ARMY CLIMATE RESILIENCE HANDBOOK

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CHANGE 1






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Change 1:

Corrected cost information in Appendix C tables C.8, C.9, and C.10
Corrected typos, citations, and references where necessary
Clarified language by replacing impact with hazard where appropriate, and to reflect that the tool identifies exposure, which is only part of vulnerability

Photo credits:

Top Left Photo: U.S. Coast Guard photo: Floodwaters accumulate as the Tar River overflows in Greenville, North Carolina. Photo by Coast Guard Petty Officer 3rd Class Corinne Zilnicki, October 12, 2016. https://www.dobbins.afrc.af.mil/News/Article-Display/Article/996078/16-eplos-support-hurricane-matthew-relief-efforts/

Top Right Photo: U.S. Geological Service photo: Coastal permafrost eroding in Alaska. https://www.globalchange.gov/sites/globalchange/files/permafrost-coastal-erosion-alaska-usgs.jpg

Middle Left Photo: U.S. Air Force photo: Wildfire burning in Colorado in June 2012. Photo by Master Sgt. Jeremy Lock, June 28, 2012. https://archive.defense.gov/news/newsarticle.aspx?id=116975

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Bottom Right Photo: U.S. Fish and Wildlife Service photo: Aerial photograph of Hurricane Sandy storm damage at Mantoloking, New Jersey coastline. Photo by Greg Thompson, November 2, 2012. https://prd-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/styles/full_width/public/thumbnails/image/USFWS-mantoloking%20NJ-Thompson.jpg

USACE CLIMATE PREPAREDNESS AND RESILIENCE

EXECUTIVE SUMMARY

The effects of a changing climate are currently and will continue to be a national security issue, impacting Department of Army installations, operational plans, and overall missions. Army recently released a memo directing installations to plan for energy and climate resilience efforts by identifying the installation's vulnerability to climate-related risks and threats. This memo is consistent with Department of Defense guidance per 10 USC § 2864 (Master plans for major military installations, April 2020). To address these risks and threats, the Army Climate Resilience Handbook (ACRH) takes Army planners through the process to systematically assess climate hazard exposure risk and incorporate this knowledge and data into existing installation planning processes such as master plans.

The 2019 NDAA Section 2805 defines climate resilience as the "anticipation, preparation for, and adaptation to utility disruptions and changing environmental conditions … ." Using this understanding of climate resilience, the ACRH guides Army planners through a four-step risk-informed planning process. Working through the ACRH, the Army planner will develop a Climate Vulnerability Assessment that:

(1) identifies the installation's climate resilience goals and objectives
(2) identifies how exposed the installation is to current nuisance and extreme weather events and to projected future climate hazards
(3) identifies how sensitive infrastructure, assets, mission, and readiness are to these hazards and how difficult adapting to these threats may be
(4) identifies a list of potential measures that can be used to improve an installation's preparedness and resilience

A key element of the ACRH process is the Army Climate Assessment Tool, or ACAT (Gade et al. 2020). ACAT provides climate change hazard information at the installation, command, and headquarters levels that is specifically developed for use in the screening-level assessment described in the ACRH. ACAT also includes reports that identify those installations that have the greatest exposure to analyzed climate change hazards.

This handbook is divided into two main sections—an ACRH overview and an in-depth explanation of the four-step ACRH process. The report utilizes a simulated Army base as an example to give a cohesive understanding of the outputs from each step. Appendices provide resilience measures, additional climate change and ACAT information, a short user's guide for the ACAT, and a glossary of terms.

Throughout the world, DoD installations are exposed to the risks of climate change, jeopardizing our nation's security. By anticipating future climate change conditions, Army can reduce climate impacts to missions and operations and protect its real property investments by reducing exposure. The ACRH is intended to help Army planners in this effort.

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LIST OF ABBREVIATIONS

ACAT – Army Climate Assessment Tool

ACRH – Army Climate Resilience Handbook

AD – Army Directive

AEP – Annual Exceedance Probability

AFB – Air Force Base

AR5 – Fifth Assessment Report

ATP – Army Techniques Publication

ASA – Assistant Secretary of the Army

CAC – Common Access Card

CARSWG – Coastal Assessment Regional Scenario Working Group

CIS – Capital Investment Strategy

CONUS – Contiguous United States

DA – Department of the Army

DoD – U.S. Department of Defense

E&W – Energy and Water

EPA – U.S. Environmental Protection Agency

ERCIP – Energy Resilience and Conservation Investment Program

ERDC – Engineer Research and Development Center

EWN – Engineering With Nature

FEMA – U.S. Department of Homeland Security Federal Emergency Management Agency

GIS – Geographic Information System

GCM – General Circulation Model

HUC – Hydrologic Unit Code (a standard number for designating U.S. watersheds)

ICLUS – Integrated Climate and Land Use Scenarios (EPA product)

IDP – Installation Development Plan

IE&E – Installations, Energy and Environment

IEWP – Installation Energy and Water Plans

INRMP – Integrated Natural Resources Management Plan

IPCC – Intergovernmental Panel on Climate Change

IPS – Installation Planning Standards

ISR – Installation Status Report

KBDI – Keetch-Byram Drought Index

MILCON – Military Construction

NAVFAC – Naval Facilities Engineering Command

NCA4 – Fourth National Climate Assessment

NCEI – National Centers for Environmental Information

NDAA – National Defense Authorization Act

NFHL – National Flood Hazard Layer

NIDIS – National Integrated Drought Information System

NNBF – Natural and Nature-Based Features

NOAA – National Oceanic and Atmospheric Administration

OSD – Office of the Secretary of Defense

OWA – Ordered Weighted Average (a component of a WOWA score)

QRPA – Real Property Maintenance

QUTM – Army Energy and Utility Program

RCP – Representative Concentration Pathway

RPMP – Real Property Master Plan

RSL – Relative Sea Level

RUSLE – Revised Universal Soil Loss Equation

SLC – Sea Level Change

SLVAS – Screening Level Vulnerability Assessment Survey

SPEI – Standardized Precipitation Evaporation Index

UFC – Unified Facilities Criteria

USACE – U.S. Army Corps of Engineers

USDA – U.S. Department of Agriculture

USGCRP – U.S. Global Change Research Program

USGS – U.S. Geological Survey

WBGT – Wet Bulb Globe Temperature

Wm^{-2} – Watts per meter squared

WOWA – Weighted Ordered Weighted Average

WUI – Wildland Urban Interface

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1. Introduction

1.1. Background

In recent years, Department of Army (DA) installations have suffered billions of dollars in damage due to extreme weather events, such as the intense precipitation in 2015 at Ft. Benning; flash flooding at Ft. Hood in 2016; wildfire at Ft. Carson in 2018; and hurricane at Ft. Bragg in 2018. Department of Defense (DoD) damages include flooding at Offutt Air Force Base (AFB) in 2019; and increasingly frequent “sunny day” (i.e., chronic) tidal flooding at Naval Station Norfolk. These extreme weather events impact installation infrastructure, training, and readiness to deploy.

As a result, climate change has been identified by Army and DoD as a critical national security threat and threat multiplier (e.g., DoD Quadrennial Review (DoD 2014a), National Defense Authorization Act 2018 (2018 NDAA), ASA(IE&E) 7 April 2020). Observed and projected climate change hazards include more frequent and intense temperature extremes, extreme weather events (e.g., more frequent precipitation of increasing intensity), longer fire seasons with more frequent and severe wildfires, changing sea levels, reduced snowpack, lower stream flows, and longer and more severe droughts.

Army Directive (AD) 2017-07, Installation Energy and Water Security Policy (DA 2017), required that Army planners identify climate threats to installations and incorporate installation resilience to changing climate hazards during installation planning. AD 2020-03, Installation Energy and Water Resilience Policy (DA 2020), which supersedes AD 2017-07, states that threats both man-made and natural can jeopardize mission capabilities. Army installations must secure reliable access to energy and water by identifying and mitigating vulnerabilities that can disrupt these systems and mission readiness. Resilience must be built into the energy and water infrastructure across installations.

Additional direction for incorporating exposure to climate hazards into installation planning includes 10 USC § 2864 Master plans for major military installations (April 2020), which directs planning for energy and climate resilience efforts by identifying climate-related risks and threats and determining installation vulnerability to them. It also amends the Unified Facilities Criteria (UFC) 1-200-01 DoD Building Code (DoD 2019a) and UFC 1-200-02 High Performance and Sustainable Building Requirements (DoD 2019b) to require the use of authoritative sources of information and tools including resilience planning handbooks.

Updated guidance directs installations to incorporate climate hazard risks into Integrated Natural Resource Management Plans (INRMP). DoD Manual 4715.03 Integrated Natural Resources Management Plan Implementation Manual (Nov. 2013) requires climate assessments be incorporated into INRMPs, and the DoD planning document Climate Adaptation for DoD Natural Resource Managers (Stein et al. 2019) outlines a method for conducting climate assessments for INRMPs.

Under requirements in Section 335 of the 2018 NDAA and at the direction of the U.S. Army Office of the Assistant Secretary of the Army for Installations, Energy and Environment [ASA(IE&E)], the U.S. Army Corps of Engineers (USACE) conducted a climate change exposure assessment of 113 Army installations against six climate hazards—coastal flooding, riverine flooding, desertification, wildfire, thawing permafrost, drought—along with volcanic and seismic hazards. This study built on previous assessments of climate change exposure using methods developed by the USACE Climate Preparedness and Resilience Program for its Civil Works program.

The result was an interim draft report titled Evaluation of Climate Change Effects on Army Locations (White et al. 2019) and a web-based tool for assessing climate hazard exposure risk, displaying hazards across a portfolio of installations and ranking installation exposure risk. The Army made the tool available as an interim planning tool for use by installations for climate resilience planning in April 2020 [ASA(IE&E) 7 April 2020] while awaiting completion of the Army Climate Assessment Tool (ACAT). The ACAT reflects updated Army understanding of climate exposure, expands the number of installations for which climate exposure data are available, and increases the number of projected climate hazards assessed.

The Army Climate Resilience Handbook (ACRH) provides the methodology and process to systematically assess climate exposure hazard risk and incorporate this knowledge and data into existing installation planning processes such as master plans. The ACRH is designed to be supported by the ACAT, which provides updated information on U.S. climate trends and related hazards by region; supplies climate hazard exposure data for seven hazard areas; and provides data on historical weather extremes. The process laid out in the ACRH is aligned with that developed for Navy in its Climate Change Planning Handbook: Installation Adaptation and Resilience (NAVFAC 2017).

To meet these requirements, Army installations will first need to identify the degree to which they face various climate risks, including extreme weather events, sea level rise, and wildfires, and then update their installation planning standards and other components of their Real Property Master Plans (RPMPs) as necessary to facilitate development that incorporates an appropriate level of climate resilience. By accounting for future climate change conditions, Army can increase the resilience of its real property investments by reducing their exposure.

1.2. DoD and NDAA Background

These Army approaches are consistent with the 2014 DoD Climate Change Adaptation Roadmap (DoD 2014b), which laid out a framework with three overarching goals:

- Identify and assess the effects of climate change on the Department.
- Integrate climate change considerations across the Department and manage associated risks.
- Collaborate with internal and external stakeholders on climate change challenges.

DoD Directive 4715.21, Climate Change Adaptation and Resilience (2016), requires mission planning and execution to include:

- Identifying and assessing effects of climate change on the DoD mission.
- Taking those effects into consideration when developing plans and implementing procedures.
- Anticipating and managing any risks that develop as a result of climate change to build resilience.

