense installations today. We appreciate the privilege of partnership in Engineering With Nature initiatives, including this publication, and the opportunity to continue delivering solutions that challenge today and reinvent tomorrow.

Tim Byers
Senior Vice President and General Manager
Federal and Environmental Solutions, Jacobs

Innovative Partnerships for Nature-Based Resilience

The Department of Defense (DoD) is an important partner in conservation and in our work to adapt to the effects of the climate emergency. Nature-based solutions provide a tremendous opportunity to meet those challenges and to build a stronger, more resilient future. These multibenefit solutions are effective and sustainable ways to help us meet our infrastructure needs; provide clean and reliable water; support wildlife habitats; sequester carbon; and reduce risk from floods, sea level rise, storm surge, droughts, and wildfires. And these solutions can save money, too. After Hurricane Sandy in 2012, Nature Conservancy scientists and insurance-sector partners determined that coastal wetlands prevented more than $625 million in potential property damages.

DoD is actively working to integrate nature-based solutions in its resilience plans and projects and is uniquely positioned to deploy those solutions in partnership with the U.S. Army Corps of Engineers (the Corps) and others as a key element of their strategies to protect the military mission, military installations and ranges, and surrounding communities. At The Nature Conservancy, we are proud of our long-standing and expanding partnership with DoD and U.S. military installations across the country to conserve critical landscapes and to develop innovative nature-based solutions to build climate resilience. In this publication, we have highlighted our partnership with the U.S. Navy to protect and restore over 9 miles of coastal wetlands in Southern California that provide protective services and risk reduction for a critical naval base while also providing critical habitat for coastal species. We are actively engaged in similar efforts with the DoD to leverage nature-based solutions to enhance climate resilience at a number of installations around the country.

We commend our partners at the Corps's Engineering With Nature Program for their leadership in bringing together this collection of diverse projects, best practices, and innovative collaborations focused on improving resilience and mission assurance. We share their commitment to the global collaboration needed to revolutionize the use of nature-based solutions.

We look forward to our continued partnership with Engineering With Nature and across DoD to advance the science, tools, and support needed to build a stronger and healthier future.

Jennifer Morris
Chief Executive Officer
The Nature Conservancy

Flooding at Offutt Air Force Base, March 2019, after a winter of record snowfalls caused high water levels in the surrounding waterways. (Photo by TSgt Rachelle Blake)

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Storm clouds gather over the dunes at Tyndall Air Force Base. (Photo by Todd Bridges, U.S. Army Corps of Engineers)

Introduction

Introduction

Engineering With Nature at Department of Defense Facilities

The Resilience Value of Nature

The Department of Defense (DoD) faces a complex set of challenges in the twenty-first century. Many of these challenges, and associated opportunities, relate to developing and sustaining the infrastructure needed for mission resilience. The goal of this book is to support a conversation and collaboration across DoD and its partners about the use of natural infrastructure to support readiness and resilience.

DoD and its 3 million team members operate on more than 25 million acres and nearly 5,000 sites in different regions, climates, and landscapes in the U.S. and around the world.[1] The natural landscapes, features, and processes operating on that land (and water) represent 25 million acres of natural infrastructure potential—potential that science, engineering, and investment can focus to create nature-based solutions that support mission resilience. Given the complexity of DoD's mission, we can expect there will be a limited number of cases where simple "silver bullet" infrastructure solutions prevail. Rather, when considering the role of infrastructure, working toward coordinated combinations of built and natural infrastructure to achieve multipurpose function presents a path to achieving enduring resilience.

Natural Infrastructure

Natural infrastructure (or nature-based solutions) can address both the challenges and opportunities before DoD in the twenty-first century. The timeline marking the conceptualization, methodological development, and application of nature-based solutions is long and passes through many technical fields. Different definitions of natural infrastructure or nature-based approaches and related terms (e.g., ecosystem-based approaches and green infrastructure) have been used by many organizations pursuing the approach. However, the predominant element among these definitions is the focus on conserving, restoring, and engineering nature for the benefit of people, human systems, and the ecosystems we inhabit. It is difficult to pinpoint the very beginning of the nature-based solutions timeline, but it stretches across several decades. In the

1. Carol Hardy Vincent, Laura A. Hanson, Lucas F. Bermejo, *Federal Land Ownership: Overview and Data*, (Washington, DC: Congressional Research Service, 2020), https://fas.org/sgp/crs/misc/R42346.pdf.

The construction of islands from dredged sediment creates shallow-water habitat for native species, such as the American lotus. (Photo by U.S. Army Corps of Engineers–New Orleans District)

1960s, the ecologist Howard T. Odum and others developed a foundation for ecological engineering, and in 1969 the landscape architect Ian McHarg published his seminal book *Design with Nature*. Natural infrastructure includes river floodplains, inland and maritime forests, freshwater and coastal wetlands, living shorelines, dune and beach systems, coastal and riverine islands, reefs and living breakwaters, and many other examples and combinations that operate in different ways and can be used to achieve different purposes and engineering functions.

Discovering, developing, and delivering projects that use natural infrastructure to produce mission value will involve engineering across a range of scales. The use of trees as infrastructure can illustrate the point. Trees around buildings can reduce the amount of energy required to cool and heat those buildings. Trees planted in association with the outdoor walkways, gathering places, and training areas can significantly reduce ground-level summer and heat-wave temperatures. Investment in forests and networks of forests can reduce inland and coastal flood risks, minimize wind damage from storms, and support drought resilience while also sequestering carbon.

Future strategies and investments in natural infrastructure must be science and evidence based. Fortunately, the science and evidence relevant to nature-based solutions has been growing rapidly and substantively for many years. A recent study found that mangrove forests along the coast of Florida are averting billions of dollars in flood damages from extreme storms by attenuating storm surge and waves.[2] Many other studies have documented the contribution that large-scale natural and nature-based features, such as wetlands and coral reefs, are making to reduce flood risks and damages from small and large storms, including hurricanes.[3] Many other examples, ranging the full scope of nature's landscapes, illustrate that nature holds tremendous "practical" value in relation to resilience. The challenge and opportunity before us is to "figure out" how to integrate this value into our collective engineering processes in the twenty-first century and beyond. We

2. Siddharth Narayan, Christopher Thomas, Joss Matthewman, Christine C. Shepard, Laura Geselbracht, Kechi Nzerem, and Michael W. Beck, V*aluing the Flood Risk Reduction Benefits of Florida's Mangroves* (Maitland, FL: The Nature Conservancy, Gulf of Mexico Program, 2019), https://www.nature.org/content/dam/tnc/nature/en/documents/Mangrove_Report_digital_FINAL.pdf.

3. Siddharth Narayan, Michael W. Beck, Paul Wilson, Christopher J. Thomas, Alexandra Guerrero, Christine C. Shepard, Borja G. Reguero, Guillermo Franco, Jane Carter Ingram, and Dania Trespalacios, "The Value of Coastal Wetlands for Flood Damage Reduction in the Northeastern USA," *Scientific Reports* 7 (2017): 9463, https://doi.org/10.1038/s41598-017-09269-z.

have also communicated this value through use of our EWN publications. For example, volumes 1 and 2 of *Engineering With Nature: An Atlas* have presented 118 constructed projects from around the world that have incorporated nature into engineering solutions to achieve sustainable, diversified value.[4]

The Resilience Challenge

DoD and its installations are subject to a range of natural hazards and combinations of those hazards. These hazards include coastal and inland storms, flooding, extreme heat, drought, wildfire, and earthquakes in addition to others, such as biological hazards like infectious diseases, pandemics, and invasive species:

- In 2016, the Canyon Wildfire at Vandenberg Air Force Base burned 10,000 acres.[5]
- In 2018, Hurricane Michael devastated Tyndall Air Force Base in Florida. It is now estimated that the rebuild of Tyndall will cost as much as $4.9 billion.[6]
- The same year, Hurricane Florence caused $3.6 billion in damage to Marine Corps Base Camp Lejeune in North Carolina.
- In 2019, inland flooding at Offutt Air Force Base in Nebraska produced more than $1 billion in damage to the installation.[7]

The effects of sea level rise are also observed with more and more frequency. Norfolk, Virginia, home to Naval Station Norfolk (the world's largest navy base) is currently

4. T. S. Bridges, E. M. Bourne, J. K. King, H. K. Kuzmitski, E. B. Moynihan, and B. C. Suedel, *Engineering With Nature: An Atlas*, ERDC/EL SR-18-8 (Vicksburg, MS: U.S. Army Engineer Research and Development Center, 2018), http://dx.doi.org/10.21079/11681/27929; T. S. Bridges, E. M. Bourne, B. C. Suedel, E. B. Moynihan, and J. K. King, *Engineering With Nature: An Atlas, Volume 2*, ERDC SR-21-2 (Vicksburg, MS: U.S. Army Engineer Research and Development Center, 2021), http://dx.doi.org/10.21079/11681/40124. More information is available at https://ewn.el.erdc.dren.mil/atlas.html.

5. Office of Inspector General, *Fiscal Year 2021 Top DoD Management Challenges*, (Alexandria, VA: Department of Defense, Office of Inspector General, 2020), 28, https://www.oversight.gov/sites/default/files/oig-reports/Top%20DOD%20Management%20Challenges%20Fiscal%20Year%202021.pdf.

6. Natalie Williams, "Tyndall Air Force Base on Its Way to Becoming the 'Base of the Future,'" WJHG News Channel 7, 2 May 2021, https://www.wjhg.com/2021/05/03/tyndall-air-force-base-on-its-way-to-becoming-the-base-of-the-future/.

7. Office of Inspector General, 27.

confronted with chronic infrastructure issues and flooding related to rising sea levels. The trend and expectation is that such natural hazards and the damage, costs, and mission impacts of such events will increase and expand in the future.

A report published by the Office of the Undersecretary of Defense and Acquisition and Sustainment considered the risk and vulnerability of 79 installations to climate change and extreme weather.[8] Of those installations, 53 are currently vulnerable to repeated flooding while 43 and 36 are currently at risk from drought and wildfires, respectively. Extreme drought conditions and extended fire seasons pose a greater threat to military installations and operational readiness in the western U.S. than at any other time in our nation's history. Developing broadly based resilience for this range of hazards and combinations of hazards calls for a systems approach to engineering readiness and resilience.

The portfolio of potential interventions that will be used to assemble future infrastructure systems should be diverse and innovative. By adopting an all-of-the-above approach to thinking, planning, and ultimately implementing infrastructure systems, DoD can develop enduring solutions for an individual installation, support collaborations with surrounding communities that provide regional resilience, and sustain the network of installations across the nation and globe that deliver the mission of DoD. Creating "multiple lines of defense" against natural hazards by combining built and natural infrastructure offers tremendous potential to provide complete and adaptable solutions for DoD's resilience challenge.

Military engineers and commanders have long recognized the importance of nature and its landscapes. Major General Horatio Gates, the Commander of the Northern Army during the Battle of Saratoga in 1777, wrote his friend Dr. Benjamin Rush, after the victory, about the role of a Polish-born engineer officer named Colonel Tadeusz Kosciuszko. Gates wrote, "The great tacticians of the campaign were hills and forests, which a young Polish engineer was skillful enough to select for my encampment."[9]

8. Office of the Under Secretary of Defense for Acquisition and Sustainment, *Report on Effects of a Changing Climate to the Department of Defense* (Washington, DC: Office of the Under Secretary of Defense for Acquisition and Sustainment, 2019), https://media.defense.gov/2019/Jan/29/2002084200/-1/-1/1/CLIMATE-CHANGE-REPORT-2019.PDF.

9. Reneé Critcher Lyons, *Foreign-Born American Patriots: Sixteen Volunteer Leaders in the Revolutionary War* (Jefferson, NC: McFarland & Company), 114–115.

Surveying damage to the dormitories at Tyndall Air Force Base following Hurricane Michael. (Photo by SSgt Keifer Bowes)

Supporting Personal and Personnel Resilience

There is also an important opportunity and need for using natural infrastructure to support the personal well-being of the people who work, train, and live at DoD facilities. Science is increasingly documenting the numerous and significant ways in which the character and quality of the built and natural environment affect our physical, mental, and emotional well-being. We understand through our own personal experiences and from established science how the built, indoor environment affects us physically and mentally. Quality design and architecture for our work and personal spaces support quality work performance and personal well-being.[10] In regard to the difference in cost between bad and good design, Sarah Williams Goldhagen wrote, "And it turns out that, more often than not, it takes just as many resources to build a bad building—or landscape or townscape—as a good one."[11] Over the last 30 years, a growing body of science has demonstrated the important, substantive connections that exist between human physical and mental health and contact and experiences in natural environments. In fact, governments around the world, including in Japan, South Korea, and Finland (among others), have established programs and entire organizations that are devoted to developing natural and nature-based systems to support human health.[12] The natural infrastructure on DoD's 25 million acres of land, water, and the natural landscape represents a huge opportunity to support the personal resilience of DoD's 3 million team members and their families.

10. Sarah Williams Goldhagen, *Welcome to Your World: How the Built Environment Shapes Our Lives* (New York: Harper, 2017).

11. Goldhagen, xxxi.

12. Florence Williams, *The Nature Fix: Why Nature Makes Us Happier, Healthier, and More Creative* (New York: W. W. Norton, 2017).

The EWN Initiative

The Engineering With Nature® (EWN®) Initiative formally began in 2010 within the U.S. Army Corps of Engineers as an approach for highlighting good past-practice examples while advancing current and future capabilities for delivering nature-based solutions. The initiative has grown to include many partner organizations and collaborators in the U.S. and abroad. The EWN Initiative supports more-sustainable practices, projects, and outcomes by pursuing the *intentional alignment of natural and engineering processes to efficiently and sustainably deliver economic, environmental, and social benefits through collaboration* (www.engineeringwithnature.org).