The DoD Roadmap (DoD 2014b) identified four areas where adaptation (also known as climate preparedness and resilience) is essential (Table 1):

- Plans and operations include the activities dedicated to preparing for and carrying out the full range of military operations. Also included are the operating environments in the air, on land, and at sea, both at home and abroad, that shape the development of plans and execution of operations.
- Training and testing, including access to land, air, and sea space that replicate the operational environment is essential to readiness.
- Built and natural infrastructure.
- Acquisition and supply chain, including fielding and sustaining equipment.

Table 1: Potential effects of climate change on the Department of Defense (adapted from Annex 2, DoD 2014 Climate Change Adaptation Roadmap)

Plans and Operations
• Increased demand for Defense Support of Civil Authorities. • Increased demand for disaster relief and humanitarian assistance overseas. • Increased need for air, sea, and land capabilities and capacity in the Arctic region. • Altered, limited, or constrained environment for military operations. • Instability within and among other nations.
Training & Testing
• Increased number of black flag (suspended outdoor training) or fire hazard days. • Decreased land-carrying capacity to support current testing and training rotation types or levels. Some training/testing lands may lose their carrying capacity altogether. • Increased dust generation during training activities, which may result in more repairs to sensitive equipment or may require more extensive dust control measures to meet environmental compliance requirements. • Greater stress on threatened and endangered species and related ecosystems that are on or adjacent to DoD installations, resulting in increased endangered species and land management requirements. • Increased operational health surveillance and health and safety risks to Department personnel. • Increased maintenance/repair requirements for training/testing lands and associated infrastructure and equipment (e.g., training roads, targets).
Built & Natural Infrastructure
• Increased inundation, erosion, and flooding damage. • Changes to building heating and cooling demand, impacting installation energy intensity and operating costs. • Disruption to and competition for reliable energy and fresh water supplies. • Damage from thawing permafrost and sea ice in Alaska and the Arctic region. • Increased ecosystem, wetland, sensitive species, and non-native invasive species management challenges. • Increased maintenance requirements to keep runways and roads operable on extremely hot days and reduce damage from extreme heat. • Changed disease vector distribution, increasing the complexity and cost of ongoing disease management efforts and requiring changes in personnel health resources, facilities, and infrastructure.

Acquisition & Supply Chain
• Changed operational parameters for current and planned weapons and equipment, resulting in increased associated maintenance requirements or requirements for new equipment. • Reduced availability of or access to the materials, resources, and industrial infrastructure needed to manufacture the Department's weapon systems and supplies. • Interrupted shipment/delivery or storage/stockpile of materials or manufactured equipment and supplies. • Alterations in storage/stockpile activities. • Reduced or changed availability and access to food and water sources to support personnel.

In response to increasingly frequent and larger impacts on installations, the U.S. Congress in Section 335 of the 2018 NDAA required a report be submitted to them by DoD on the exposure of military installations to specific set of climate hazards. Section 335 further states that it is the sense of Congress that "military installations must be able to effectively prepare to mitigate climate damage in their master planning and infrastructure planning and design …"

Title 10 U.S.C. § 2864 was amended in August 2018 to require that master plans address climate resilience DOD wide, and UFC 2-100-01 Installation Master Planning (DoD 2019c) was amended in November 2018 to require that anticipated changes in environmental conditions be considered and incorporated into military construction designs and modifications.

The 2019 John S. McCain National Defense Authorization Act (2019 NDAA) Section 2805 requires an amendment to the United Facilities Criteria: "to anticipate changing environmental conditions during the design life of existing or planned new facilities and infrastructure, projections from reliable and authorized sources such as the Census Bureau (for population projections), the National Academies of Sciences (for land use change projections and climate projections), the U.S. Geological Survey (for land use change projections), and the U.S. Global Change Research Office and National Climate Assessment (for climate projections) shall be considered and incorporated into military construction designs and modifications."

The 2019 NDAA Section 2805 (as amended in 2019) also requires planning for energy and climate resilience as part of the master planning process for major military installations. This NDAA defines energy and climate resilience as the "anticipation, preparation for, and adaptation to utility disruptions and changing environmental conditions and the ability to withstand, respond to, and recover rapidly from utility disruptions while ensuring the sustainment of mission-critical operations."

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1.3. Handbook Purpose

This section describes the intent of the Army Climate Resilience Handbook (ACRH), as well as its target audience, focus, organization, and desired output of the planning process outlined in the ACRH.

Intent: The intent of the ACRH is to provide the analytical framework and methodology to help Army installation planners understand how to consider climate change in their installation planning processes, including RPMPs, Installation Energy and Water Plans (IEWPs), and Installation Natural Resources Master Plans (INRMPs).

The ACRH follows risk-informed planning, which is a framework for making decisions under uncertainty (Yoe and Harper 2017). Risk-informed planning is a process that can be used to asses exposure to current and future climate harms, evaluate the consequences of this exposure, and identify the kinds of adaptations that may be necessary for an installation to continue to support its missions and other functions. Vulnerability is the term that captures the combination of exposure, consequence, and ability to adapt. Appendix C provides information on measures that can be taken to improve resilience by reducing vulnerability to the climate change hazards identified in the ACAT.

The ACRH planning process is iterative: it is meant to be revisited with each planning cycle. In addition, some or all steps in the ACRH process will likely need to be repeated—perhaps several times—as the level of detail desired in the assessment evolves.

Prior to beginning the process outlined in the ACRH, it may be useful to review the Climate Change Essentials (Section 1.4) and the four steps to get a full understanding of how each step leads to the next and aligns with other Army planning processes. It is important to note that the projected climate exposure, risk assessment, and range of climate preparedness and resilience measures can change in response to the best available science and information as it becomes available.

The ACRH is designed to be used in conjunction with the ACAT, which provides access to climate change hazard information at the installation, command, and headquarters levels. This tool is described in more detail in Appendix D.

The intended output is a concise review of climate change threats facing an installation and a portfolio of possible climate preparedness and resilience action alternatives that can be incorporated to address planning challenges.

Target Audience: Army installation planners are the target audience for this handbook.

Focus: This document applies to the planning, design, construction, sustainment, restoration, and modernization of all Army-owned facilities. It is applicable to all methods of project delivery and levels of construction regardless of funding type and location. The ACRH provides planners with a clear methodology for using authoritative climate information to inform the Army planning processes. This handbook will serve as a desktop reference to guide climate-informed decisions for master planning, natural resource planning and installation resilience in both the near term and the far term.

Handbook Organization: The main body of the ACRH is composed of an introductory section, the steps required to complete the ACRH process, and a conclusion section. Figure 1 provides an overview of the four steps detailed in the ACRH. The arrows within the steps show the iterative process necessary in risk-informed planning.

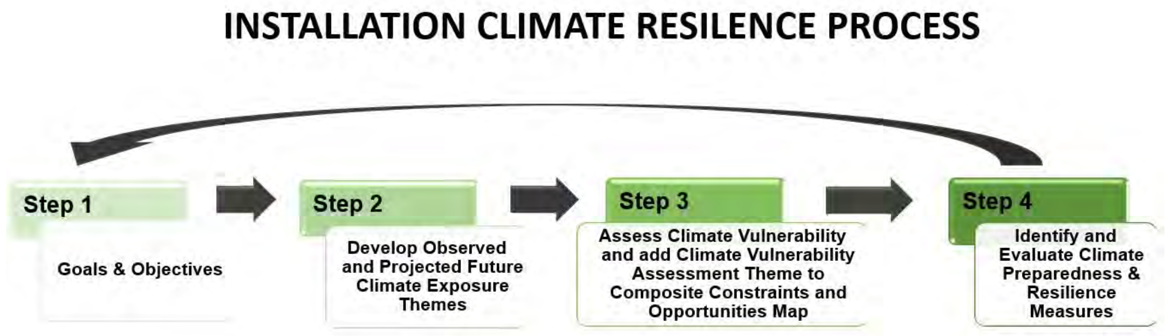

Figure 1: The iterative planning steps included in the Army Climate Resilience Handbook

Throughout this document, an example of planning products and information is provided using a fictitious installation (Ft. Patton, see Section 2.1). Additional information about the ACAT, as well as potential resilience measures that could be implemented to address an installation's exposure risk, may be found in the appendices:

- **Appendix A**: Hazard and Indicator Descriptions
- **Appendix B**: ACAT Indicator Fact Sheets
- **Appendix C**: Climate Preparedness and Resilience Measures
- **Appendix D**: ACAT Quick Guide
- **Appendix E**: Glossary

The ACRH is designed to align with and serve as a companion tool throughout the RPMP, IEWP, and INRMP processes. Although the ACRH is explicitly aligned only with these three planning processes, it is intended that these same risk-informed climate resilience steps will be taken with all planning processes (e.g., encroachment management plans, wildland fire and wildfire plans, installation information management systems, etc.).

The RPMP ensures that real property priorities support every aspect of the troops and their missions. By incorporating climate resilience into the RPMP process, planners make it possible for an installation's buildings, structures, land, and utilities to support the troops and their missions well into the future.

AD 2017-07 required the Army to (1) plan for and support energy and water requirements on an installation sufficient for a minimum of 14 days, (2) have a dependable energy supply, (3) have infrastructure that reliably meets onsite mission requirements, and (4) have continued energy and water security system planning and sustainment. AD 2020-03 (DA 2020), which supersedes AD 2017-07 and earlier IEWP policy, provides installation commanders flexibility to determine the duration of critical mission assured access to utilities, taking into consideration the timeframes to accomplish, curtail, or relocate the critical mission(s). When this duration has not been specified, energy and water must be sustained for a minimum of 14 days. IEWP guidance to meet the new AD 2020-03 is forthcoming. Understanding how an installation's water and energy infrastructure will be impacted by climate change is critical to meeting the goals outlined in AD 2020-03 and 2017-07.

The INRMP ensures that military installations with significant natural resources manage those resources by integrating the installation's mission requirements, environmental and master planning documents, cultural resources, and outdoor recreation planning documents. In 2019, the Naval Information Warfare Center partnered with the National Wildlife Federation to write a guide on incorporating climate considerations into INRMPs (Stein et al. 2019). The ACRH aligns with the INRMP climate incorporation guide.

Figure 2 shows how the four climate resilience planning steps detailed in this handbook align with the RPMP, IEWP, and the INRMP processes. Within each step, the ACRH will refer to these relationships and offer a checkpoint to make sure climate resilience is being fully integrated into the RPMP, IEWP, and INRMP planning processes (NOTE: these checkpoints can also apply to other planning processes). By fully integrating the steps offered in this climate resilience handbook into the earlier stages of the planning process, Army planners can reduce the risks associated with climate change in later stages of the planning process.