Below: Great blue heron feeding in marshes located in the Chesapeake Bay. (Photo by Frank Aquino)

Four critical elements define the EWN approach:

Mission Assurance

Using science and engineering to produce operational efficiencies supporting sustainable delivery of project benefits and mission

Using Natural Processes

Using natural processes to maximum benefit, thereby reducing demands on limited resources, minimizing the environmental footprint of projects, and enhancing the quality of project benefits

Broadening Benefits

Increasing the value provided by projects to include social, environmental, and economic benefits

Promoting Collaboration

Using science-based collaborative processes to organize and focus interests, stakeholders, and partners

Throughout this book, the four critical elements that define progress and success related to EWN are used to describe each of the representative projects. In this way, we illustrate the efficiencies that can be gained, the interconnectivity of natural and engineered systems, the array of project benefits that can be produced, and the power of collaboration in project development.

Top: Tyndall's coast. (Photo by Jacobs)

Bottom: Coastal dune habitat at Tyndall Air Force Base. (Photos by Jacobs)

Example Hazards and Approaches to EWN

This book illustrates some of the current challenges and hazards experienced by military installations, and the content highlights activities at seven military installations to achieve increased resilience through natural infrastructure. The table on the next page highlights several natural hazards, the nature-based approaches to problem-solving, and the outcomes that the problem-solving achieves.

Below: The Helicopter Sea Combat Squadron providing firefighting support to battle wildfires at Naval Base Ventura County Point Mugu. (Photo by PO1 Chris Fahey)

Below: Table of natural hazards, approaches, and outcomes.

NATURAL HAZARD	EXAMPLE EWN APPROACHES	OUTCOMES
 Coastal Erosion  Coastal Flooding  Sea Level Rise	• Restore beaches and dunes • Construct beaches and dunes • Place sediment offshore • Construct horizontal levees • Establish an oyster reef or living shoreline • Create native coastal vegetation succession strategies • Construct islands	• Reduced flood risk to base assets • Increased and improved habitats • Reduced coastal erosion • Recreational opportunities • Aesthetic viewsheds of native forest • Improved base personnel well-being • Improved aesthetics and personnel retention • Regional collaboration and shared funding
 Stormwater Flooding  Fluvial Flooding	• Restore historical longleaf pine forests • Use a “treatment train” water-quality strategy • Use a “microbasin” stormwater management strategy • Align stormwater and ecological restoration strategies	• Reduced flood risk to base assets • Increased natural infiltration of stormwater • Improved water quality in adjacent natural waterbodies • Increased and improved overland and aquatic habitats • Slowed and reduced overland stormwater flows • Groundwater recharge • Reduced capital expenditures of gray infrastructure system
 Wind	• Establish tree species with greater natural wind resilience • Use a tree-canopy-massing strategy	• Layered vegetative strategy to reduce damage to base assets • Increased and improved habitats • Aesthetic viewsheds of native forest • Improved base personnel well-being • Improved base character and first impression for personnel retention and attraction • Increased tree canopy for reduced surface temperatures • Regional collaboration and shared funding
 Extreme Heat	• Establish green roofs and facades • Strategically plant trees and vegetation for shading buildings, walkways, parking areas, and roads	• Reduced heat load on individual buildings, resulting in energy cost savings • Mitigated heat-island effect by reducing aggregate heat gain on buildings, parking surfaces, roads, and walkways • Improved experience and reduced heat exposure in pedestrian walkways and outdoor gathering spaces

NATURAL HAZARD	EXAMPLE EWN APPROACHES	OUTCOMES
Drought	• Develop and maintain wetland systems to attenuate drought periods • Improve forest management and planting practice • Introduce natural features in riverine systems to slow and retain water • Restore flood plains to capture water during flashy storm events • Establish green roofs, rain gardens, and cisterns for stormwater capture • Use permeable pavements	• More water retained in systems and watersheds • Lengthened residence time of surface water to increase groundwater recharge • Captured stormwater used to maintain viability of wetlands, etc., during dry periods
Wildfire	• Diversify forest conditions • Integrate open patches and spaces, pocket meadows, and fire-resistant trees • Introduce smaller, more frequent, and prescribed burns	• Reduced availability of "fuel" and risk of catastrophic forest fires • More diverse and healthier habitats • Expanded recreational opportunities
Climate Change	• Assess the resulting natural hazard risks • Explore EWN approaches effective for those hazards	• Reduced risk to base assets • Increased resilience as climate change continues

In conjunction with the EWN elements and icons offered in the previous section, the icons for natural hazard risks in the table will appear on the first page of each military installation described in this book. This will alert the reader to hazards experienced at a particular installation and the associated nature-based approaches in use or under consideration. From site-wide vulnerability assessments and master planning to the actual installation of specific types of nature-based features, the goal of this book and the enclosed materials is to fuel creative ideas and to explore opportunities for use of natural infrastructure. In turn, this understanding of EWN applications and possibilities leads to more innovation and an increased number of resilience measures that ultimately support of our nation's military installations and the warfighter.

Above: Using natural infrastructure helps protect coastal communities. (Photo by the National Oceanic and Atmospheric Administration)

Tyndall Air Force Base

Tyndall Air Force Base

Panama City, Florida, United States

Tyndall Air Force Base

Tyndall Air Force Base
Coastal Resiliency Project

Panama City, Florida, United States

ECOREGION:
Southeast Coastal Plains

NATURAL HAZARD RISKS TO MISSION ASSURANCE

Sea Level Rise | *Stormwater Flooding* | *Wildfire* | *Extreme Heat* | *Coastal Flooding* | *Coastal Erosion* | *Wind*

In October 2018, Hurricane Michael, a powerful Category 5 storm, struck Florida's Panhandle region. Positioned in the direct path of the hurricane, Tyndall Air Force Base (AFB) was devastated, losing more than half its buildings and infrastructure. In response to this devastation and with the intention of mitigating future storm impacts, Tyndall AFB embarked on a massive rebuild program to create a resilient, sustainable, and smart "Installation of the Future," utilizing innovative solutions.

To that end, specific goals for this rebuild included the following:

- Achieving a nexus of mission assurance, cost efficiency, and social and environmental sustainability
- Ensuring a resilient and sustainable base that will be a model for other Department of Defense installations and coastal facilities
- Utilizing the opportunity to reimagine the environmental and operational functions needed at Tyndall AFB, both now and in the future
- Collaborating with the local community and a wide range of stakeholders to develop long-term partnerships

The Installation of the Future rebuild is a comprehensive approach affecting Tyndall AFB's entire built environment, infrastructure, and land. The rebuild will manage and reduce risks from several hazards, such as high winds, extreme heat, wildfire, extreme rainfall, coastal flooding, and coastal erosion. This project profile focuses on the Coastal Resiliency Project, which is exploring an EWN approach to coastal flooding and coastal erosion. The work involves the creation of four pilot projects and integrates into a wider rebuild program and landscape master plan that considers the full range of hazards, including high rainfall, high winds, and wildfire.

Tyndall Air Force Base

Mission Assurance

With its low-lying location on the Gulf of Mexico, Tyndall AFB is particularly vulnerable to extreme weather that can produce high winds, extensive rainfall, and elevated water levels. The high water levels generated in storm surges and by high rainfall are capable of inundating low-lying parts of the base and affecting base operations and access. In the coming decades, the risks associated with these extreme weather events are expected to increase with climate change and sea level rise. There are several strategies for managing coastal flood risk—making infrastructure resilient to flooding, moving infrastructure out of harm's way, elevating structures out of the flood danger zone, and building defenses to keep marine waters out.

In its program to develop sustainable and resilient infrastructure for mission assurance, Tyndall AFB is exploring several innovative approaches that incorporate traditional risk-reduction techniques with nature-based solutions to achieve enhanced performance and long-term success.

Future mission assurance for Tyndall AFB means addressing the risks from coastal flooding and erosion, as well as high rainfall, strong winds, and wildfire. The reenvisioning of Tyndall AFB considers variables that may have changed since the original buildings were constructed (e.g., flood elevation and expected wind loads). Additionally, the base must meet the modern standards for the design and reconstruction of its facilities, including the infrastructure needed to accommodate the new F-35 Lightning II aircraft. The new installation must withstand not only present-day hazards but also projected future environmental conditions, impacts, and associated risks.

Previous page: Aerial perspective rendering for Tyndall Air Force Base Rebuild Program. (Image by Jacobs)

Top: A portfolio of interconnected approaches. (Image by Jacobs)

Bottom: F-22 Raptor and a T-38 Talon fly above Tyndall. (Photo by MSgt J S. Wilcox)

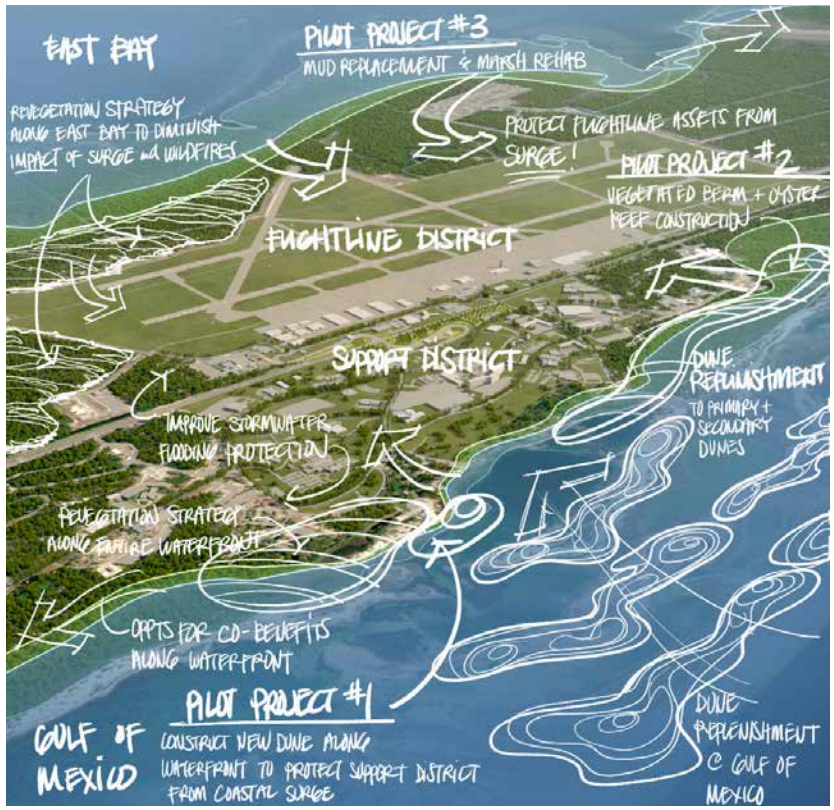
Using Natural Processes

Coastal defenses include conventional approaches, such as walls and levees, as well as a range of nature-based approaches, such as restoring marshes and beaches and enhancing dunes. Tyndall AFB is exploring four pilot projects to evaluate the effectiveness of nature-based solutions in reducing coastal flood risks and erosion. Compared with more-conventional coastal defenses, nature-based solutions can be less costly, be self-maintaining, and offer a range of complementary benefits (e.g., recreational opportunities and habitat for threatened and endangered species). Nature-based solutions used in combination with more-conventional solutions provide multiple lines of storm defense.

The pilot projects at Tyndall include the following:

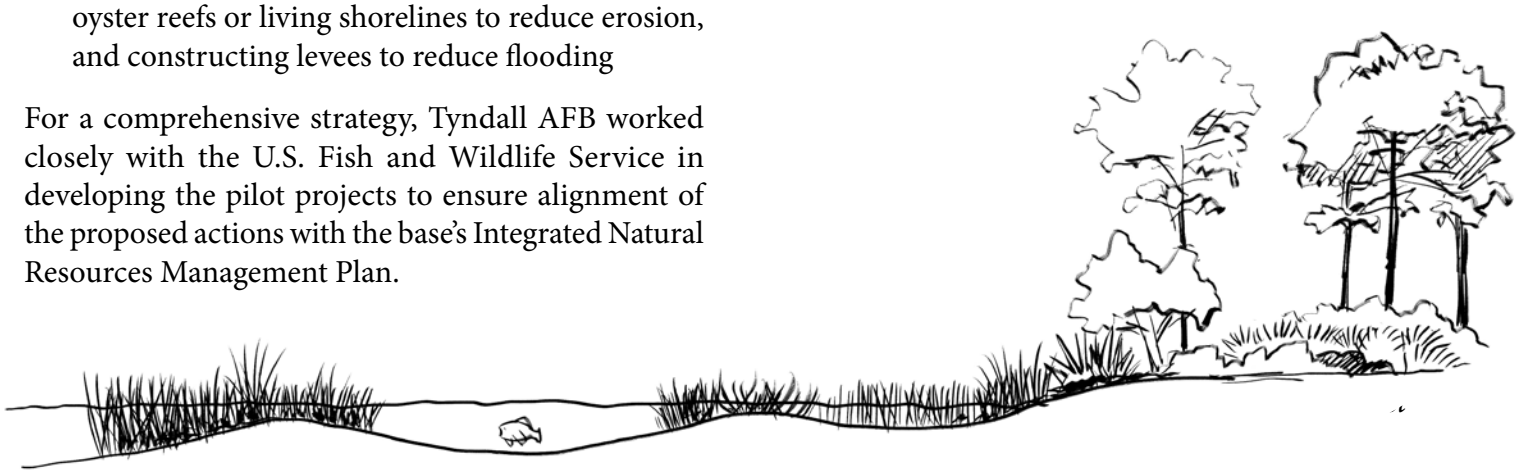
- Innovative methods for reinforcing dunes on the edge of the base, providing defenses for areas vulnerable to coastal flooding
- New strategies for rebuilding dunes on the barrier islands, including trapping sand by using fences, woody debris, and new vegetation
- Analysis of strategic placement of subtidal sediments and sand to enhance natural environments by buffering wave energy and reducing storm surges
- Exploring opportunities for placing sediment to enhance intertidal flats and salt marshes, using oyster reefs or living shorelines to reduce erosion, and constructing levees to reduce flooding

For a comprehensive strategy, Tyndall AFB worked closely with the U.S. Fish and Wildlife Service in developing the pilot projects to ensure alignment of the proposed actions with the base's Integrated Natural Resources Management Plan.



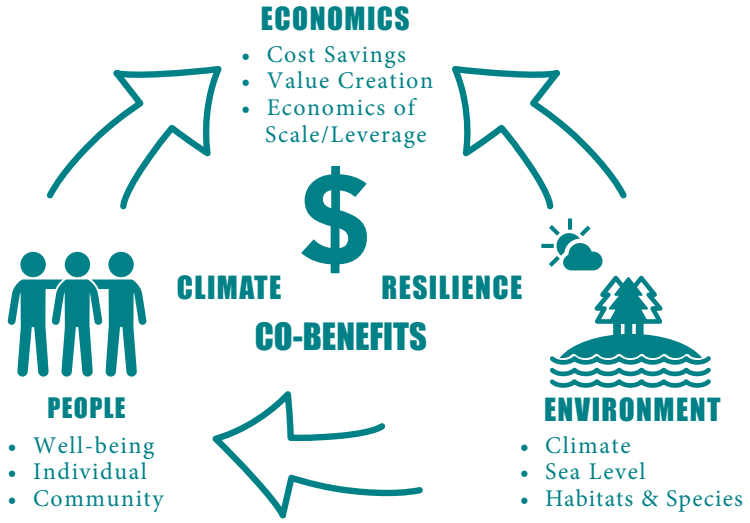
Above: Drawing of various EWN approaches superimposed on an aerial image of Tyndall AFB. (Image by Brett Wylie, Jacobs)

Below: An illustrative section of salt marsh and maritime forest. (Image by Brett Wylie, Jacobs)



Broadening Benefits

By incorporating nature-based approaches, Tyndall AFB is committed to improving its mission assurance by reducing its risks from future storms and coastal flooding. The combination of conventional and nature-based engineering approaches to reimagining the base can provide a range of enhanced risk reductions and create important social, cost, and environmental benefits. These broadened benefits include improved social and aesthetic values for Air Force personnel, their families, and the surrounding communities; new and improved recreational opportunities around the base; and improved habitat areas for native and threatened species. Tyndall AFB is pursuing integrated land management techniques, including native long-leaf pine restoration. The increased shade from the tree canopy will reduce the heat-island effect and improve walkability and energy conservation. Further, proper management of long-leaf pine forests can reduce the risk of catastrophic wildfires.



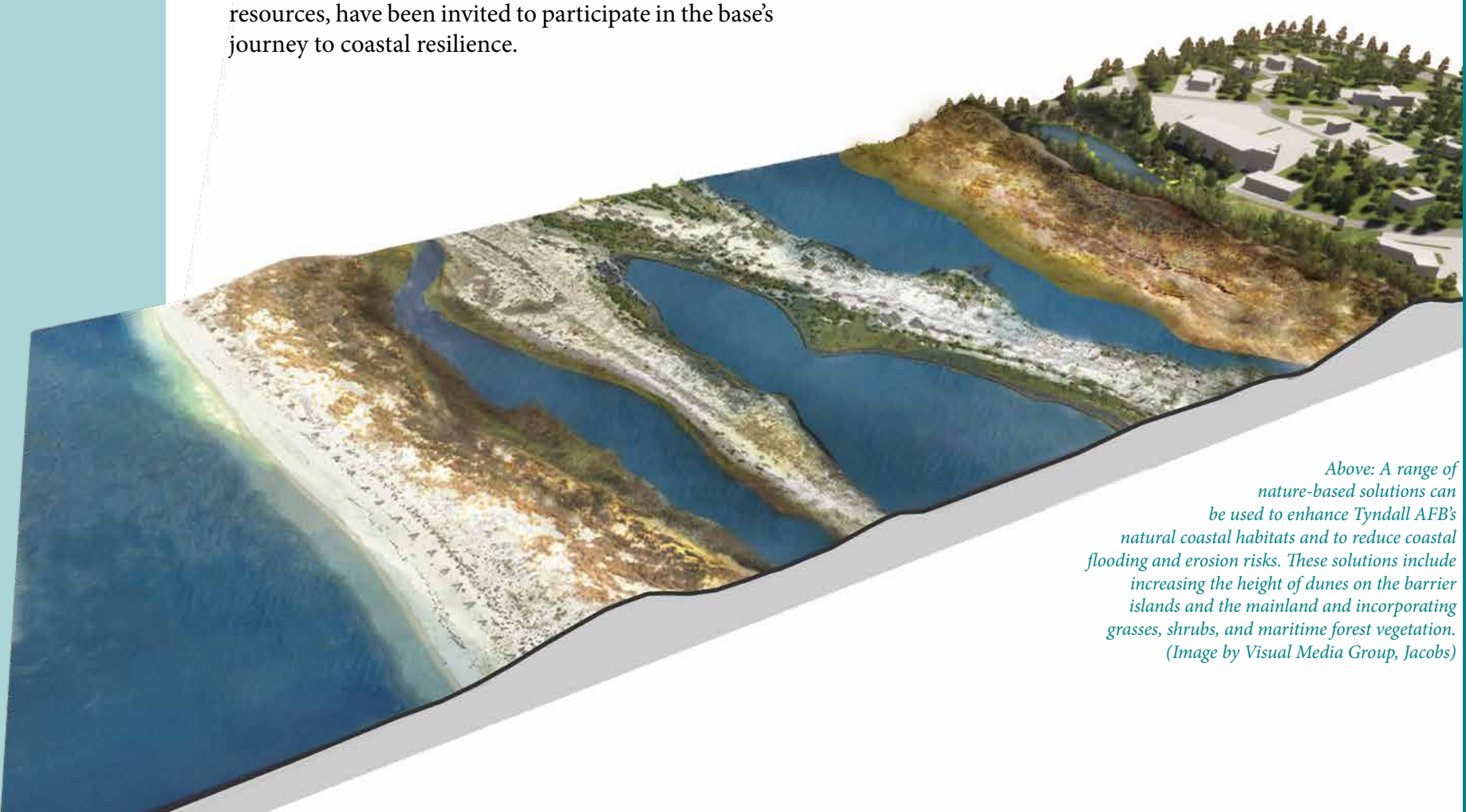
Above: Interrelated benefits from nature-based approaches. (Image by Jacobs).

Below: Tyndall Air Force Base is dedicated to supporting mission readiness, improved base resilience, and enhanced quality of life through optimized land management practices. (Image by Babak Aliabadi, Jacobs Visual Media Group)

Promoting Collaboration

To expand opportunities for additional nature-based solutions, Tyndall AFB is inviting collaboration in the form of alternative funding and financing, in-kind support, technical support, or other measures from external stakeholders to support the implementation of nature-based coastal resilience solutions. The base created a Coastal Resilience Working Group, seeking involvement from a range of stakeholders from the U.S. Department of Defense; local, state, and federal agencies; conservation organizations; and academia. To encourage positive, forward-thinking dialogue and to identify solutions that benefit the base and neighboring communities, Tyndall AFB organized a series of stakeholder engagement meetings to present the base's current plans and proposed coastal resilience pilot projects and to receive stakeholder comments and feedback. Organizations interested in becoming long-term partners, through funding and in-kind resources, have been invited to participate in the base's journey to coastal resilience.

Above: For protecting inland assets from coastal flooding, nature-based solutions include enhanced sand trapping on the barrier islands and dune construction along the mainland. (Photo by Jacobs)



Above: A range of nature-based solutions can be used to enhance Tyndall AFB's natural coastal habitats and to reduce coastal flooding and erosion risks. These solutions include increasing the height of dunes on the barrier islands and the mainland and incorporating grasses, shrubs, and maritime forest vegetation. (Image by Visual Media Group, Jacobs)

In 2021, Tyndall AFB was awarded the UK Environment Agency's Flood & Coast Excellence Award in the category of International Excellence. This prestigious award recognizes important work that has contributed to managing flood and coastal risk, building flood resilience, and addressing climate change. The Environment Agency noted that "the judges were inspired by this collaborative, international effort and its identification of innovative nature-based solutions for rebuilding in complex and sensitive coastal locations. The judges were also impressed with the alternative finance strategies the study identified and how this could be used to fund similar projects in other settings in the future."

Above: Task Force Hammer recovery operations at Tyndall following Hurricane Michael. (Photo by Dustin Gautney)

Below: Dr. Gian Basili from the U.S. Fish and Wildlife Service describing dune habitat and dynamics for the Tyndall AFB coastal resilience planning team. (Photo by Jacobs)

Tyndall AFB Working Group Mission Statement

"Create a collaboration platform to identify and implement the best coastal resilience solutions for Tyndall AFB to assure the Tyndall mission, benefit the surrounding community, advance the state of coastal resilience in the region, and provide mutual benefits to participating organizations where their mission overlaps with Tyndall's mission."

Tyndall AFB Working Group Members

- Audubon Florida
- Bay County, Florida
- Conservation International
- Defense Advanced Research Projects Agency
- Florida Department of Environmental Protection
- Florida Fish and Wildlife Conservation Commission
- National Fish and Wildlife Foundation
- National Oceanic and Atmospheric Administration
- Northwest Florida Water Management District
- Southeast Regional Partnership for Planning and Sustainability
- Restore America's Estuaries
- The Nature Conservancy
- University of Florida, Engineering School of Sustainable Infrastructure and Environment
- University of Georgia, Institute for Resilient Infrastructure Systems
- U.S. Army Corps of Engineers
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service

MAJOR TAKEAWAYS

1. Integrating nature-based solutions with traditional infrastructure reduces risks, creates co-benefits and optimizes returns on investment.
2. Assembling a diverse working group increases project support, speed, efficiency, and impact.
3. Connecting with external stakeholders at the strategy level before engaging on projects results in higher regulatory and financial support.
4. Creating a diverse menu of nature-based solutions is critical to accommodate the range of site conditions encountered at military installations.
5. Investing in foundational science and a permitting strategy are critical to success.

Right: Tyndall's coastal dune habitat. (Photo by Jacobs)

Marine Corps Base Camp Lejeune

Marine Corps Base Camp Lejeune

Jacksonville, North Carolina, United States

Marine Corps Base Camp Lejeune

Marine Corps Base Camp Lejeune

Enhancing Coastal Resilience

Jacksonville, North Carolina, United States

ECOREGION:

Middle Atlantic Coastal Plain

NATURAL HAZARD RISKS TO MISSION ASSURANCE

Sea Level Rise

Coastal Erosion

Marine Corps Base Camp Lejeune is a 156,000-acre installation used extensively to train Marines for combat and peacekeeping missions around the world. It also attracts bilateral and North Atlantic Treaty Organization (NATO)–sponsored exercises. The installation has a diverse array of assets available for training, including 11 miles of beach for amphibious operations, 34 gun positions, 50 tactical landing zones, 80 live-fire ranges, and facilities that allow for simulating military operations in urban environments. Camp Lejeune's geographical location creates additional value and complexity, consisting of a mix of beaches and dunes, marsh, and remote pine forests. Commercial, industrial, and residential land uses are colocated in the immediate vicinity of the base with two port cities (Wilmington and Morehead City, North Carolina) also in close proximity.

This large coastal installation includes barrier islands and salt marsh habitats that provide and protect critical training areas. However, a decade of coastal wetland research on base has illustrated the vulnerability of low-lying salt marsh to increased inundation. Therefore, the National Oceanic and Atmospheric Administration (NOAA) National Centers for Coastal Ocean Science (NCCOS) designed two large pilot projects, addressing two different approaches to increasing marsh resiliency through application of dredged sediment. At low-lying Freemen Creek, the project added sediment to existing marsh in replicated treatment plots. This controlled experiment measured the effects of thin-layer sediment application on plant production and sediment biogeochemistry. In a ponded, fragmented marsh at Mile Hammock Bay, dredged sediment was used to restore the ponded area to the elevation of the surrounding marsh and was successfully planted. The positive results demonstrate the potential of these management techniques for long-term maintenance of the installation's marsh habitats.

Mission Assurance

Camp Lejeune is a critical training base with the mission of maintaining combat-ready troops for expeditionary deployment. The 156,000-acre base includes barrier island, coastal wetland, and forested habitats that provide a variety of training venues. Erosion of the Intracoastal Waterway and the New River Estuary were of particular concern as they provide "splash points" for amphibious assault training exercises.

Previous page: The Atlantic Intracoastal Waterway bisects the back-barrier island salt marshes on Camp Lejeune. NOAA scientists tested thin-layer application of dredged sediment to increase the resiliency of marshes bordering the navigation channel. (Photo by NOAA-NCCOS)

Right: Aerial of the fragmented Mile Hammock Bay salt marshes. (Image from Google Earth)

Below: Boat wakes increase erosion and add to sediment deposition in the channel of the Atlantic Intercoastal Waterway that bisects Camp Lejeune. The waterway is an important commercial and recreational navigation channel, as well as a crucial military training area. Maintenance of the fringing salt marshes is important for reducing dredging costs and preserving ecosystem function. (Photo by NOAA-NCCOS)

Using Natural Processes

Natural coastal marshes are able to build surface elevation by trapping sediment particles suspended in the water column. In systems where suspended sediment is plentiful, this trapping function allows marshes to build elevation at a rate commensurate with sea level rise. In systems without adequate suspended sediment concentrations, thin-layer application of dredged sediments provides an alternative mechanism for sediment delivery that essentially simulates the natural process by which marshes adapt to changing water levels.