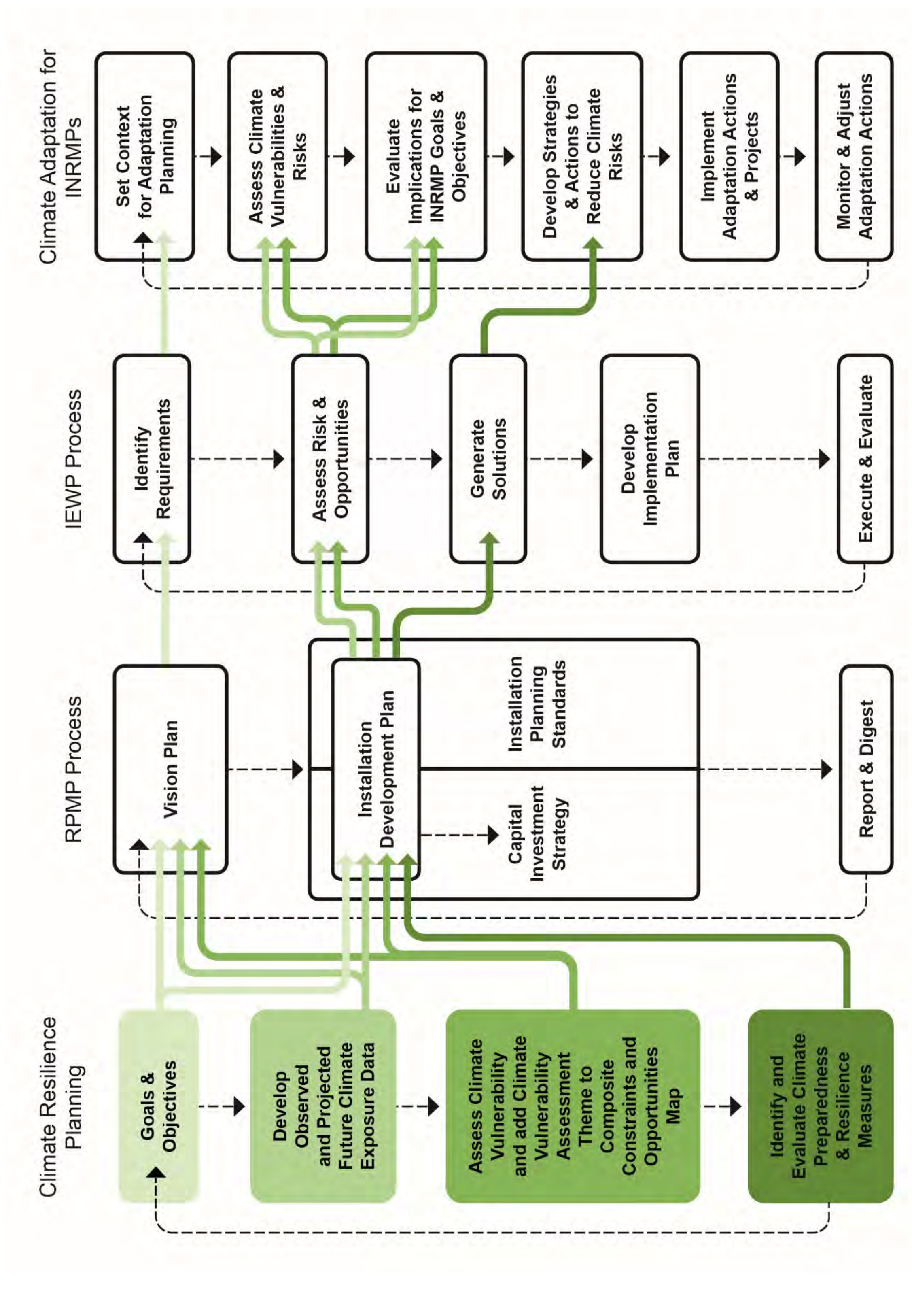

Figure 2: The climate resilience planning process is designed to bring risk-informed climate resilience planning into the RPMP process, the IEWP process, and the climate preparedness and resilience INRMP process

Desired Output: At the completion of the ACRH process, the Army planner should have developed a Climate Vulnerability Assessment that will identify how exposed the installation is to current extreme weather and projected future climate hazards; how sensitive infrastructure, assets, mission and readiness are to these hazards; and how difficult it may be to adapt to these threats. Finally, the planner will develop a list of potential measures that can be used to improve installation preparedness and resilience. This information is intended to serve as another input into the Installation Development Plan (IDP) and component area development plans (ADPs) in the installation's RPMP, and should also feed into the IEWP, the INRMP, and other planning processes (Figure 2).

Because of the inherent uncertainties in projecting future conditions (discussed in Section 1.5), the identified climate exposure and portfolio resilience measures should be periodically updated. These updates should reflect changes in strategic objectives, technology or climate preparedness and resilience methods, or with the addition of new information about climate change.

The inherent uncertainty about the magnitude and timing of the climate threat also means that adaptation measures need to be flexible and selected in a way that confers protection under a range of potential future conditions. For this reason, there is an emphasis on the concept of resilience: resilience is the ability to prepare, absorb, recover, and adapt (USACE 2017; Yoe and Harper 2017) to changed conditions.

For planning purposes, resilience means infrastructure that is designed to anticipate future performance conditions, such as replacing non-engineered levees with engineered levees to protect against increased future flood magnitudes. These levees may be designed to fail in specific ways if these conditions are exceeded (e.g., hardened levee sections that direct overtopping floods away from housing into below-grade parks that double as detention basins). After failure, there also needs to be a way to recover, such as through controlled release of floodwaters from such detention basins. Finally, the stormwater system must be able to adapt if flood magnitudes continue to increase; for example, by having additional land already zoned for parks and recreation that can be remodeled into detention basins in the future. These principles provide a lifecycle perspective for resilience-related actions that recognizes that adverse events do happen, and conditions change over time, due in part to climate change.

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1.4. Climate Change Essentials

Climate is the long-term (30-year) average seasonal weather conditions typical of a given location; *weather* refers to the day-to-day conditions at that location. Climate defines the average and extreme weather conditions a person might reasonably expect to occur. For example, New Mexico has an arid climate, receiving about 10 inches of rain per year, mostly in late summer. Spring is usually dry, but one year a late-spring storm dropped 3 inches of rain in three days. That was an extreme weather event that is not typical of the climate of the area.

Over the last several decades, climate has begun to change throughout the world. The accumulation of greenhouse gases in the atmosphere has led to an overall increase in earth's average temperature of at least 1°F since the mid-20th century, and computer models agree that this warming is likely to continue for the foreseeable future (IPCC 2018). Scientists agree that this warming has several significant consequences:

- Increases in the number of hot and extremely hot summer days and nights; longer and more intense heat waves; and increases in average winter temperatures (cold extremes will still occur). These changes are anticipated to affect outdoor military training and activities; change energy needs for buildings; damage roads, runways, and railroads; and impact critical habitat and species of concern. Warmer temperatures also contribute to vegetation stress, beetle kill, and other sources of tree die-off.

  In circumpolar regions, where permafrost occurs, warmer temperatures increase the depth of the active layer, causing buildings to sink and roads and utility infrastructure to buckle. At the same time, warmer spring and fall temperatures dramatically reduce the season during which ice roads facilitate the transport of goods, personnel, and materiel. Changes due to temperature increases have already been observed in many parts of the world.

- Increases in abnormal precipitation patterns, including both extreme precipitation and drought. For every increase in temperature of 1.6°F, the atmosphere is able to hold 7% more moisture, allowing for the development of more intense storms or, if relative humidity is low, driving higher rates of evaporation. Extreme storm events are anticipated to result in greater stormwater and riverine flooding. Increases in precipitation extremes due to climate change have already been observed in many parts of the world.

- Wildfires—either an unplanned fire caused by natural or human sources or an escaped prescribed fire—are expected to burn more intensely and over larger areas, driven in part by increases in evaporation and more frequent drought. Due to the resulting wildfire risk, drought is likely to curtail live-fire and other training and may threaten installation water supplies. Wildfire may directly threaten installation lands and buildings as well as off-base homes and facilities. Increased wildfire risk is also likely to drive greater vegetation management needs (such as forest thinning) both on and adjacent to the installation. Changes in wildfire risk due to climate change have already been observed in the western U.S. and other regions of the world.
- Rising sea levels due to melting glaciers, warmer ocean temperatures, land subsidence, and other factors contributes directly to coastal installation flooding during storm events, king tides, and, increasingly, regular chronic flooding. During extreme precipitation events, higher sea levels raise the elevation of stream outlets and storm drain systems, reducing drainage rates and increasing flood elevations. This leads to higher and more extensive flooding in coastal areas and can result in salt water intrusion in both groundwater and aquifers used for local water supply. Increased coastal erosion, another significant consequence, is particularly severe in polar areas where permafrost thaw reduces soil cohesion and loss of sea ice enables development of larger, more energetic waves. Sea level changes have been observed worldwide.

The DoD and the Army have identified the following climate risks to be of particular concern for installation planners: temperature extremes, precipitation extremes, drought, wildfire, land degradation (inland erosion, coastal erosion, and permafrost degradation), riverine flooding, and sea level rise, as well as hurricanes and tornadoes (DoD 2018; 2019 NDAA). The ACRH provides specific information and strategies for addressing these risks to installations.

1.5. Climate Change Uncertainty

Like many scientists, climate scientists rely heavily on computer models. They use these models to understand the complex ways that increased temperatures alter climate at every location on Earth. These models are grounded in established physical and chemical processes, but they do differ in the level of detail they are able to resolve and the accuracy or precisions with which they are able to represent climate processes and Earth-atmosphere interactions. There is value in the information provided by the different models due to their different formulations, so we do not expect them to all provide the same answers.

In addition, there are many aspects of weather and climate that scientists are still trying to understand, particularly now that greenhouse gas (GHG) concentrations exceed those for observed past weather conditions. Although the broad relationship between greenhouse gas concentration in the atmosphere and global temperatures has been known for over 130 years, details about how these changes are likely to impact climate in a specific area may be uncertain, and models may differ in the magnitude of the changes they project. The further into the future projections go, the more variability there is in the model results. (This is true of most models generally, not just climate models.)

At this point in time it is not possible to know which climate model has the most accurate projection for the future. Different models may be better than others for say, the east coast vs. the west coast of the U.S., or for winter vs. summer precipitation. Consequently, the best practice is to use an ensemble (group) of models and consider the average result across those models as the best estimate for future conditions within a given area. The ACAT uses a 32-model ensemble to assess climate exposure. Using only one or a few models may introduce considerable bias (error) and basing decisions on such an analysis should be avoided.

We call the variability in model projections of the future model uncertainty. There is also knowledge uncertainty—sometimes called epistemic uncertainty—because we don't fully understand many climate phenomena, or how the earth system (water, land, ecosystems and living creatures) will respond to changes at scales both local and global. In addition, installation planners are faced with planning uncertainty that arises from an imprecise knowledge of future mission requirements and staffing on an installation; changes to policy and guidance; resource availability; and other factors affected by DoD or DA decisions.

Note that uncertainty in the context of climate change does not mean uncertainty as to whether it has occurred or will continue to occur. But uncertainty does exist around specific local effects, the magnitude of effects, and the processes and causes of these effects. The uncertainty lies in being able to describe exactly how and when these changes resolve themselves in a specific location.

One accepted method for planning when future conditions are highly uncertain is to use scenario planning (Ringland 2014; Walker and Salt 2006). Rather than dealing with a single prediction of future conditions that may or may not be valid, planners work with several storylines (called scenarios) that bracket the range of potential future conditions in their area of responsibility. In this way, they ensure resilience under changing conditions even if there is a great deal of uncertainty in how much change may occur and how soon.

The ACRH and associated ACAT use two planning scenarios, described as “higher” or “lower” depending on the projected accumulation of GHGs in the atmosphere. The model of future rates at which heat is trapped in the atmosphere by accumulating greenhouse gases is called a representative concentration pathway (RCP). The higher scenario, RCP 8.5, reflects a greater accumulation of GHGs in the atmosphere (resulting in higher temperatures). The lower scenario, RCP 4.5, assumes a lower net accumulation of GHGs in the atmosphere (due to lower emissions rates and/or technological developments that effectively mitigate these emissions) and a less dramatic rise in temperatures.