The coastal salt marshes of Camp Lejeune are bisected by the Atlantic Intracoastal Waterway. Boat wakes increase erosion rates, and the channel serves as a "trap" for eroded sediments. Because sediments are largely deposited in the waterway rather than on the surfaces of adjacent marshes, the marshes do not receive the sediment that they need to build elevation, and the channel requires periodic maintenance dredging to ensure navigability. Pairing dredging activities with thin-layer application can reduce the cost of managing sediments dredged from the waterway while simultaneously increasing the resilience of sediment-starved marshes.

Right: The sediments under the salt marsh store large amounts of plant-produced carbon, where they remain undisturbed for hundreds to thousands of years. (Photo by NOAA-NCCOS)

Broadening Benefits

Healthy marshes with dense vegetative cover protect adjacent inland regions by attenuating wave energy and slowing the inland transfer of water during flood events. Application of dredged sediments to low-lying and fragmented marshes can promote vegetative growth and, as a consequence, enhance the capacity of these systems to buffer adjacent developed regions from wave energy and extreme water levels. Healthy salt marshes also provide essential fish habitat, serving as primary nursery grounds for many commercially and recreationally important fish species. Additional studies conducted by NCCOS and partners at Camp Lejeune marshes documented the carbon sequestration, or "blue carbon" value, of these habitats.

Right: Dredged sediment was added to a pond in the fragmented Mile Hammock Bay marsh and planted with smooth cordgrass. Experimental plantings examined the impact of fertilizer and "clumping" on transplant growth. (Photo by NOAA-NCCOS)

Promoting Collaboration

State and federal regulatory agencies, including the U.S. Army Corps of Engineers (USACE)–Wilmington District, NOAA's National Marine Fisheries Service, NOAA-NCCOS, the U.S. Fish and Wildlife Service, and North Carolina's Department of Environmental Quality and Department of Natural and Cultural Resources, worked collaboratively on project scoping to determine optimal dredged sediment placement locations and to minimize potential adverse impacts to marsh and benthic habitat and to endangered species. Further, Wilmington District provided use of their dredge (*R/V Snell*) and crew for hydraulically dredging and placing sediment into an adjacent marsh. Finally, design of the project also benefited from collaborative discussions with experts from the USACE–Philadelphia District.

MAJOR TAKEAWAYS

1. Salt marshes provide crucial ecosystem services, including protecting training areas from erosion and storm impacts.
2. Coastal ecosystems on military installations bisected by the Atlantic Intracoastal Waterway are vulnerable to both sea level rise and shoreline erosion.
3. Beneficial use of dredged sediments can build elevation capital in a low-lying salt marsh.
4. Dredged material and subsequent planting can restore fragmented, ponded marshes, increasing plant production and resilience to sea level rise.
5. A decade of research to support ecosystem-based management provided the required data to ensure the project's success.

Left: NCCOS scientists measured plant response to changes in marsh surface elevation in experimental and control plots. Elevated fiberglass boardwalks reduce impact of sampling on the marsh plants, which can grow up through the grating. (Photo by NOAA-NCCOS)

Right: The U.S. Army Corps of Engineers' R/V Snell *dredging sediments in collaboration with NOAA researchers to test sediment placement strategies at Camp Lejeune. (Photo by NOAA-NCCOS)*

United States Military Academy, West Point

United States Military Academy, West Point

West Point, New York, United States

United States Military Academy, West Point

United States Military Academy, West Point

Treatment Wetland Infrastructure

West Point, New York, United States

ECOREGION:
Northern Piedmont

NATURAL HAZARD RISKS TO MISSION ASSURANCE

Stormwater Flooding | *Climate Change* | *Extreme Heat* | *Drought*

Founded in 1802, West Point is the oldest continuously occupied military post in the United States. It is located approximately 50 miles north of New York City on the Hudson River and has become a major tourist destination. The student body, or Corps of Cadets, numbers 4,400; and the academy graduates more than 900 new officers each year. The campus and central post area make up only a small portion of the nearly 16,000-acre reservation on which cadets train.

West Point Directorate of Public Works requested the assistance of the U.S. Army Engineer Research and Development Center (ERDC) to develop an approach to mitigate impacts of an aging combined stormwater and sewer infrastructure. The goal was to integrate green infrastructure in a way that would respect the historic architecture and landscape and improve the campus experience for the Cadets. The campus is home to historic buildings and grounds. Its location on the bedrock shoreline of the Hudson River presents many challenges for stormwater management. This site faced some specific issues:

- A historic campus framework
- Inadequate soils, shallow bedrock, and steep slopes
- Intense rainfall events and a cold weather climate
- Dated infrastructure and combined sewer outfalls
- Densely developed areas with little room for stormwater retrofit


BEAT
NAVY

Mission Assurance

West Point has a risk and history of flooding due to its location along the Hudson River. The installation also has an antiquated combined sewer system in which wastewater and stormwater are collected through the same pipes. When flooding occurs, the system discharges into the Hudson River. Sewage discharges of any kind have a negative impact on the quality of the receiving waterbody. The release of sewage and collected runoff can also negatively affect the health of the receiving waterbody and its ecosystem, as it increases the nutrient density of the water. This can encourage harmful algal blooms, which are overgrowths of algae in nutrient-rich water. They can produce dangerous toxins that sicken people, kill animals, create dead zones in the waterbody, and harm local economies. They also raise treatment costs for drinking water; and even then, treatment may not produce the desired results.

Above: Cadets prepare for pass and review. (Photo by PO1 Chad J. McNeeley)

Previous page and below: Stormwater management concept plan at West Point. (Image by USACE, HDR, and The LA Group)

Using Natural Processes

West Point's plan is based on a landscape approach and the benefits of treatment wetland infrastructure. The plan was developed to improve campus-wide stormwater management and to reduce impacts on the existing stormwater and wastewater infrastructure and drainage network. The plan included the following goals:

- Create stormwater management solutions that add value and functionality and that enhance the aesthetics of the campus.
- Reduce stormwater-related impacts on the existing infrastructure.
- Harvest and reuse stormwater where feasible.
- Develop concepts and approaches that can be applied throughout the campus and at other federally owned and operated facilities.

Broadening Benefits

West Point's creative solutions included natural features. Proposed solutions included bioswales that replicate natural cobblestone streams meandering through gathering places and tiered stone walls that cascade runoff through a series of planted bioretention cells to create a water feature. These concepts can

- become beautiful landscape features,
- create comfortable places for gathering,
- provide water-quality benefits,
- reduce runoff volume, and
- have design flexibility that allows implementation in areas with challenging terrain.

Top and middle: First Class Club concept plan at West Point. (Images by USACE, HDR, and The LA Group)

Bottom: A multinational flyover of West Point. (Photo by TSgt Jensen Stidham)

The campus environment must efficiently accommodate a large number of parking spaces that can serve multiple functions from everyday classes to premier football games.

Strategically placed stormwater planters not only address stormwater issues but also help to efficiently restructure parking and create safer circulation patterns. Generous tree plantings within these planters and parking areas

- provide stormwater-filtering properties,
- improve aesthetics by breaking up expansive areas of asphalt, and
- create shade that reduces the heat-island effect.

Buffalo Solider Field, a historic campus environment with a multipurpose athletic field, collects a large amount of runoff. However, any stormwater infrastructure in the area must creatively blend into the historic landscape to limit obstructions to the popular destination. The designed system does the following:

- Harvests rainwater from adjacent building roofs and filters pollutants into landscaped stormwater planters
- Conveys the water to an underground cistern, removing it from the combined sewer system, and storing it for reuse as irrigation for the athletic field
- Relocates a historic monument and incorporates it into a new water feature fed from cistern water, creating a more visible and beautiful gathering space where the history of the location can be celebrated
- Potentially conserves thousands of gallons of water each year and reduces the demand on existing wastewater infrastructure.

Promoting Collaboration

ERDC created a team of local civil hydrologists and regulatory specialists (HDR, Inc.), landscape architects with extensive experience in campus greenway design (LA Group), an in-house civil hydrologist, historic landscape architects, an agronomist, and urban planners. A series of design charettes with stakeholders at West Point identified five focus areas and established goals and objectives for a campus-wide stormwater management approach. Additional collaboration with the University of Illinois Departments of Civil Engineering and Agricultural and Biological Engineering Senior Design further refined the designs.

West Point's plan served as a pilot in the development of a process for stormwater management plans that other federally owned or operated facilities can replicate.

Left and right: First Class Club concept plan at West Point. (Images by USACE, HDR, and The LA Group)

MAJOR TAKEAWAYS

1. Pursue stormwater management solutions that increase value and aesthetics of the surrounding landscape.
2. Equate stormwater as a resource for use in maintaining a diverse array of green features.
3. Derive multiple benefits by using innovative, natural approaches to stormwater management.
4. Maintain design flexibility to achieve a diverse range of implementation strategies.
5. Prioritize designs that maximize natural features and processes.

MacDill Air Force Base

MacDill Air Force Base

Tampa, Florida, United States

MacDill Air Force Base

U.S. AIR FORCE

MacDill Air Force Base
Living-System Shoreline Stabilization

Tampa, Florida, United States

ECOREGION:
Southern Coastal Plain

NATURAL HAZARD RISKS TO MISSION ASSURANCE

Sea Level Rise | *Stormwater Flooding* | *Wildfire* | *Coastal Flooding* | *Coastal Erosion* | *Wind*

MacDill Air Force Base (AFB) lies on 5,697 acres approximately 7 miles south of Tampa, Florida. Activated as MacDill Field in 1941, it later became one of the original bases for the U.S. nuclear deterrent force, Strategic Air Command. In 1994, it became home to the 6th Air Base Wing. Today, the 6th Air Refueling Wing provides aerial refueling squadrons and combat support Airmen around the globe. It also provides operational support to Headquarters, U.S. Central Command; Headquarters, U.S. Special Operations Command; and 31 other mission partners. Personnel assigned to the base include 12,000 military personnel and 1,300 civilians, with approximately 1,200 active-duty members living on base. Located on Tampa Bay, MacDill AFB is home to 1,195 acres of wetlands and more than 20 protected and endangered species, including the American Bald Eagle.

The Oyster Reef Shoreline Stabilization Project demonstrates Engineering With Nature at work. This project, a collaborative effort between MacDill AFB and Tampa Bay Watch, aimed to reduce coastal erosion and provide an alternative to "hardened" shorelines. By using marine-friendly materials, the project created a living system to restore natural stabilizers. The creation of nearshore oyster reefs reduces wave energy, encourages sediment accumulation, and restores the natural coastal vegetation that traditionally protected the shoreline from erosion. The project offers three primary benefits: shoreline stabilization, water-quality improvement, and habitat enhancement. This project was executed in five phases from 2004 to 2016 and won the Future of the Region Award for Natural Resources and Environment in 2014. Additional work is ongoing.


AIR FORCE

Mission Assurance

Significant erosion was occurring along the base's shoreline, resulting in the loss of native plant species, such as black mangroves, palms, and century-old live oaks. In response, marine-friendly materials small enough to install by hand were placed within the intertidal environment—parallel to the shoreline—to create a living oyster reef system. The reef dissipates wave energy and traps sediment, encouraging establishment of native vegetation. This living shoreline is self-maintaining, regrowing quickly when impacted by storm events and adjusting naturally to gradual sea level change.

Using Natural Processes

Creation of a nearshore reef stabilizes the shoreline by reducing wave energy, trapping sediment deposits, and allowing salt marsh and mangrove habitat to establish along the barren shoreline. The reduced wave energy and trapped sediment stabilize the shoreline by encouraging the growth of native marsh grasses and mangroves. Additionally, the oyster reef filters water and increases marine habitat, providing refuge, food, and structure for a host of fish and other marine organisms.

Previous page, clockwise: MacDill's southeastern corner (circa 2008) was initially stabilized with a nearshore oyster reef that supported the later establishment of salt marsh and mangrove habitat (photo by Tampa Bay Watch); an area that was once bare sand now holds stands of dense smooth cordgrass, which quickly established behind a man-made oyster reef to stabilize a long-eroding shoreline (photo by Jason Kirkpatrick); military and civilian volunteers carry heavy oyster reef balls into the shallow nearshore waters to provide the structure for oysters to grow (photo by Tampa Bay Watch); and the MacDill AFB community pitches in to pass shell bags bucket-brigade-style into the water to build a reef and stabilize a section of salt marsh that has begun to disappear under the relentless pressure of wind and waves (photo by Jason Kirkpatrick).

Right, top to bottom: What was once an eroding shoreline stripped of naturally stabilizing vegetation was restored through the use of a nearshore oyster reef and vegetative plantings; native vegetation is able to gain purchase and return to a highly productive and more resilient shoreline following the installation of reef-building materials in the nearshore waters parallel to the shoreline; and signs of erosion abound along MacDill's eastern shoreline but are replaced by a dense vegetative buffer thanks to the installation of a man-made oyster reef. (Photos by Jason Kirkpatrick)

Broadening Benefits

Volunteer reef-building events created opportunities to involve the community and provide education about coastal ecosystems—more than 1,490 volunteers and 4,480 person hours contributed to reef building and planting salt marsh. This innovative yet cost-effective living-system approach for natural shoreline stabilization improved water quality, enhanced upland and marine habitat diversity, and provided economic benefits to the base. Baitfish, mullet, minnows, sheepshead, conchs, blue crabs, heron, ibis, egret, and raccoon use the reef as habitat or as a food source. As intended, the project decreased erosion along the eastern shoreline, particularly at the southeast corner. The stabilized shoreline prevents the loss of natural resources and coastal habitat and protects an archaeological site and government assets.

Promoting Collaboration

The community-based coastal restoration project was a collaborative effort between MacDill AFB and Tampa Bay Watch, a nonprofit organization focused on education and the restoration of Tampa Bay. Considered innovative when it began in 2004, the project garnered both financial and hands-on support from multiple partners, including the U.S. Fish and Wildlife Service, the National Oceanic and Atmospheric Administration, Hillsborough County, and the Tampa Bay Estuary Program. Since 2004, MacDill and community residents have dedicated more than 3,400 hours to rebuilding the shoreline, installing over 7,500 feet of reef, comprising 402 tons of fossilized shell and over 9,000 oyster reef balls.

MAJOR TAKEAWAYS

1. Creation of nearshore reefs reduced wave energy, promoted sediment accumulation, and promoted the restoration of coastal vegetation.
2. A well-designed, natural approach to shoreline resilience is self-maintaining and regrows quickly when impacted by storm events.
3. Nature-based strategies achieve resilience goals while also increasing marine habitat and providing refuge, food, and structure for marine organisms.
4. Collaboration achieves the best and most desirable outcomes in the shortest time.
5. People want to volunteer and contribute to these EWN Projects; this creates outreach opportunities for installations and adjacent communities.

Right: Military and civilian volunteers place oyster reef balls along the shoreline. (Photo by Peter Clark, Tampa Bay Watch)

U.S. Army Fort Hood

U.S. Army Fort Hood

Fort Hood, Texas, United States

U.S. Army Fort Hood

U.S. Army Fort Hood
Treatment Wetland Infrastructure

Fort Hood, Texas, United States

ECOREGION:
Edwards Plateau

NATURAL HAZARD RISKS TO MISSION ASSURANCE

Drought

Stormwater Flash Flooding

Climate Change

Fort Hood is the largest active-duty armored post in the U.S. Armed Services and is the only post in the United States capable of supporting two full armored divisions. Located in Central Texas approximately 60 miles north of the capital city of Austin, it covers a total of 335 square miles.

Fort Hood comprises approximately 218,823 acres, 132,525 acres of unimproved open training lands, 64,272 acres of impact area, and 15,900 acres of maneuver and air training area on West Fort Hood. Fort Hood's cantonment area consists of areas located within the main cantonment, North Fort Hood, West Fort Hood, Belton Lake Outdoor Recreation Area, and the east and west range training areas. These cantonment areas make up 22,026 acres of the installation's footprint and house approximately 6,109 buildings and 5,849 family quarters. Another 196,797 acres are undeveloped shrub lands used for maneuver training and live-fire ranges, an extremely important part of Fort Hood's mission. The installation's primary mission is to train, house, and support Corps units. The continued growth of Fort Hood in terms of population and mission has presented and continues to pose new challenges to the installation stormwater infrastructure and requires innovative design methods for dealing with increases in stormwater. Issues with stormwater are a big concern given that Fort Hood has a high risk of flash flooding due to its climate region and tight soils.

Mission Assurance

Over the last 10 years, Fort Hood has invested in improvements to the cantonment's stormwater infrastructure. This includes implementing an integrated stormwater management approach with extensive installation-wide modeling to determine locations vulnerable to flooding and areas with increased infiltration capacity. As part of these efforts, Fort Hood has adopted low-impact development (LID) approaches to stormwater and water management. This approach has several goals:

- Reduce the impacts of stormwater on the existing infrastructure network.
- Reduce runoff volume.
- Beautify the site.
- Have a design template to replicate across Fort Hood's cantonment.

Previous page: Constructed wetland at Fort Hood. (Photo by ERDC)

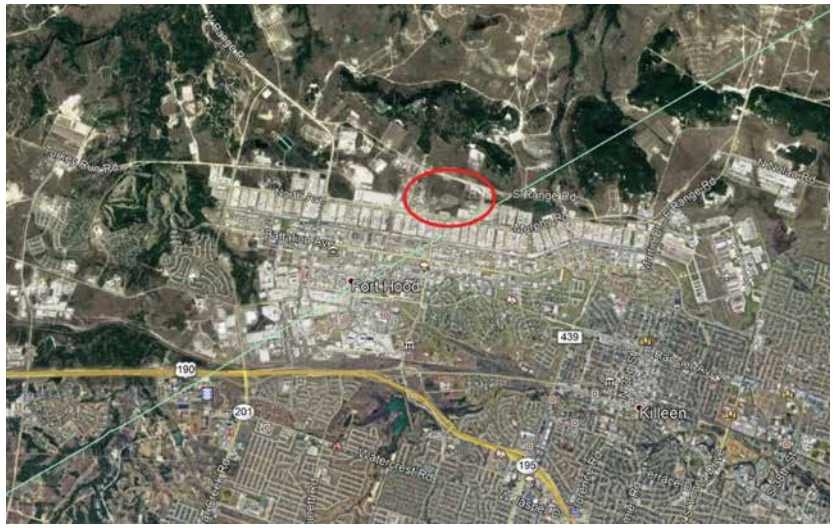
Above: Refueling after range exercises. (Photo by SSG Nathan Hoskins)

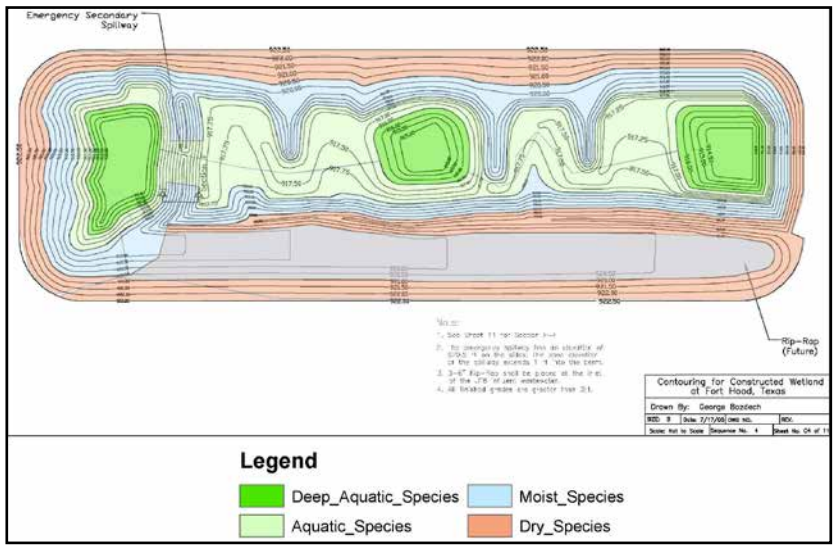
Below: A series of retention cells in the constructed wetland. (Photo by ERDC)

Using Natural Processes

One of the LID solutions included integrating bioswales that reduced flow intensity and increased infiltration, drought resilience, and water conservation. Fort Hood and the U.S. Army Engineer Research and Development Center' (ERDC) investigated the use of a bioswale for stormwater management along Santa Fe Avenue. The bioswale has a two-chamber system, providing increased infiltration capacity and overflow for the high-intensity, short-duration storm events. The bioswale vegetation received specific attention to ensure the following:

- Native to the area
- Locally adapted to Fort Hood
- Able to withstand 8 hours of inundation
- Drought tolerant
- Capable of filtering stormwater, including for petroleum, oil, and lubricants (POL)
- Low maintenance
- Appropriate for beautification projects





Top: Location of the constructed Wetland in Fort Hood, Texas. (Map data from Google)

Middle: Wetland areas and species type composing the dosing basin. (Image by Niels Svendsen and George Bozdech, ERDC)

Bottom: Rendering of a conceptual plan for a constructed wetland. (Image by ERDC and Erich Sprague)

Broadening Benefits

Fort Hood's climate region experiences prolonged periods of drought. As part of a water-savings effort, Fort Hood had ERDC investigate the use of oil-water separator effluent as a potential source of water for its Centralized Tactical Wash Facility (CTWF). The treatment wetland infrastructure was designed in a way that resulted in removal of POL. The first step allowed for harvesting of POL-contaminated wastewater from the oil-water separator. In turn, the water was conveyed through a series of vegetated retention cells that provide phytoremediation of POLs. The resulting water was of sufficient quality that it could be resupplied to the CTWF for the purpose of washing tactical vehicles. This outcome has the potential to conserve thousands of gallons of water each year.

The success of this project can be attributed to the selection of plant species for the system. Long-term success required vegetation native to the Fort Hood region. These locally adapted plant species also had to demonstrate an ability to remediate or accumulate POL-unique contaminants with minimal maintenance requirements.

Below: Early phase of construction for the wetland treatment system. (Photo by ERDC)

Promoting Collaboration

Working with Fort Hood, ERDC conducted two pilot demonstrations. U.S. Army Corps of Engineers Headquarters funded the first project, a bioswale, while Fort Hood funded the second, development of a wetland for the CTWF. Collaborating with Fort Hood Environmental, Engineering, Natural Resources, and Training Departments, ERDC was able to integrate stormwater management function with the installation requirements for low maintenance, nativeness, aesthetics, drought resilience, reduced sedimentation, POL treatment, and reduced pressure on stormwater infrastructure. Both projects were an opportunity to bring together folks from a range of backgrounds with diverse requirements to ensure function and resiliency.

The Fort Hood projects provide an alternative natural approach to stormwater management and water reuse. An integrated approach to address stormwater and common pollutants can provide a low-cost alternative solution to traditional engineering efforts. These pilot projects have the ability to inform future low-impact development designs for Fort Hood and other Army installations.

MAJOR TAKEAWAYS

1. Stormwater treatment systems such as wetlands and bioswales provide high resiliency to changes in precipitation frequency and duration.
2. Bioswales and wetlands provide beneficial treatment of typical road and parking lot stormwater pollutants.
3. Bioswales and wetlands offer an aesthetically valuable option to decentralize stormwater treatment systems.
4. Soil amendments to bioswales and wetlands vary depending on the desired treatment function and existing soil permeability.
5. Water-level control structures for stormwater treatment system are necessary to maximize functionality.

Right: Mature vegetation located within the wetland treatment system. (Photo by ERDC)

U.S. Army Aberdeen Proving Ground

U.S. Army Aberdeen Proving Ground

Harford County, Maryland, United States

U.S. Army Aberdeen Proving Ground

U.S. Army Aberdeen Proving Ground
Coastal Resiliency Project

Harford County, Maryland, United States

ECOREGION:
Northern Piedmont

NATURAL HAZARD RISKS TO MISSION ASSURANCE

Sea Level Rise *Stormwater Flooding* *Coastal Erosion* *Coastal Flooding*

First established in 1917 during World War I, Aberdeen Proving Ground (APG) is one of the United States' most important facilities for research, development, testing, and evaluation of military weapons and equipment. The installation hosts teams of military and civilian scientists, research engineers, technicians, and administrators. APG is the Department of Defense's Center for Excellence for C5ISR (Command, Control, Computers, Communications, Cyber, Intelligence, Surveillance, and Reconnaissance); Chemical and Biological Defense; Research and Development; Test and Evaluation; Public Health; and Personnel Security Investigation. A $1 billion research and development resource, and a key player in the nation's homeland defense and international counter-terrorism efforts, APG is an economic and technology resource for the region. With more than 18,000 civilians and soldiers, APG is also one of Harford County's largest employers and one of the largest in Maryland.

APG is located in the Upper Chesapeake Bay region. With the Chesapeake Bay—the largest estuary in the United States—expected to experience some of the highest rates of relative sea level rise along the entire Atlantic Coast, stakeholders recognized that planning efforts required a regionally coordinated effort. Relative sea level rise in the region is predicted to increase water levels up to 2.3 feet by 2050 and 6.9 feet by 2100. Storm surge and wave action will further increase water levels, causing both periodic and prolonged flooding.

In 2019, APG participated in a regional planning effort to develop a strategy to address sea level rise and shoreline stabilization for the surrounding Susquehanna Flats and Upper Chesapeake Bay region. Other partners in the effort included Harford County; the Chesapeake Science and Security Corridor Joint Land Use Study Committee; and EA Engineering, Science, and Technology, Inc., PBC. Jointly, this group developed a planning-level report titled *Planning for Coastal Resiliency in the Northern Chesapeake Bay* (the Plan).

Mission Assurance

Coastal storm events and hurricanes that affect the upper Chesapeake Bay impact not only operational readiness on APG but also off-installation readiness. For example road closures due to flooding, damage to supply chains, and other situations affect both the surrounding community and APG. Coastal adaptation strategies focused primarily on ensuring that mission-critical elements at APG were supported through the use of a regionally based approach that also protected civilian needs.