The rate of accumulation of GHGs to the atmosphere is directly related to the rate at which temperatures increase and drive changes to the entire climate system and to the water cycle. Consequently, in most cases the higher scenario is a faster, bigger change scenario whereas the lower scenario is a slower, smaller change scenario. These two scenarios capture the currently accepted range of likely future outcomes for the climate system[1].

Army planners must be intentional about climate, knowledge, and planning uncertainty during the planning process. Using a range of scenarios allows the planner to make sound decisions that anticipate, prepare for, and respond to climate change on the installation. Most importantly, as with all military preparedness activities and risks, Army planners should not wait to act until every knowledge gap or uncertainty has been addressed. Using the ACRH and risk-informed planning, Army planners have enough information on the risk associated with climate change to formulate solutions.

[1] The most recent National Climate Assessment (USGCRP 2017) introduced an “Upper Bound” scenario representing the extreme high tail of the RCP 8.5 data. This scenario is not currently included in the ACRH and associated tool, but information on using it is available through the National Climate Assessment.

1.6. Risk-Informed Planning

The DoD defines risk as "potential future events or conditions that may have a negative effect on achieving program objectives for cost, schedule, and performance. Risks are defined by (1) the probability (greater than 0, less than 1) of an undesired event or condition and (2) the consequences, impact, or severity of the undesired event, were it to occur" (DoD 2017). The ACRH follows risk-informed planning, a framework for making decisions under uncertainty (e.g., Yoe and Harper 2017). The process of risk-informed planning is iterative in nature as evidence gathering and risk management are cycled through each step in the process. An example of the U.S. Army Corps of Engineers (USACE) risk-informed planning process is shown in Figure 3. This process aims to reduce uncertainty with each iteration of the planning process.

The risk-informed iterative process is the best method for dealing with the uncertainty that is inherent in climate change. Uncertainty can increase or decrease with new information. As new information becomes available during an installation's climate resilience planning, the Army planner's understanding may improve, requiring the planner to review the work previously completed.

Figure 3: USACE Risk-Informed Planning Process (Yoe and Harper, 2017)

Risk-informed planning is consistent with the integrating, iterative approach to risk management outlined in Army Techniques Publication (ATP) 5-19, Risk Management (DA 2014). The steps outlined in this handbook align with Steps 1 to 3 of the ATP 5-19 risk management process. With climate resilience built into Steps 1 to 3 of the risk management process, Army planners can buy down the risks inherent in Steps 4 and 5 (Figure 4).

	Risk management steps	Operations process activities
Steps 1-4 of the Army Climate Resilience Handbook	Step 1 – Identify the hazards	Planning
	Step 2 – Assess the hazards	Planning
	Step 3 – Develop controls and make risk decisions	Planning and preparing
Less Risk	Step 4 – Implement controls	Planning, preparing, and executing
	Step 5 – Supervise and evaluate	Planning and executing

Figure 4: The risk management in the operations process outlined in ATP 5-19 (DA 2014) is shown on the right. By feeding in climate resilience (on the left), Army planners can reduce risk

1.7. Additional Climate Change Resources

More information regarding climate change, climate change exposure across DoD installations, and tools to aid in resilience planning are provided below. This is an evolving list of resources and every attempt should be made to find the most up-to-date information available.

- The U.S. Fourth National Climate Assessment provides detailed information on the causes and consequences of climate change in the U.S. Volume 1 is the Climate Science Special Report (USGCRP 2017), while Volume 2, Impacts, Risks, and Adaptation (USGCRP 2018), places more emphasis on regional and cross-sectoral impacts. These reports can be found at https://www.globalchange.gov/nca4.
- The Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC 2013, IPCC 2014) provides information on climate change at a global scale. This report and supporting information can be found at https://www.ipcc.ch/reports/.
- The USACE Climate Preparedness and Resilience site https://www.usace.army.mil/corpsclimate/ has additional public-facing tools, information, and data by which to assess and adapt to the risk associated with climate change.
- State Climate Summaries, prepared by the National Oceanic and Atmospheric Administration (NOAA) and updated on a rolling basis, are located at https://statesummaries.ncics.org/.

DoD guidance for addressing the impacts of climate change on installations and additional related information includes:

- Updated United Facilities Criteria UFC 1-200-02, High Performance and Sustainable Building Requirements, October 2019 (DoD 2019b). Incorporates climate-related hazards and provides minimum requirements and guidance for planning, designing, constructing, renovating, and maintaining high performance and sustainable buildings. This is available online here: https://www.acq.osd.mil/eie/Downloads/IE/UFC_1_200_02.pdf.
- Report on Effects of a Changing Climate to the Department of Defense, January 2019. This report is available online here: https://media.defense.gov/2019/Jan/29/2002084200/-1/-1/1/CLIMATE-CHANGE-REPORT-2019.PDF.
- Climate Change Installation Adaptation and Resilience Planning Handbook, (NAVFAC 2017). Used by planners to assess climate hazards and evaluate adaptation options in the existing IDP process. Includes worksheets to be used in documenting the results of planners' assessment and evaluation. This report is available online here: https://www.fedcenter.gov/Documents/index.cfm?id=31041.

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2. Installation Climate Resilience Planning Process

The installation climate resilience planning process is divided into four steps (Figure 5). Once the army planner determines the assessment goals and objectives (Step 1), he or she will identify how and where the installation is exposed to current nuisance and extreme weather events and projected future climate hazards (Step 2).

Then the planner will combine this information with installation-specific data on facilities, infrastructure, mission and other factors to assess the degree to which these exposures make an installation vulnerable to climate and climate change (Step 3). Lastly, the planner will review and choose relevant climate preparedness and resilience metrics that will add to the installation's climate resilience (Step 4).

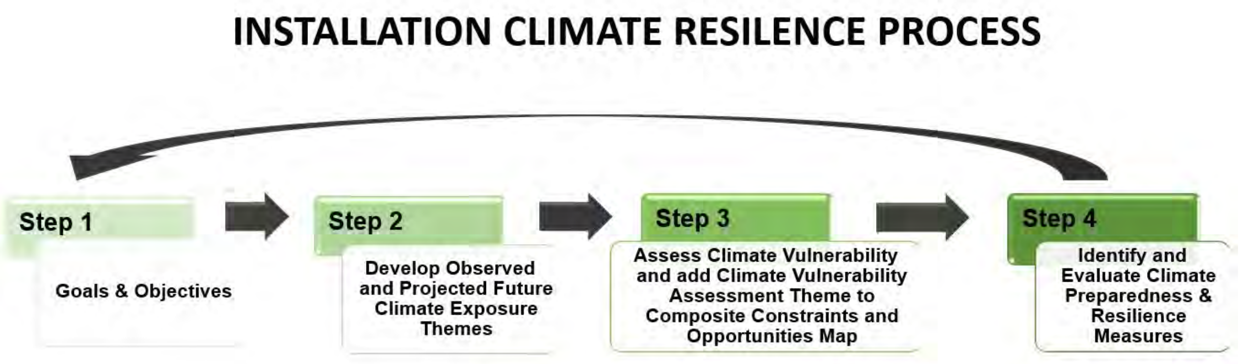

Figure 5: The four steps of the installation climate resilience process

Knowledge about climate change and its current and future hazards is an evolving science. The ACRH follows the best available, actionable science. Better information may be available in the future that enables more quantitative analysis of climate hazards at finer spatial and temporal scales—for example, when the next National Climate Assessment is released or when DoD updates its recommended sea level rise scenarios.

Installation planners are expected to periodically refine climate change information as new information becomes available. In addition, if analyses reveal that all or part of an installation may be subject to climate hazards in the future, this information should inform the vision plan and the long-range plan for the installation.

Ft. Patton: To ensure the broadest possible distribution of this manual, this document provides examples of planning products using the maps and data for a fictitious installation in the southeastern U.S. called Fort Patton. This approach makes it possible to provide a variety of detailed information types that may exist on an installation for illustrative purposes.

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2.1. Step 1: Goals and Objectives

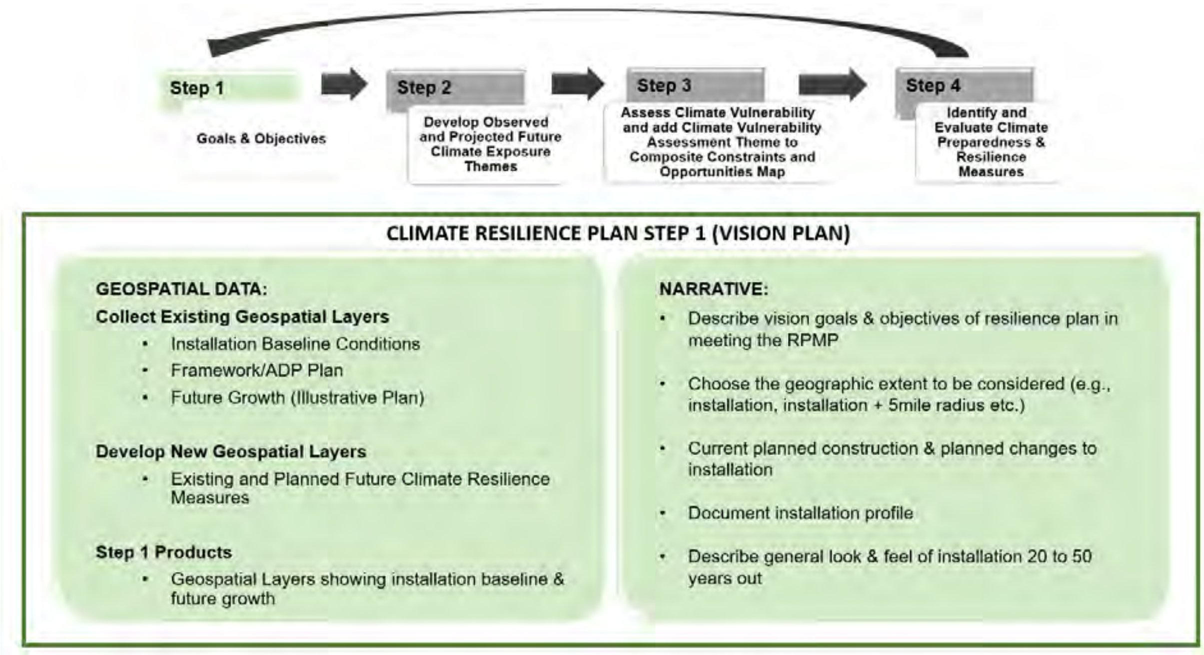


Figure 6: Data and products developed in Step 1

As outlined in Figure 6, the first planning step is to update the installation profile and vision plan, describe the potential look and feel of the installation 20 to 50 years out, and outline the goals and objectives of the installation in relation to mission success. Following risk-informed planning, this step is considered scoping, and includes such information as the geographic extent of the subject area (installation, installation with 5 mile buffer, etc.), intended lifespan of the existing infrastructure, and the current planned construction or changes across the installation. A good scope provides a road map for how climate preparedness and resilience will be built into Army planning.

2.1.1. Installation Profile

The installation profile includes a map and brief description of the installation. This description of the map should include the major topographic elements (mountains, rivers, floodplains, coastlines), important natural features, and kinds of land cover (hardwood forests, conifer forests, grasslands, developed areas, etc.). It should also include an overview of installation facilities and how these are distributed (location of housing vs. facilities vs. range activities, etc.), especially with respect to the natural features just described. Mission-critical facilities or activities should also be described and areas of ecological or cultural significance identified.

2.1.2. The Future of the Installation (20 to 50 years out)

Identifying the installation's future growth areas and missions. Will the installation be adding more barracks? Will the installation be adding another mission requirement or reducing the number of missions? Any future areas of growth or construction should be compiled into a geographic information system (GIS) map layer. For example, an installation may be preparing to expand its training mission to include more troops housed in the barracks. The sites where barracks will be built would be part of this "future growth layer."

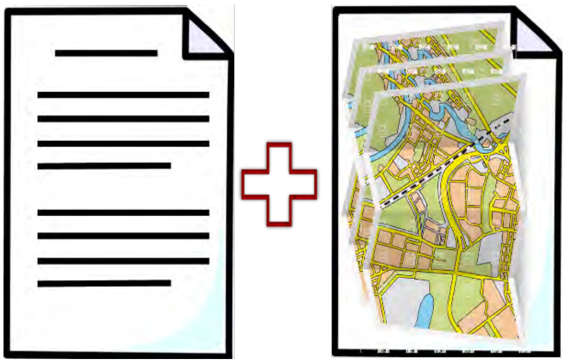
The installation map should also include an "existing resilience" GIS map layer that contains information about climate resilience. Such a layer might include existing flood protection—ring levees, flood walls, elevated structures, structures where critical infrastructure (e.g., generators, computer servers) are located on floors above flood level—and other resilience measures.

A "future climate resilience" GIS map layer can be added to show any plans for reducing climate risks that have not been implemented or existing plans that may need to be updated. Examples include moving critical facilities to locations outside an area impacted by floods or reducing fire risk on installation forest lands through thinning and prescribed burns. Such efforts should be documented on this layer of the installation profile map.

2.1.3. Step 1 Products

Upon completion of the installation profile and the future 20-to-50-year outlook for the installation, the Army planner should have a clear understanding of the following:

- Scope of the climate resilience assessment.
- Sites where development may/will occur, installation growth, and other future mission requirements.
- Any proactive or DoD-required climate resilience measures that are currently being taken or planned for the immediate future.



All this information should be briefly described in a few paragraphs, along with an installation profile map that shows baseline conditions and has GIS map layers for future growth, existing resilience, and future climate resilience (Figure 7). Using this information, the Army planner can formulate installation goals and objectives regarding climate resilience. For example: *To accommodate and achieve the growing combat training mission, the installation plans to upgrade and increase the housing units (increasing energy and water needs) and increase the firing range area within the 100-year floodplain in the next 20 years. In order to meet AD 2020-03, the installation will produce and store 50% of its energy use within the next 35 years.*

Outlining the goals and objectives points the Army planner and the rest of the risk-informed planning process in the best direction to meet the needs of climate resilience on the installation. As the rest of the steps are completed, this first step will likely be revisited many times (as it should be, due to the nature of the iterative process).

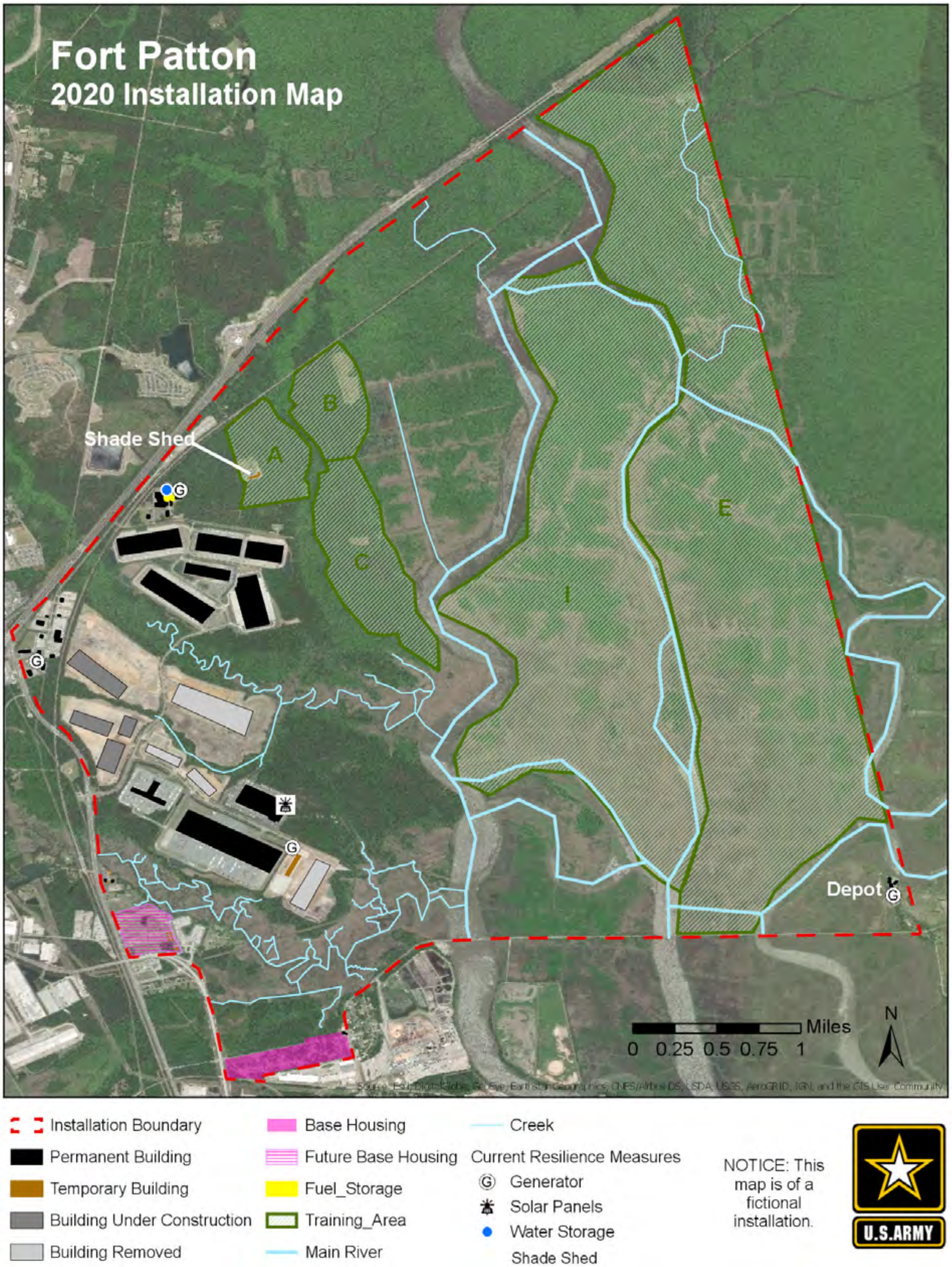


Figure 7: Example installation profile map that includes the GIS map layers produced during Step 1

2.1.4. Relating the ACRH Step 1 to Other Planning Processes

RPMP: The ACRH Step 1 aligns with the vision statement and IDP of the RPMP process. The first step in the RPMP process is the vision statement, which guides the master planning process by outlining the goals and objectives of the installation and the look and feel of the installation 20 to 50 years out. The focus is on facilities and real property at all scales. The elements of the vision plan include the main vision statements, the installation profile, the list of goals and objectives, and the Commander's Letter of Endorsement.

Another aspect of the RPMP process is the IDP and associated ADPs. The IDP is a plan that guides the long-range use of land and facilities (i.e., 20 to 50 years out). This step includes collecting all baseline information, assessing installation capacity, and determining future direction of the installation. It also identifies the relationship between on- and off-post resources and infrastructure; realizes elements of the installation planning standards; and incorporates functional and spatial relationships within the installation—as well as environmental concerns—in developing and evaluating alternative plans for the installation consistent with its known and projected mission requirements. The IDP prioritizes actions that receive their full expression in the Capital Investment Strategy (CIS).

IEWP: The IEWP Guidance Requirements that correspond with ACRH Step 1 are:

3.1.2 Describe the specific energy and water goals of the installation.

3.1.3 Identify energy and water needs for critical missions.

3.1.4 Develop a comprehensive energy and water (E&W) baseline, including the installation's current E&W use, infrastructure condition, resource availability, and system operations.

INRMP: The ACRH Step 1 aligns with the first step of the INRMP climate preparedness and resilience planning process, which is to set the context for adaptation planning. This step involves program scoping, assembling a planning team, engaging stakeholders, and compiling background information. The main area of alignment is program scoping, when the planner must articulate the installation's mission requirements (current and planned), identify relevant natural resources, and clarify the goals and objectives related to the installation's natural resources. All this information is used to establish the geographic scope and time frame for the installation's adaptation planning. The INRMP process takes into account the fact that natural processes happen at geographic scales larger than an installation's footprint and at temporal scales longer than the typical 20-50 years installations plan for. This important piece of climate resilience planning (ACRH Section 2.3) is also built into the INRMP climate adaptation planning.

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2.2. Step 2: Observed and Expected Future Climate Exposure Themes

Existing conditions are the current conditions of installation, including facilities, environmental resources, land use, utilities, transportation, airfields, and ranges and training lands. In gathering information about existing conditions, the planner is asked to evaluate the current condition and demand and whether a gap exists between current and expected future conditions.

Figure 8 outlines the geospatial data and narrative products for this step.

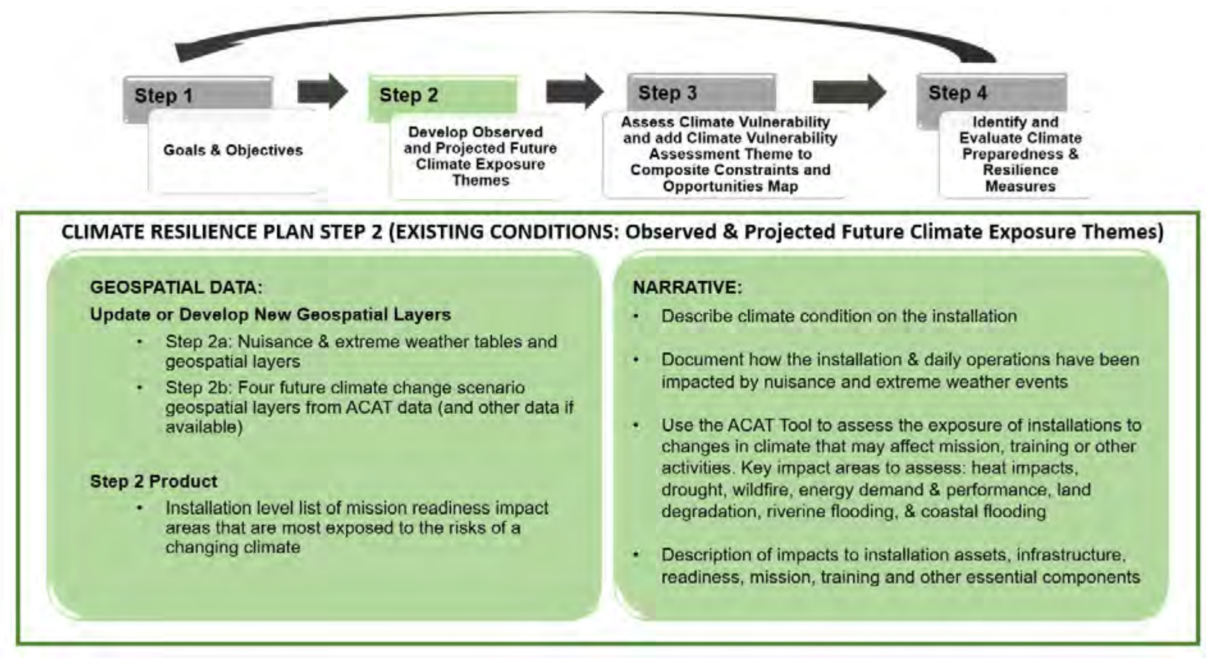


Figure 8: Geospatial data and narrative products for Step 2

For climate exposure assessment purposes, the planner is asked to assess installation exposure to current and historical extreme weather events as well as projected future climate conditions (average and extremes). Because different data sets are used to assess current/historical exposure and future exposure, the analysis is divided into two steps.