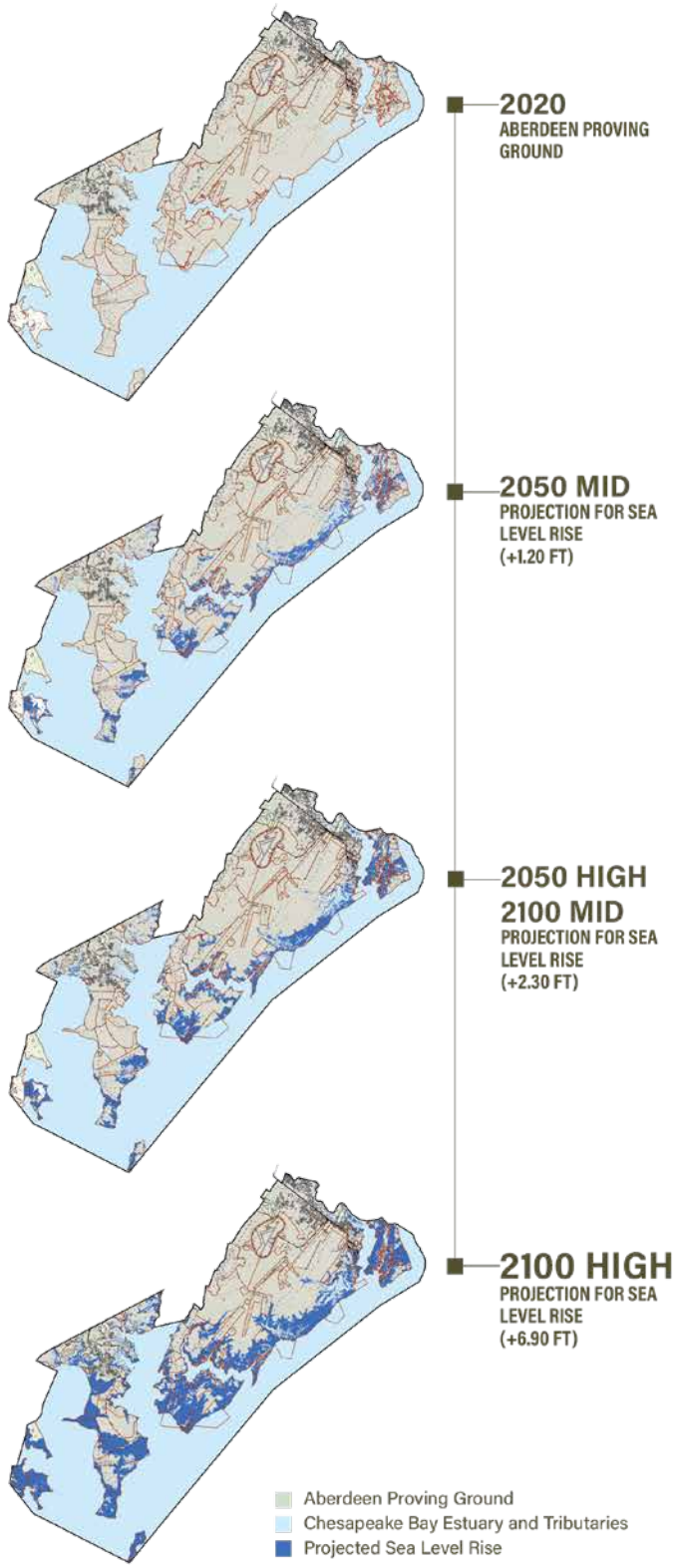
IMPACTS FOR SEA LEVEL RISE AT ABERDEEN PROVING GROUND

Previous page: With a 64,000-square-mile watershed that draws from six states, the Chesapeake Bay is the largest estuary in North America. (Photo by Amy Lambert)

Above: Vulnerabilities for APG include mission-critical areas and the installation's sizable infrastructure network. Both could be impacted significantly by sea level rise and future storm events. (Image by EA Engineering, Science, and Technology, Inc., PBC)

Right: Based on data available at the time of the study, relative sea level rise in the Upper Chesapeake Bay region is predicted to increase water levels up to 2.3 feet by 2050 and 6.9 feet by 2100. Additional impacts from storm events, including storm surge and wave action, will further increase water levels, resulting in both periodic and prolonged flooding. (Image by EA Engineering, Science, and Technology, Inc., PBC)

PROJECTIONS FOR SEA LEVEL RISE



Using Natural Processes

A primary objective of the Plan was the exploration of adaptation options focused on the use of natural and nature-based features. Because the Plan was regionally focused, options such as using dredged material from the Susquehanna Flats area were evaluated for enhancing marsh elevation, creating habitat, and reducing flood energy throughout the Upper Chesapeake Bay region. Other natural processes that were evaluated and subsequently proposed included living shorelines, submerged aquatic vegetation (SAV) beds, and island restoration on APG and in various locations within vulnerable and degraded portions of the coastal landscape.

Above: The Susquehanna Flats region of the Upper Chesapeake Bay includes a large area of SAV beds encompassing approximately 20 square miles. Depending on storm characteristics, SAV beds provide wave attenuation for adjacent lands. Expanding SAV beds was an alternative proposed under the coastal resiliency plan prepared for APG and the surrounding northern Chesapeake Bay communities. (Photo by Kathleen Voigt)

NATURAL AND NATURE-BASED FEATURES

Viable Alternatives for APG in Lighter Color

	Benefits and Processes	Factors Affecting Performance
Beaches and Dunes	• Breaking of offshore waves • Attenuation of wave energy • Slow inland water transfer	• Berm height and width • Beach slope • Sediment grain size and supply • Dune height, crest, and width • Presence of vegetation
Salt Marshes and Seagrass Beds	• Breaking of offshore waves • Attenuation of wave energy • Slow inland water transfer • Increased infiltration	• Marsh, wetland, or SAV elevation and continuity • Vegetation type and density
Oyster Reefs	• Breaking of offshore waves • Attenuation of wave energy • Slow inland water transfer	• Reef width, elevation, and roughness
Barrier Islands	• Wave attenuation and/or dissipation • Sediment stabilization	• Island elevation, length, and width • Land cover • Breach susceptibility • Proximity to mainland shoreline
Land Restoration or Creation	• Wave attenuation and/or dissipation • Shoreline erosion stabilization • Soil retention	• Land elevation, length, and width • Land cover • Breach susceptibility • Proximity to mainland shoreline

Left: Man-made nature-based measures enhance coastal resilience using the same processes as natural features. (Image from Bridges et al. 2015)

Broadening Benefits

The Plan incorporated a more regional approach to address coastal flood vulnerabilities, taking advantage of the benefits that support resilience for multiple stakeholders. It also took advantage of sediment for beneficial use that is not typically available at the individual property level or that larger statewide vulnerability assessments and adaptation plans may not identify as a source. The regional nature associated with development of the Plan ensured that a wide variety of stakeholders benefited, rather than just a few entities.

Right: Like many coastal estuaries in the U.S., the Upper Chesapeake hosts a multitude of uses, including recreation. The joint planning process between the community and APG ensured that the Plan promoted the use of natural infrastructure inherently benefiting these and other uses. (Photo by Kathleen Voigt)

Below: Coastal storm events also impact off-installation readiness through road closures, damaged supply chains, and other functions intertwined between APG and the surrounding community, such as the nearby waterfront town of Havre de Grace. (Photo by Amy Lambert)

Promoting Collaboration

The effort was lead by the Joint Land Use Study Work Group, which included members from Harford, Cecil, and Kent Counties and installation representatives from APG. The Plan's collaborative approach focused on examining and solving the shared vulnerabilities between the community and APG and on planning for sharing the raw materials available for nature-based responses, such as beneficial use of dredged material. The Plan examined a range of solutions for elements on and off the installation, including infrastructure, emergency services, utilities, historic districts, and more. It includes several adaptation and resilience strategies:

- Accommodation—Altering existing structures or building new infrastructure that is better able to withstand climate change
- Protection—Using engineered solutions to decrease risk to existing structures and areas
- Managed Retreat—Relocating existing structures and limiting new construction in areas vulnerable to flooding

Funding provided by the Office of Local Defense Community Cooperation (formerly the Office of Economic Adjustment) within the Department of Defense allowed APG and surrounding communities to assess vulnerabilities under various time scales and develop response scenarios that focus on the use of natural infrastructure to increase resilience of the coastal landscape.

MAJOR TAKEAWAYS

1. A regional planning approach can reduce implementation costs and increase regional benefits.
2. The Chesapeake Bay region is expected to experience some of the highest levels of relative sea level rise along the Atlantic Coast.
3. Use of natural and nature-based features increases resilience potential and helps to ensure military readiness.
4. Use of sediment from navigational dredge projects to improve coastal resilience reduces overall costs to the federal government and helps eliminate waste.
5. Protection and conservation of military range operation was a key focus of the Plan.

Right: Using natural infrastructure during the coastal resilience planning process was critical to protect the wide variety of both military and civilian infrastructure present in the region. (Photo by Chris Overcash)

Naval Base Ventura County

Naval Base Ventura County

Ventura County, California, United States

Naval Base Ventura County

Naval Base Ventura County
Coastal Adaptation Strategy

Ventura County, California, United States

ECOREGION:
Southern California / Northern Baja Coast

NATURAL HAZARD RISKS TO MISSION ASSURANCE

Sea Level Rise | *Coastal Flooding* | *Coastal Erosion* | *Fluvial Flooding*

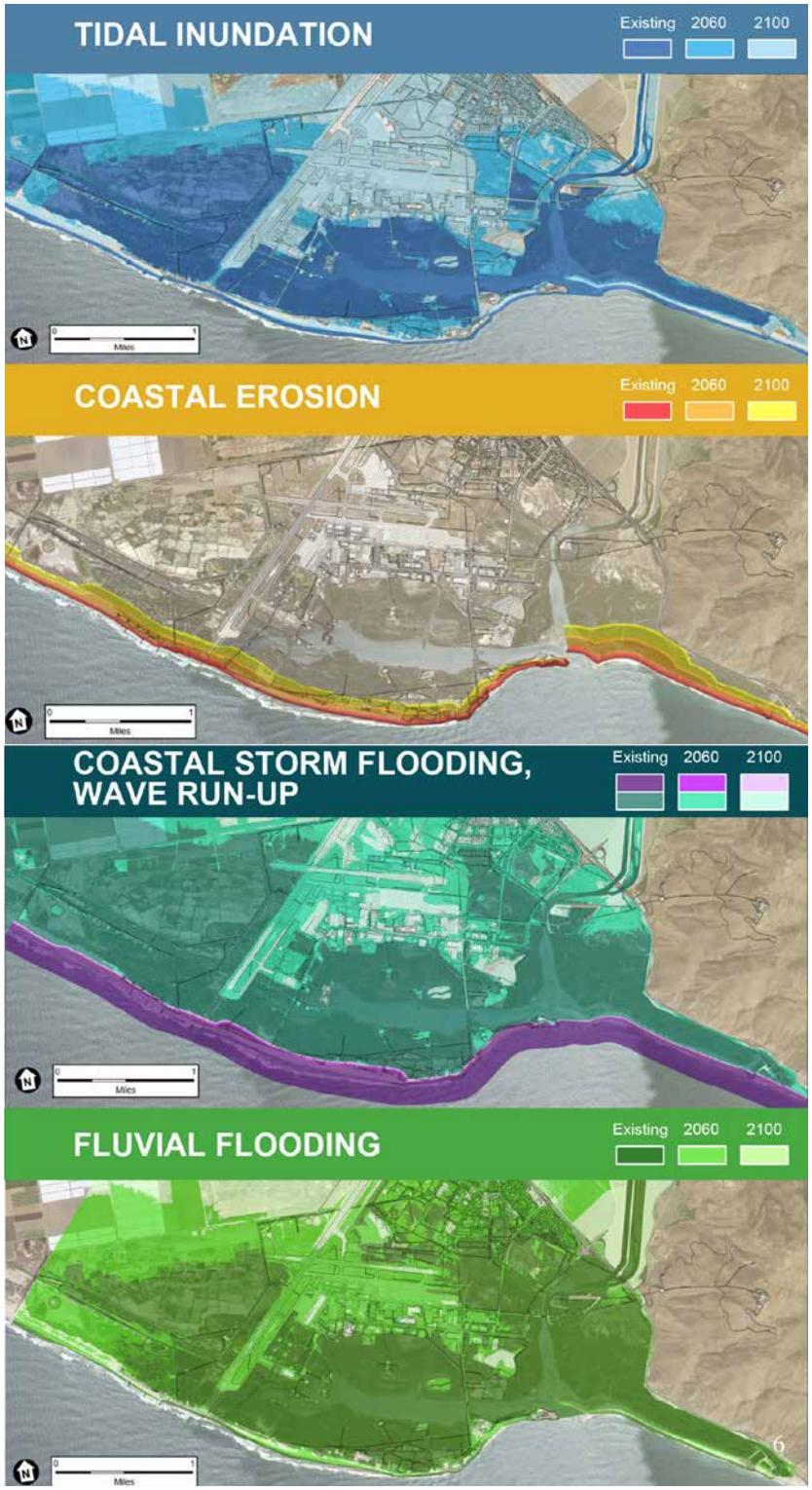
Naval Base Ventura County (NBVC), 55 miles west of Los Angeles on the Ventura coastline, is a critical Navy asset that allows direct access to restricted air and sea space in the 36,000 square miles of the Point Mugu Sea Range. Within the Point Mugu operating area of NBVC is Mugu Lagoon, the largest and most intact coastal marsh in Southern California. Because of its coastal location, NBVC faces impacts from coastal erosion and wave run-up, inundation from high tides, and flooding from coastal storm surges and Calleguas Creek. These hazards are increasing in intensity, frequency, and duration and will increase further as sea levels rise, damaging the built infrastructure and natural habitats of the base. Through a first-of-its-kind partnership between the U.S. Navy and The Nature Conservancy, a Coastal Adaptation Vision (referred to here as the "Vision") was completed in 2020. The goal was to evaluate vulnerabilities to sea level rise and coastal hazards at Point Mugu and to develop a vision for adaptation to achieve long-term resilience and to support the military mission.

The Nature Conservancy, NBVC, and partners identified strategies to improve the resilience and function of built infrastructure and natural ecosystems. This Vision recommends protecting critical assets that must remain in place and identifies opportunities to consolidate other base infrastructure to reduce current and future vulnerability. This approach improves the natural habitats and the protective services they provide to built assets. NBVC is incorporating these recommended actions into its Installation Development Plan, conducting deeper analyses where needed, and developing an actionable adaptation plan.

Mission Assurance

The mission of NBVC is to "provide integrated shore services to support the diverse needs of the Fleet, Fighter, and Family" through safe and secure base operations. NBVC is important to the Department of Defense (DoD) infrastructure because it provides direct access to restricted air and sea space. NBVC supports more than 80 tenant commands and 20,000 total jobs. The base is a major economic contributor in Ventura County, providing jobs and affecting multiple economic sectors. NBVC's contribution to the regional economy is estimated to be $2 billion per year. Tenant commands include three warfare centers: Naval Air Warfare Center Weapons Division; Naval Surface Warfare Center, Port Hueneme Division; and Naval Facilities Engineering Command and Expeditionary Warfare Center. NBVC is home to deployable units, including the Pacific Seabees and the West Coast E-2 Hawkeyes. NBVC is also becoming an emerging hub for unmanned aerial systems (UAS), such as the MQ-4 Triton, the MQ-8 Fire Scout, and the MQ-25A Stingray. Future growth and expansion of existing programs will provide benefits to the regional economy and increase the economic contribution of NBVC to the surrounding communities.

Mugu Lagoon is fronted by approximately 6 miles of beach backed by dunes. NBVC assets are built on beach strand, on fill in the lagoon wetland habitats, and on uplands. Coastal erosion and wave run-up, inundation from high tides, and flooding from coastal storm surges and Calleguas Creek are hazards to the built infrastructure and natural habitats. With climate change, these hazards are increasing in intensity, frequency, and duration. Each of these five hazards was modeled to measure how exposure may impact built assets and natural habitats under current conditions and for years 2030, 2060, and 2100. The results show that under current and future sea level rise, most of the built assets of the base are at risk to hazard impacts, including increased flooding and wave forces.



Previous page: Dune system located on property belonging to Naval Base Ventura County. (Photo by Peter Dixon, The Nature Conservancy)

Above: Flood maps with four hazards. (Images by Environmental Science Associates)

Modeling of impacts on natural habitats indicates that, if built assets are defended in place with armoring, beaches will erode away while mudflats and salt marsh habitats will submerge and convert to open water. These natural areas need to be connected with natural water and sediment flows to allow them to accrete sediments and grow vertically to keep pace with rising seas. Armoring prevents these natural processes from occurring and impedes the ability of habitats to migrate inland. Working with nature will improve natural habitat function and resilience, enhancing the protective services they provide to NBVC assets.

The hazards that NBVC faces will impede its ability to maintain its viability as a premier training and testing site, jeopardizing the long-term resilience of NBVC's operations and mission. Ensuring NBVC's resilience is mission critical. The Vision for NBVC was developed to recommend and vet a suite of adaptation actions to improve the resilience of built assets and to restore natural habitats and their benefits, preserving base functionality and supporting the military mission.

Top: Sand erosion impacts NBVC's coastline. (Photo by Julia Brownley)

Middle: Mugu Lagoon and Ormond Beach (Photo © Kevin Arnold)

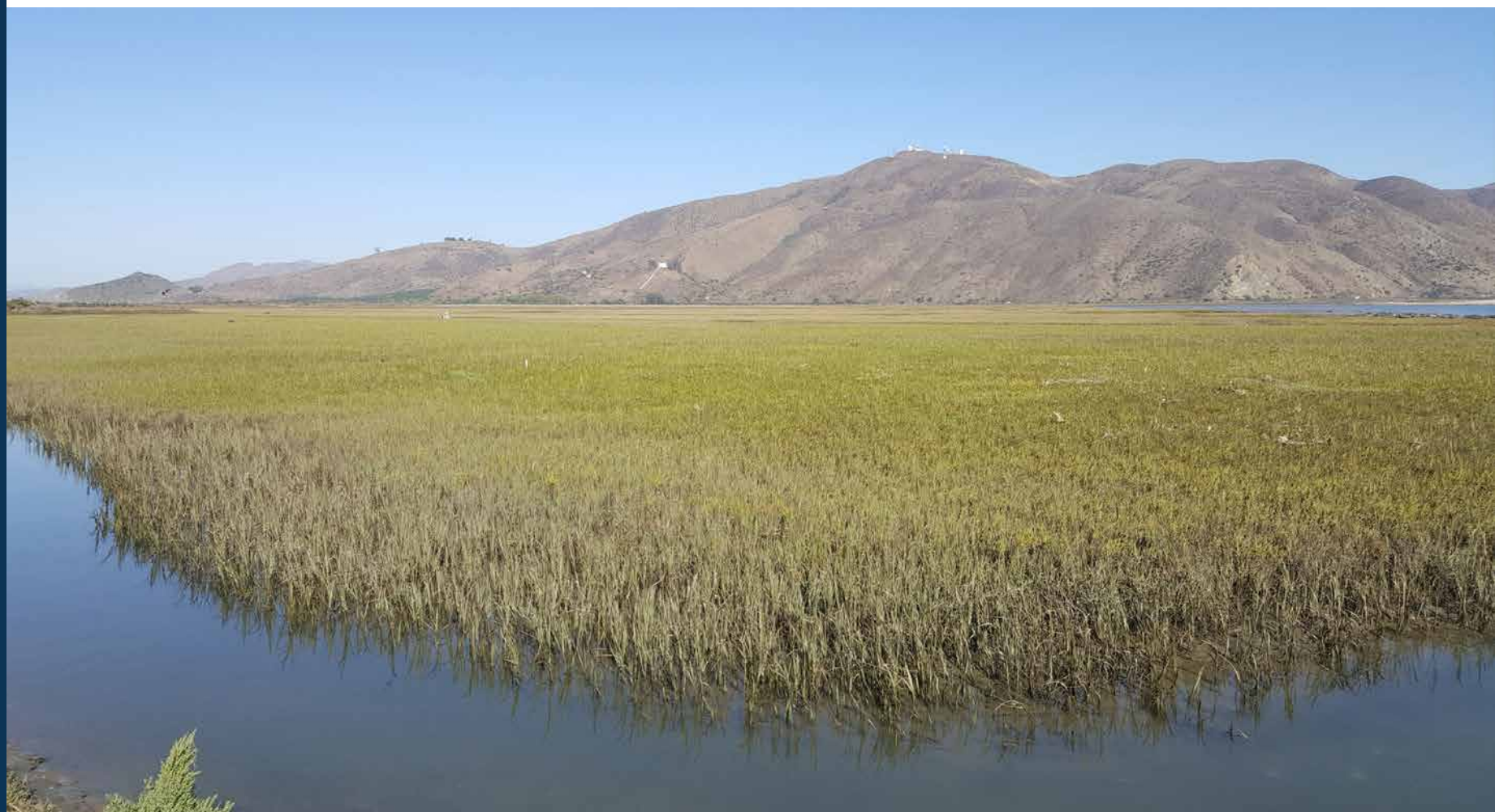
Bottom: Base Aerial View. (Photo by NBVC)

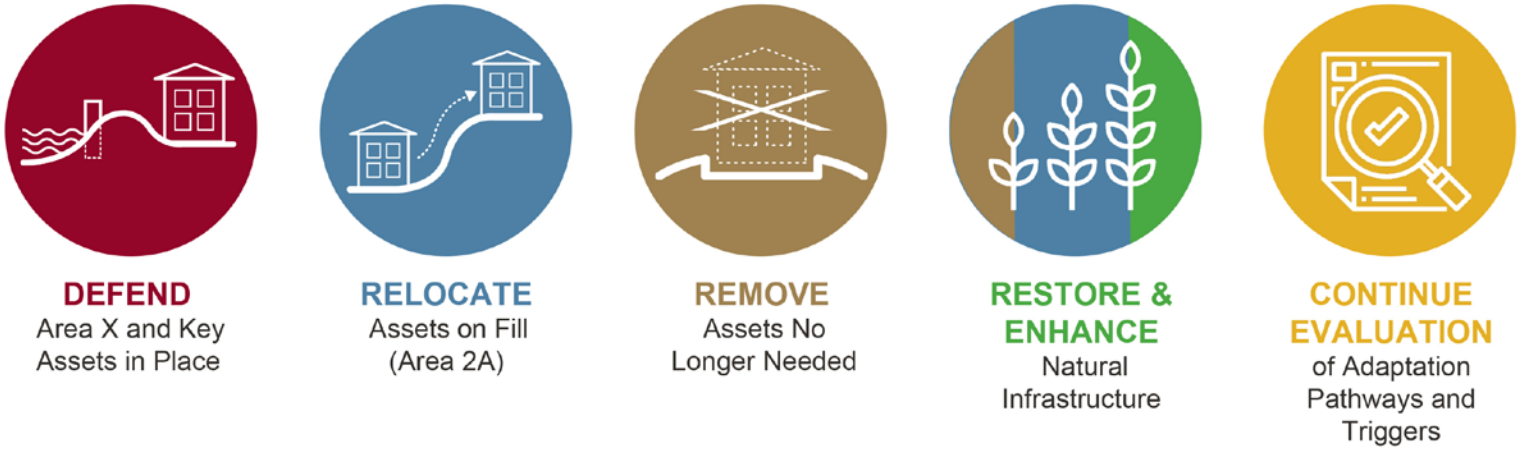
Using Natural Processes

NBVC holds the largest and most intact collection of beaches, dunes, estuarine, and salt marsh habitats in Southern California, which supports great biodiversity, including rare and imperiled species. This mosaic of habitats also provides many benefits to the base and people, including aesthetics, recreation, clean water, and attenuation of flood waters. To confer these benefits and protective services to built assets, natural processes—including sediment and water movement—need to be allowed to occur. Armoring and infrastructure dispersed throughout these habitats disrupt these processes and prevent habitats from keeping pace with rising seas and migrating landward. With the existing base configuration and sea level rise, beaches and dunes will be lost to erosion; and most mudflats, salt marshes, and transitional marshes will be submerged by open water.

The Vision recommends both moving base assets and armoring out of hazard zones into safer grounds where possible and restoring natural habitats and ecological processes in their place. The team calculated asset-specific risks from aggregating all five hazards and then characterized the results into three action categories: Defend, Relocate, and Remove. *Defend* includes mission-critical built assets that must remain in place. *Relocate* includes assets with critical functions not specific to that location that can be moved to higher ground. *Remove* includes built areas and assets that are no longer needed (redundant, derelict, or obsolete). Relocate and Remove areas give rise to Restoration and Enhancement opportunities. Continued Evaluation of adaptation pathways and triggers was identified as a crucial adaptation action. Together, these actions will directly increase the

Below: Mugu Lagoon. (Photo by NBVC)



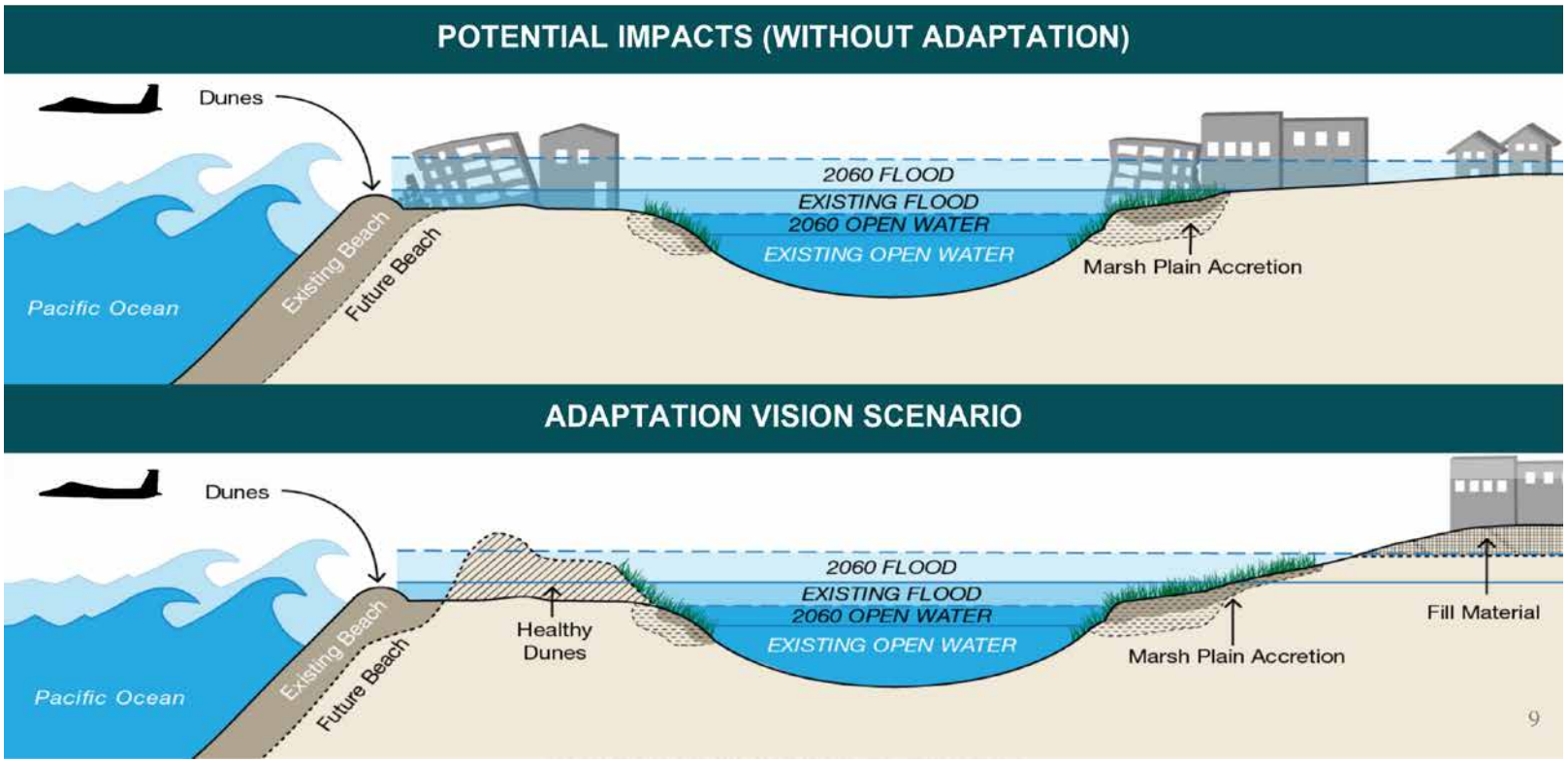


Above: Adaptation actions to enhance base and coastal habitat resilience. (Image by The Nature Conservancy)

long-term resilience of base function and give rise to healthier coastal habitats and their protective services.