- Step 2a: Current and Historical Exposure to Nuisance and Extreme Weather Events
- Step 2b: Projected Future Climate Exposure

2.2.1. Step 2a: Current and Historical Exposure to Nuisance and Extreme Weather Events

During Step 2a, Army planners will record nuisance weather events and historical extreme weather events and begin to think of both in the context of climate change. Once both the nuisance and extreme weather events are added to the installation inventory profile map, planners can begin to identify the facilities, resources, and mission areas currently experiencing nuisance hazards and weather extremes.

2.2.1.1. Current Climate Conditions and Nuisance Weather Impacts

Building on Step 1, a discussion of the current climate conditions should be included in the installation profile. The current climate conditions include a general discussion of seasonal temperature and precipitation, and how these “average” conditions impact the installation. The following questions should be answered for the installation:

- What are average seasonal conditions?
- What is the normal range of variation?

Known climate hazards should be discussed with respect to the topographic and natural features of the installation, and situated with respect to existing and planned facilities, infrastructure, critical natural resources, and areas of natural and cultural significance.

To provide a clear picture of the day-to-day disturbances that occur due to weather, an inventory of the installation’s nuisance weather, flood, and coastal impacts should be taken. A nuisance impact is a small but regularly occurring result of climate or coastal processes. For example, the inventory might say that “the installation medical facility and nearby housing are located within the river’s floodplain and have a history of flood impacts in the last three years” or that “chronic” salt water flooding routinely affects the power plant building near the coast.”

It is important to note any trends in nuisance impacts. If this impact is due at least in part to climate change, the presence of a trend will be your biggest indicator that today’s nuisance may become more significant or more frequent by mid-century. Such changes may indicate long-term unsuitability of a location for a given use.

A Nuisance Impacts Table should be added to the installation profile to track nuisance impacts due to climatic, weather, or fire processes on the installation; their frequency; and whether this frequency has changed in recent years (Table 2). If damage estimates are available, include these with the description of the impact. Impacts due to ordinary nuisance weather (such as sunny day coastal flooding, routine urban/interior flooding, or frequent black flag days) should be included. The table should have the following headers and information:

- Nuisance Hazard
- Impact (what action/infrastructure/etc. is impacted)
- Frequency (how often is the event happening)
- Trend (increasing/decreasing in magnitude or frequency)
- Actions Taken (actions that have been taken to reduce exposure to nuisance weather impacts and planned actions to address these)

Table 2: Nuisance Impacts Table example. Notice the level of detail included; table should have enough detail to serve as a quick reference tool when viewing the installation profile map

Nuisance Hazard	Impact	Frequency	Trend	Actions Taken
Black Flag Heat Days	Training, Cooling Infrastructure	Annual (Jun-Sep)	Increasing in frequency (local weather data).	Added 2 shade structures near rifle range A. Info distributed regarding indoor temp settings for all infrastructure.
50-Year Flood Events	Training, Backup Generators, Depot & Boat Launch Access, Base Housing (Quality of Living)	Every two or three years (Mar-May)	Increasing. Now receiving 50-year events every couple of years.	Raised electrical equipment off ground in buildings 1004-1007 at depot. Move depot generator when storms are imminent. Spray for mosquito control post storm.
Stormwater Flooding	Training, Backup Generators, Building Access, Base Housing, Fuel Storage Facility	Annual (Mar-Sep)	There have always been stormwater flooding events on the base. Not sure of trend at this time.	Ditch dug out in rifle range after every storm event to drain field. Generators moved out of flood risk (most of the time). All electrical components elevated in infrastructure at the Fuel Storage Facility. Spray for mosquito control post events.

If data on the frequency of nuisance events is readily available, it should be used to describe the trend (changes in event frequency over time). However, qualitative descriptions of trend may also be used if more precise trend estimates are not available, e.g., “Department of Public Works reports flooding seems to be occurring more frequently at this intersection in recent years than previously.”

Nuisance impacts should be compiled into a GIS layer that can be used as an input into the climate exposure theme for the installation constraints and opportunities map. In addition to the location of specific impact events, areas that should be identified on the map include (but are not limited to) areas prone to wildfires, areas or infrastructure prone to flooding, infrastructure that is routinely unable to keep up with energy demands, and so on. An example of such a map can be found in Figure 9.

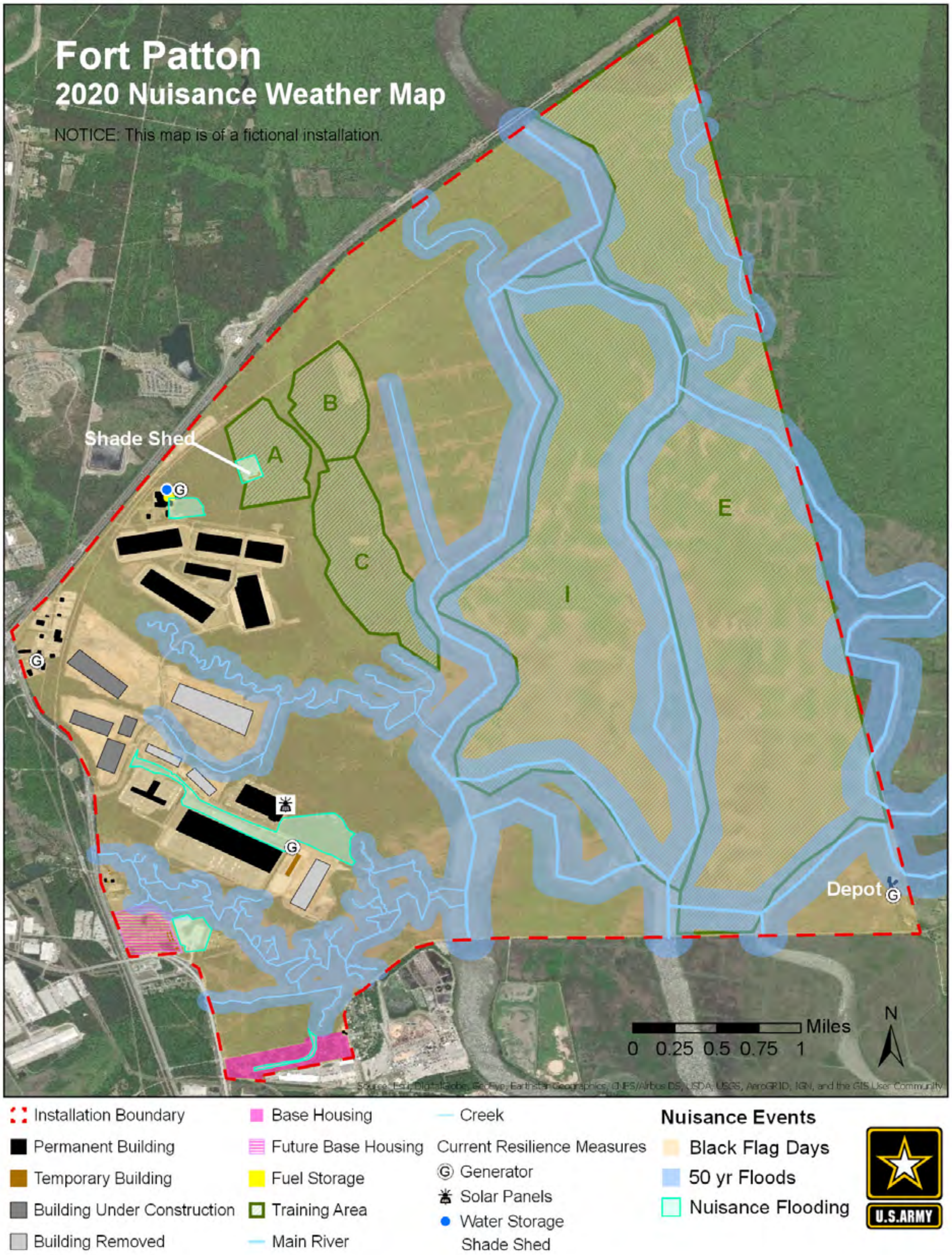


Figure 9: Example nuisance weather map. The map includes the nuisance weather impacts GIS layer produced during Step 2a

2.2.1.2. Extreme Weather Events

Extreme weather events are already occurring on and around installations, as documented in the recent Screening Level Vulnerability Assessment Survey (SLVAS) study (DoD 2018). The SLVAS study found that approximately half of DoD installations worldwide reported experiencing extreme weather events.

An inventory of historical and current extreme weather events should be taken and maintained based on installation records, National Weather Service data[2], and Air Force climate data[3]. Weather events that have caused significant damage since the installation was established should be identified. For the years since 2000, an Extreme Weather Impacts Table should be added to the installation profile that tracks extreme weather impacts to the installation (see Table 3). The table should include the following headers and information:

- Event
- Dates
- Hazard Category (extreme temperatures/heat waves, drought, wildfire, extreme precipitation, land degradation, riverine flooding, coastal flooding, other)
- Event Characteristics
- Location Name (impacted sector/asset/area name)
- Impact Description
- Impact Magnitude
- Recovery and Recovery Costs (rough order of magnitude if exact costs are not available)
- Resilience Measures Taken (measures to reduce future exposure to this kind of event if any)
- Information Sources

[2] https://w2.weather.gov/climate/

[3] https://www.557weatherwing.af.mil/Units/2d-Weather-Group/14th-Weather-Squadron/

Table 3: Extreme Weather Impacts Table examples. Notice the amount of detail included; table should have enough detail to serve as a quick reference tool when viewing the installation profile map

Event: 2012 – 2015 Drought of Record	**Date:** 2012 – 2015	**Hazard Category:** Drought	**Damages / Recovery Costs:** $3.5 Million, Ongoing Training Impacts
Event Characteristics: A 3-year notable drought of record			
Impacted Location(s) and Facilities: Electrical brownout affected all training areas, water storage, and base housing.			
Impact Description and Magnitude: Flow levels in the Pat River were reduced to the point that the Ton Power Plant could not properly cool and the installation and surrounding area experienced intermittent electrical brownouts in August 2013. This led to 28 service members being treated for heat-related illness during the month of August as well as approximately $20 million spent on generator fuel for the backup generators. In January 2014, the water storage (backup water supply) hit critical levels and approximately $10 million was spent on water delivery to the base in February and March 2014. Vegetation and tree mortality across the installation occurred due to the river's low flow and a mandatory no-irrigation policy. The tree and vegetation die-off is still impacting the installation's banks along the Pat River as erosion has become a major issue during flash flood events. To date, approximately $3.5 million has been spent on vegetation restoration efforts in the training areas and landscaping across the installation.			
Resilience Measures Taken: A generator was added to the depot area to supply power during future brownouts/blackouts. The water storage facility was updated and expanded to hold 50,000 gallons. Installation-wide landscaping was changed to include only native plants (except for grass in the base housing area) to eliminate the need for irrigation.			
Information Sources: Ft. Patton Records, NOAA Weather Service, USGS			

Event: 2016 Training Area I Fire	**Date:** 21 – 28 August 2016	**Hazard Category:** Wildfire	**Damages / Recovery Costs**: $5 Million, Ongoing Training Impacts
Event Characteristics: Live fire in Training Area I started a 7-day wildfire on the installation.			
Impacted Location(s) and Facilities: Training areas I and E			
Impact Description and Magnitude: Due to the 2012 – 2015 notable drought of record, the vegetation die-off across the training areas led to a stockpile of fuel on the island known as Training Area I. During a live-fire exercise, Training Area I caught on fire and quickly spread to Training Area E. The fire burned for 7 days across 929 acres and was ultimately contained within Training Areas I and E. Dense vegetation training has been impacted by this wildfire.			
Resilience Measures Taken: Fuel clearing has occurred throughout the training areas to reduce the risk of future wildfires.			
Information Sources: Ft. Patton Records, USGS			

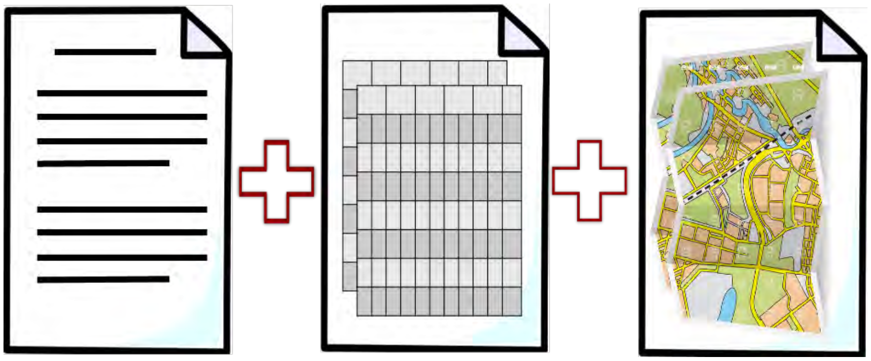
Event: 2019 100-year flood event	**Date**: 23 – 28 April 2019	**Hazard Category:** Riverine Flooding	**Damages / Recovery Costs:** $100 Million
Event Characteristics: 100-year flood event from April 23 – 28 with waters peaking on April 25 and fully receding by April 29.			
Impacted Location(s) and Facilities: Depot, backup generators, base housing, and facilities 1001, 1003, 1005, and 1006			
Impact Description and Magnitude: A 100-year flood event occurred in April 2019. This flood event impacted 10 facilities on the base, which lead to the destruction and removal of 4 buildings and the planned construction of 4 new facilities. Two backup generators (the depot's and the central generator) were flooded out and had to be replaced. The entire depot was flooded (4 of the 10 facilities previously mentioned) as well as 6 vehicles, and 5 vessels were destroyed. The installation's construction and training missions ceased during the flood event and for 10 days after during the recovery effort. All base housing was unable to access the east entrance and exit for 4 days, and 10 base houses were flooded out. Mosquito outbreaks were particularly bad for 3 weeks following the flood.			
Resilience Measures Taken: Four facilities were removed from areas with high riverine flood exposure and will be rebuilt further away from the Pat River. Plans are in place to construct raised platforms for all generators on the base.			
Information Sources: Ft. Patton Records, USGS, NOAA, Local Weather Service			

It is important to map the location of the impacts from extreme weather events as these are unlikely to have the same effect across the installation, especially if the area is large and there are considerable topographic differences across the property. The map should show the spatial extent of impacts by type, as well as the location and kind of resilience measures already in place (such as flood walls, dry floodproofing, etc.). Hazards that affect the entire installation (such as heat waves or hurricanes) can be listed in a table on the side of the map. This data layer is important for showing whether exposure to a common hazard (e.g., topographic low spot) is impacting the installation in multiple ways at the same location. In these cases, it may be more cost-effective to address these locations as group rather than through piecemeal resilience efforts. This data layer will also provide information about areas of the installation where certain kinds of development should be restricted or prohibited (Figure 10). The mapped information constitutes the current and historical extreme weather event GIS layer that can be used as an input into the climate exposure theme for the installation constraints and opportunities map.

2.2.1.3. Step 2a Products

Upon completion of the current climate conditions, an inventory of nuisance events, and an inventory of extreme weather events since 2000, the Army planner should have a clear understanding of the following:

- Current climate condition at the installation.
- How the installation and its daily operations have been impacted by nuisance weather events.
- Extreme weather events that have impacted the installation since 2000.
- Types of nuisance or extreme events that have not impacted the installation missions and operations.



All this information should be briefly described in a few paragraphs, along with a table for nuisance weather and a table for extreme weather events since the year 2000. In addition to the write-up and tables, there should be a GIS layer highlighting the nuisance weather impacts across the installation and a separate GIS layer highlighting the extreme weather events that have impacted the installation. These new GIS layers are essential inputs into the climate exposure theme used to develop the installation constraints and opportunities map (Figure 10).

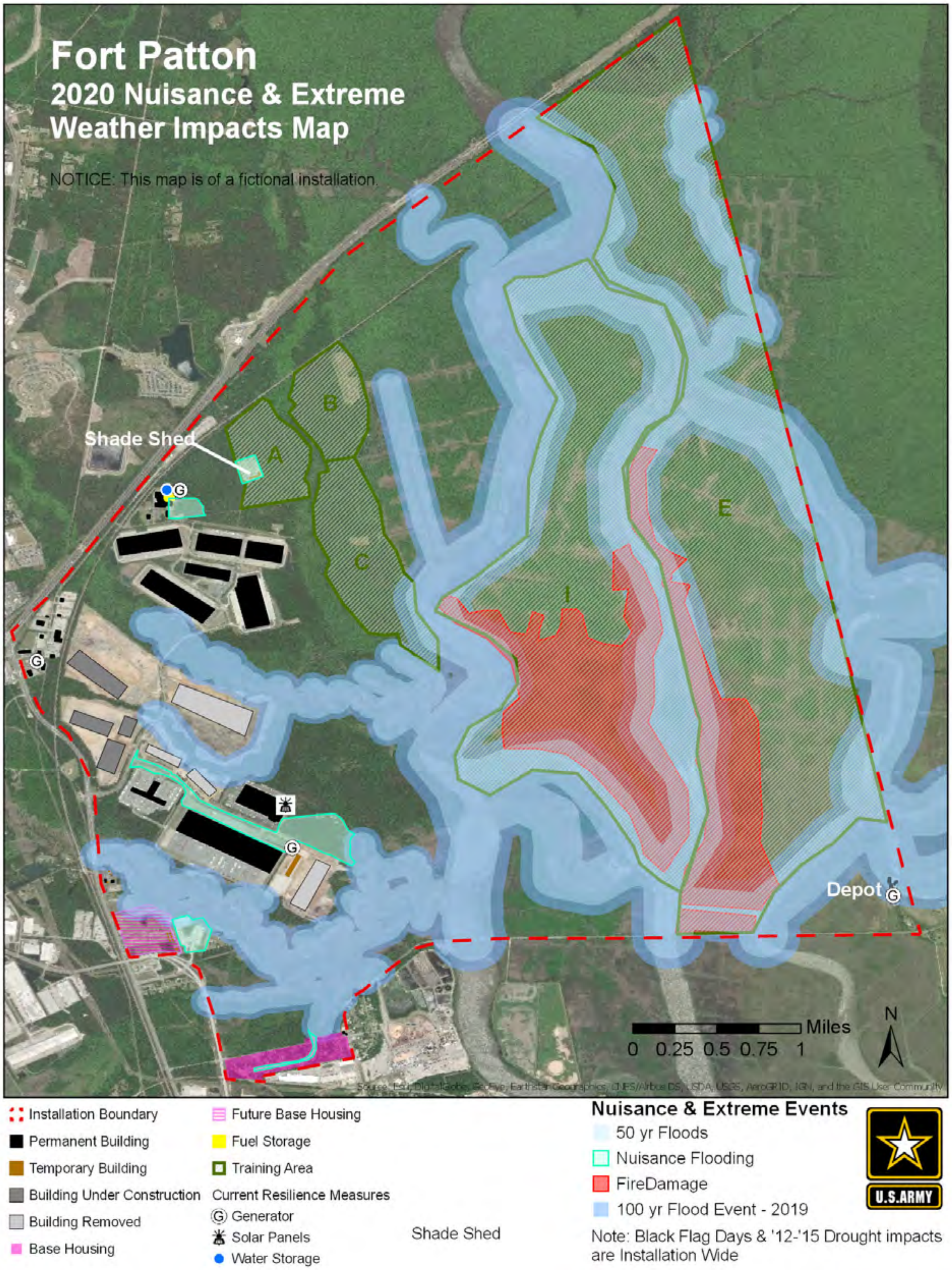


Figure 10: Example Nuisance and Extreme Weather Profile Map. The map includes the extreme weather and the previously mapped nuisance weather impacts GIS layers produced during Step 2a

2.2.1.4. Relating the ACRH Step 2a to Other Planning Processes

RPMP: The ACRH Step 2a aligns with the RPMP IDP and also may feed back into the initial vision plan. A part of the IDP is the development of GIS data layers that serve as inputs into the Climate Vulnerability Assessment Theme for the composite constraints and opportunities map. In this step, the planner collects and displays installation data on real property, facilities, environmental resources, land use, utilities, airfields, transportation/roads, and ranges and training lands. On-site and relevant off-site information should be collected. One goal of this effort is to provide the information necessary to identify and prioritize areas on the installation where development would be either ideal, restricted, or prohibited. The current climate conditions, nuisance impacts, and past extreme weather impacts represent important constraints on the siting of new infrastructure and the operation and maintenance of existing facilities. Known nuisance hazard sites and sites that are exposed to extreme weather events may be flagged as restricted areas for development.

IEWP: The IEWP Guidance Requirement that corresponds with ACRH Step 2a is:

3.2.1 Identify threats and hazards in the following categories: intentional events, non-intentional events, and natural events. The planner is tasked with identifying and documenting the frequency of occurrence and duration of impact. The risk of each combination must be evaluated.

INRMP: The ACRH Step 2a aligns with the second and third steps of the INRMP climate preparedness and resilience planning process.

In the second step, assessing climate vulnerabilities and risks, the planner is expected to project future conditions, assess exposure of target natural resources, and assess resulting impacts and risks to military missions. A part of projecting future conditions is to describe historical and current climatic conditions. Nuisance weather and historical extreme weather can help planners identify current vulnerabilities and areas of concern throughout the installation.

In the third step, evaluating implications for INRMP goals and objectives, the planner should evaluate continued achievability of existing goals, and update climate-compromised goals and objectives. Having GIS layers that clearly show the installation profile, the nuisance weather impacts, and the extreme weather impacts allows the planner to begin to consider whether existing goals and objectives for the installation are being compromised by current climatic conditions. At this stage, revisiting goals and objectives from the ACRH Step 1 may be necessary. The Army planner should be well positioned to create goals and objectives that address climate impacts to inform the INRMP process.

2.2.2. Step 2b: Future Climate Exposure

The ACAT's *Climate Awareness* tab provides you with an overview of projected changes in climate in your region.

There are maps, figures and key messages already created at a regional level that can be helpful in developing the installation profile.

During Step 2b, the Army planner will analyze future climate change scenarios in order to understand the near future climate hazards (Year 2050) and the far future climate change hazards (Year 2085) on the installation. As described in Section 1.5 of this document, the inherent uncertainty associated with climate change modeling will require Army planners to look at lower and higher scenarios. Once the near and far future climate change scenarios are added to the installation profile map, the Army planner will have a clear picture of the risks associated with current climatic and weather events, extreme weather events, and future climate change hazards across the installation.