Implementing the Vision would reduce the overall footprint of built assets by approximately 30 percent, consolidating it within an area of the base projected to be the most resilient to all hazards through 2100. This also frees up nearly 400 acres of land to be restored to natural habitat. Including the surrounding upland areas and areas already targeted for restoration by the base, this Vision will provide more than 700 acres of additional habitat, providing further wave attenuation and flood management benefits.

Below: Potential impacts and adaptation scenario. (Image by Environmental Science Associates)



Broadening Benefits

Implementing the Vision to ensure a more resilient and restored wetland system in Ventura County will be a critical contributor to California's statewide goals to protect the coast from climate change and to fight species loss. A recent study by the California State Coastal Conservancy and The Nature Conservancy, *Conserving California's Coastal Habitats*, estimates that with 5 feet of sea level rise, nearly 60 percent of coastal habitats in California are highly vulnerable to loss. With sea level rise and climate change, restoring and protecting habitats and single species will become increasingly challenging. Restoring larger mosaics of coastal habitat, such as those found in Point Mugu, will provide space and natural processes for these habitats and species to adapt to changing conditions. Restoring natural processes along this stretch of coast will improve base-wide resilience and provide regional coastal resilience benefits by reconnecting regional processes like sediment dynamics.

The collaboration, analysis, and processes—developed to support the Vision—provide an important model as DoD and military services advance resilience activities across their installations. External partnerships can fill critical gaps in expertise and capacity in developing science, convening and planning, and identifying creative resilience strategies with broader benefits.

Below: Ormond Beach dunes. (Photo by Laure Riege, The Nature Conservancy)

Right: Firefighting efforts to battle wildfires at NBVC. (Photo by PO1 Chris Fahey)

Promoting Collaboration

In 2016, Commander Navy Region Southwest and The Nature Conservancy entered into a joint Memorandum of Agreement (MOA) focused on coastal resilience planning for natural resources and asset management at NBVC. This joint MOA was the first of its kind, marking the first time the DoD partnered with a nongovernmental organization to protect a military installation from sea level rise and other consequences of climate change.

Through this years-long partnership with The Nature Conservancy, the Navy has provided essential resources for protecting the neighboring 650-acre Ormond Beach wetland complex. Jointly owned and managed by The Nature Conservancy, the California State Coastal Conservancy, and the City of Oxnard, it is the most significant opportunity for coastal restoration in Southern California and is a priority for the surrounding communities. Together, Ormond Beach and Mugu Lagoon compose the largest coastal wetland in Southern California, spanning 9 miles from Port Hueneme to Point Mugu. Protecting, restoring, and expanding Ormond Beach provides multiple benefits to the Navy's overall encroachment mitigation strategy, including buffering NBVC mission capabilities (air operations and mobility corridors), providing bird habitat away from the airfield, providing habitat for imperiled species, ensuring coastal resilience and flood protection, and preserving working agricultural lands.

The Vision was developed through a collaborative process involving a multidisciplinary team, drawing on expertise from NBVC; The Nature Conservancy; and Environmental Science Associates, a consulting firm. A robust team from NBVC provided input to this effort. It included representation from base command, public works, facilities and asset management, community planning, and natural resources and environmental management. Find more information on this collaboration at http://nature.org/cacities.

MAJOR TAKEAWAYS

1. Multibenefit strategies that include natural infrastructure will support the military mission while also achieving ecological outcomes.
2. Consider approaches and designs that result in "multiple layers of defense" to overcome risks and vulnerability.
3. In certain circumstances and settings, a combination of natural and conventional infrastructure is the appropriate strategy to pursue.
4. Pursuit of nature-based strategies at NBVC resulted in an additional 700+ acres for coastal habitat migration and restoration.
5. Foundational science and a systems approach to problem-solving are critical to identifying the best natural infrastructure solutions.

Conclusion

Conclusion

Recognizing EWN Opportunities and Encouraging Action

Partnering with Nature to Achieve Future Resilience

This book introduced a few examples of nature-based solutions on Department of Defense (DoD) installations to spark thinking and conversation about the opportunity to combine engineering and nature to build future resilience for the DoD. These examples illustrate the feasibility of nature-based solutions while also highlighting the opportunity to scale up applications to produce a range of benefits. The damage caused by recent storms and other events at DoD installations focuses the need to actively invest, adapt, and mitigate to reduce risks in the future. Nature itself provides opportunities to do just that.

Advancing science and experience pertaining to nature-based solutions around the world provides the means and tools for considering, evaluating, and implementing natural infrastructure in a way that complements investments being made in built infrastructure. Making progress to this end will involve addressing several questions. How do we assemble the expanded portfolio of engineering options, alternatives, and designs to achieve broadly based resilience for DoD installations? How do we facilitate the integration of complementary interventions to achieve system-scale resilience? How do we responsibly overcome the obstacles to delivering innovative solutions? How do work toward a future where nature itself is considered a necessary part of a comprehensive engineering solution?

Answering these and other questions to expand opportunities to create resilience through the development of natural infrastructure on DoD's 25 million acres of land and water will involve several elements.

Innovation will be key to delivering mission resilience. We have all experienced the truth of the expression that "necessity is the mother of invention." The scale and damage produced by natural hazards in the United States and elsewhere has tangibly exposed the vulnerability of our communities, installations, and infrastructure systems. Climate science has provided abundant evidence that risks to DoD facilities and our communities will increase in the future due to intensifying storms, sea level rise, wildfires, drought, and combinations of these and other hazards. As conditions, climate, and weather patterns vary across regions, so will the risk, necessitating the development of tailored strategies that draw from a diverse and innovative portfolio of engineering solutions that can

be adapted over time. Current science and common sense indicate that nature and its landscapes will be an important part of developing enduring infrastructure systems and installation resilience. Engineering future resilience will require a commitment to fostering innovation in developing a diverse portfolio of built and natural infrastructure approaches and assembling combinations of measures to provide resilience.

Partnership is a powerful lever for progress. Great strides in the pursuit of nature-based solutions and infrastructure have been made across all sectors. Harnessing these advancements through multisector collaboration and partnership will accelerate effective and efficient implementation of natural infrastructure across geographical regions and contexts. Further, collaboration between DoD and local and regional government and stakeholders on natural infrastructure will reveal opportunities to create regional resilience for installations and surrounding communities. Ultimately, strong relationships and engagement across organizations will provide capabilities to evaluate systems and options, identify appropriate engineering interventions, and deliver integrated infrastructure systems that create broad value and resilience.

Sharing and communicating experience builds momentum. Sharing information across organizational, regional, and sectoral boundaries is advancing the development of knowledge and practice for nature-based solutions. Through its expansive organizational network, DoD can accelerate knowledge transfer about nature-based solutions across the Army, Navy, Air Force, and other DoD departments, as well as with other organizations and partners. Documenting projects, pilot studies, and full-scale applications of nature-based approaches, and their outcomes, will support timely progress. Finally, describing, quantifying and communicating the mission-relevant benefits (i.e., engineering, economic, environmental, and social) accrued from these projects will be key to making the business case for future investment.

Leadership creates conditions for positive change and progress. Change poses challenges for all organizations, and change is both inevitable and necessary. There is a common saying that "insanity is doing the same thing over and over again but expecting a different result." Regarding the challenges facing DoD and its nearly 5,000 facilities around the world, new infrastructure approaches will be needed to provide the mission resilience being sought. The communicated intent of leadership provides an azimuth for organizing, setting priorities, and, importantly, establishing the degree of openness to new approaches and solutions. Leadership intent is directly relevant to the development of new approaches

regarding built and natural infrastructure and their integration. Since the beginning of the modern environmental movement in the 1960s and 1970s, organizations and processes have become accustomed to treating infrastructure and the environment as separate and even as conflicting intentions rather than part of the same system and solution. Leadership has an important role to play in moving beyond these historical approaches by enabling new thinking, integrative approaches, and business processes. Intention will be foundational to making the most of the natural infrastructure potential on DoD's 25 million acres of land and water.

Education, training and guidance will create the future. The translation of new and emerging science and knowledge into education and training programs will fuel ongoing progress and application. The range of means and technologies to support education and training have increased significantly in recent years, to include in-person, virtual, web-based, and other approaches. Such programs will support modernizing standards of practice as well as on-the-ground and in-the-water applications of nature-based solutions. Effective implementation of natural infrastructure to provide resilience for twenty-first-century installations is contingent on successfully sharing knowledge about the science, engineering, design, benefits, and performance of natural infrastructure. The *International Guidelines on Natural and Nature-Based Features for Flood Risk Management* published and released on 16 September 2021[1] will provide a solid foundation for future progress; the development of the *NNBF Guidelines* was led by the USACE Engineering With Nature Initiative, with partner and contributing organizations from around the world.

So, where do we go from here? Ultimately, that will depend on the collective will and action of the DoD and its wide-ranging departments and partners. Given the scope of the challenges and opportunities before the DoD in the twenty-first century, it makes sense to develop nature as a partner and an ally in the pursuit of enduring resilience.

1. T. S. Bridges, J. K. King, J. D, Simm, M. W. Beck, G. Collins, Q. Lodder, R. K. Mohan, eds., *International Guidelines on Natural and Nature-Based Features for Flood Risk Management*, ERDC SR-21-6 (U.S. Army Engineer Research and Development Center, 2021), http://dx.doi.org/10.21079/11681/41946. More information is available at https://ewn.erdc.dren.mil/?page_id=4351.

Overlooking the Point Mugu wetlands at Naval Base Ventura County (Photo by Julia Brownley)

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United States Military Academy, West Point, is located in West Point, New York. Project information, photos, and graphics courtesy of Rumanda Young and Billy Johnson, U.S. Army Engineer Research and Development Center. For more information concerning this project, please contact Rumanda Young by email at rumanda.k.young@usace.army.mil. Portions of this project's text have been modified and reprinted from West Point, "Fact Sheets," United States Military Academy, West Point, accessed 19 July 2021, https://www.westpoint.edu/about/public-affairs/news/fact-sheets. Additional text has been modified and reprinted with permission from Mark Taber, "Innovative Designed Solutions for Stormwater Challenges," The LA Group, 30 December 2015, https://www.thelagroup.com/2015/12/30/innovative-designed-solutions-for-stormwater-challenges/.

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MacDill Air Force Base is located in Tampa, Florida. Project information and photos courtesy of Jason Kirkpatrick and Andy Lykens. For more information concerning this project, please contact Jason Kirkpatrick by email at Jason.kirkpatrick.2.ctr@us.af.mil or Andy Lykens by email at andrew.lykens.ctr@us.af.mil. Portions of this project's text have been modified and reprinted from T. S. Bridges, E. M. Bourne, B. C. Suedel, E. B. Moynihan, and J. K. King, *Engineering With Nature: An Atlas, Volume 2*, ERDC SR-21-2 (Vicksburg, MS: U.S. Army Engineer Research and Development Center, 2021), http://dx.doi.org/10.21079/11681/40124.

U.S. Army Fort Hood is located in Fort Hood, Texas, near Killeen. Project information, photos, and graphics courtesy of Heidi Howard, U.S. Army Engineer Research and Development Center. For more information concerning this project, please contact Heidi Howard by email at heidi.r.howard.civ@mail.mil. Portions of this project's text have been modified and reprinted from Military OneSource, "Fort Hood In-Depth Overview," Military Installations, accessed 19 July 2021, https://installations.militaryonesource.mil/in-depth-overview/fort-hood.

U.S. Army Aberdeen Proving Ground is located in Harford County, Maryland. Project information, photos, and graphics courtesy of Sam Whitin, EA Engineering, Science, and Technology, PBC. The study was prepared under contract with Harford County, Maryland, with financial support from the Office of Local Defense Community Cooperation (OLDCC, formerly the Office of Economic Adjustment), Department of Defense. The content reflects the views of Harford County and does not necessarily reflect the views of OLDCC. For more information concerning this project, please contact Karen Holt, Federal Installation Administrator for Harford County and Chesapeake Science and Security Corridor Consortium by email at klholt@harfordcountymd.gov or Sam Whitin by email at swhitin@eaest.com. Portions of this project's text have been modified and reprinted from U.S. Army, "History," Aberdeen Proving Ground: Home of Innovation, last modified 10 October 2018, https://home.army.mil/apg/index.php/about/history. The table of natural and nature-based features was reprinted from T. S. Bridges, P. W. Wagner, K. A. Burks-Copes, M. E. Bates, Z. A. Collier, C. J. Fischenich, J. Z. Gailani, et al., *Use of*

Natural and Nature-Based Features (NNBF) for Coastal Resilience: Final Report, ERDC SR-15-1 (Vicksburg, MS: U.S. Army Engineer Research and Development Center, 2015), https://hdl.handle.net/11681/4769.

Naval Base Ventura County is located in Ventura County, California. Project information, photos, and graphics courtesy of Alyssa Mann and Walter Heady, The Nature Conservancy; Kendall Lousen, Naval Base Ventura County; and Bob Battalio and James Jackson, Environmental Science Associates. For more information concerning this project, please contact Alyssa Mann by email at alyssa.mann@tnc.org. Portions of this project's text have been reprinted from Naval Base Ventura County, *Naval Base Ventura County: Military Readiness Economic Contribution and Community Partnerships* (Point Mugu, CA: Naval Base Ventura County, 2018), https://www.cnic.navy.mil/content/dam/cnic/cnrsw/NBVC/pdfs/NBVC%20Economics%20VIP_APR2018_FINAL.pdf. Additional text has been modified and reprinted with permission from The Nature Conservancy, "Ventura County," Coastal Resilience, accessed 19 July 2021, https://coastalresilience.org/project/ventura-county/.

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Left: U.S. Marines clean up Marine Corps Air Station New River after Hurricane Florence. (Photo by Cpl Damaris Arias)

Right: A downed tree from Hurricane Florence at the Camp Lejeune base housing units. (Photo by LCpl Isaiah Gomez)

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