2.2.2.1. Army Climate Assessment Tool

Step 2b relies on using the Army Climate Assessment Tool (ACAT), available at https://corpsmapr.usace.army.mil/cm_apex/f?p=116. Accessing the tool will require a Common Access Card (CAC). Step-by-step instructions for the ACAT can be found in Appendix D. The tool facilitates a screening level, comparative assessment of how exposed a given installation is to climate change hazards. ACAT can assess the exposure of installations to changes in climate that may affect mission, training, or other activities. It can also both assess the hazards that contribute to an individual installation's exposure and compare installation exposure by region and by Command. Hazard areas include the following, which are of concern to the DoD and Congress:

- Heat
- Drought
- Wildfire
- Energy demand for heating and cooling
- Land degradation (soil loss, permafrost thaw, coastal erosion)
- Riverine flooding
- Coastal flooding
- Historic extremes

Hazard areas are composed of climate-based indicators that address different facets of a particular problem. All indicators are preset to standard values and supported by national data sets. Indicators and the hazards they measure, are detailed in Appendix A, as well as in the ACAT indicator fact sheets in Appendix B.

When assessing future risk resulting from climate change, the ACAT makes an assessment for two 30-year epochs of projected climate, centered at 2050 and 2085. These two periods are consistent with those used by many other national and international analyses and represent a reasonable near-term and far-term planning horizon. The tool derives data from the same primary data sets of temperature, precipitation, and hydrology as the Fourth National Climate Assessment (USGCRP, 2017); other authoritative data sets are used as well. The tool aggregates the information on exposure into the eight hazard areas listed above: heat, drought, wildfire fire, energy demand for heating and cooling, coastal flooding, riverine flooding, land degradation, and historic extremes. Based on the rate and degree of change, the hazards are further grouped into “lower” (RCP 4.5) and “higher” (RCP 8.5) categories.

Because projected climate and hydrology data are aggregated to compute indicator variables, their underlying uncertainty is also aggregated. Many indicators included in the ACAT rely on an ensemble of 32 general circulation models (GCMs) to capture some of the uncertainty inherent in climate projections. The tool reveals some of this uncertainty by presenting separate results for each of the scenario-epoch combinations rather than presenting a single aggregate result.

The tool uses the weighted ordered weighted average (WOWA) method to represent a composite index (exposure score) of how exposed a given installation is to climate change specific to a given hazard category. WOWA is a two-stage weighting process that takes into account the contribution of each indicator to a hazard, as well as the risk tolerance of the planner.

WOWA reflects the aggregation approach used to get the final score for each hydrologic unit code (HUC). After normalization and standardization of indicator data, the data are weighted with “importance weights” (the first W) determined by subject matter experts. These weights represent the contribution of each indicator to the hazard. For example, in assessing wildfire risk, the indicator measuring the frequency of fire weather may be considered the most important and therefore given the largest weighting, followed by the frequency of drought, then by other variables (such as percent of the installation with dense stands of natural vegetation, and ignition likelihood). Then, for each installation-epoch-scenario, all indicators that comprise a hazard are ranked according to their weighted score (indicator x weight), and a second set of weights—the ordered weighted average (OWA) ones—are applied, based on the specified ORness level. ORness is a measure of risk tolerance: it ranges from 1 (an asset is considered at risk if it is affected significantly by the single largest indicator) to 0.5 (an asset’s risk is determined by all the indicators taken equally). The default standard for ORness is set at 0.7, which considers all the indicators, but ascribes greater weight to those indicators that contribute more to exposure to the hazard). ORness can be modified by the user, but modifications from the standard should be justified in the write-up.

The combination of weightings yields a single aggregate score for each installation-epoch-scenario called the WOWA score. WOWA indicator contributions are calculated after the aggregation to give a sense of which indicators dominate the WOWA score at each installation.

Descriptions of the indicators used in the hazard assessment may be found in Appendix A. Step-by-step instructions on the use of this tool are provided in Appendix D.

2.2.2.2. Step 2b Products

At the completion of Step 2b, the planner will have an installation-level list of mission readiness areas that are most exposed to the risks of a changing climate. This list will consist of higher and lower scenarios as projected into the near future (2050) and the far future (2085). Four future climate change GIS layers, one for each scenario, will be created during Step 2b (Figure 11).

Analysis results should be written up in a few pages that can easily be added to the complete planning document. This write-up should include a narrative that describes expected future climate hazards on the installation and surrounding communities (as appropriate), and evaluates these hazards in terms of how critically they affect the installation’s mission and readiness; energy and water supplies; environment, and other resources.

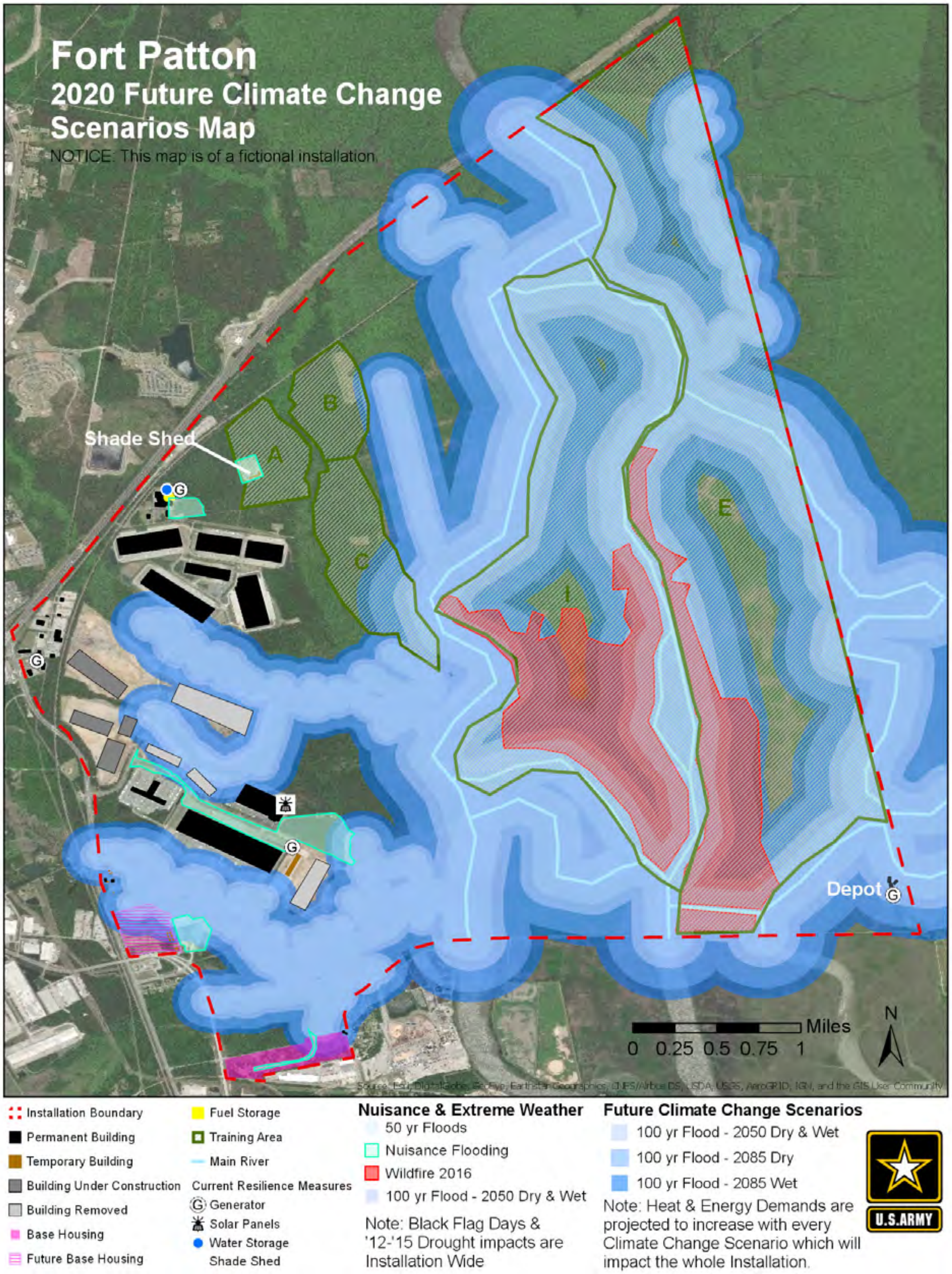


Figure 11: Example Future Climate Change Map with overlays of Nuisance and Extreme Weather impacts. The map includes the four climate-scenario GIS layers produced during Step 2b

2.2.2.3. Relating the ACRH Step 2b to Other Planning Processes

RPMP: The ACRH Step 2b aligns with the RPMP IDP and also may feed back into the initial vision plan. A part of the IDP is the development of GIS data layers that serve as inputs into the Climate Vulnerability Assessment Theme for the composite constraints and opportunities map, which provides a foundation for long-range planning. To do this, the planner must identify natural and man-made constraints—including future climate change scenarios and their impacts on the installation—that will affect future development on the installation.

IEWP: The IEWP Guidance Requirement that corresponds with ACRH Step 2b is:

3.2.2 Identify threats and hazards that could affect supply and delivery of energy and water to the installation. Determine the likelihood of occurrence and potential for significant effect.

INRMP: The ACRH Step 2b aligns with the second and third steps of the INRMP climate preparedness and resilience planning process.

In the second step, assessing climate vulnerabilities and risks, the planner is expected to project future conditions, assess exposure of target natural resources, and assess resulting impacts and risks to military missions. A part of projecting future conditions is to identify relevant climatic factors (changes in fire frequency and severity, increased droughts, shoreline loss, etc.) and to describe future change scenarios (wet or dry, near future or far future). Using the GIS layers created, planners can begin to assess the future climate change exposure of natural resources and the impacts to the installation's missions.

In the third step, evaluating implications for INRMP goals and objectives, the planner should evaluate continued achievability of existing goals, and update climate-compromised goals and objectives. Having GIS layers that clearly show the installation profile and the future climate change scenarios allows the planner to begin to consider whether existing goals and objectives for the installation will be compromised by climate change. At this stage, revisiting goals and objectives from the ACRH Step 1 may be necessary. The Army planner should be well positioned to create goals and objectives that address projected climate hazards to inform the INRMP process.

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2.3. Step 3: Creating the Climate Vulnerability Theme for the Constraints and Opportunities Map

Vulnerability is the degree to which an installation is likely to experience harm due to exposure to weather extremes and climate change (Turner et al. 2003). It consists of three factors:

- Exposure to one or more climate hazards (assessed in Steps 2a and 2b).
- Sensitivity to this exposure, which is the degree to which assets will be adversely or beneficially affected by this exposure.
- Adaptive capacity, which is the ability to adjust to or mitigate for the hazard or its consequence on sensitive assets.

During Step 3, the Army planner will look at the information prepared in Steps 1 and 2, develop thorough cause and effects, and identify constraints and opportunities to climate resilience on the installation. As in Steps 1 and 2, GIS will be an important tool during Step 3 to visualize known constraints and identify opportunities through the analysis of the stacked GIS layers created in previous steps. However, visualizing problem areas is not enough to develop comprehensive constraints and opportunities for the installation.

Step 3 will lead the Army planner through methods for developing a clear picture of the climate exposure sensitivity and an understanding of adaptive capacity through the development of cause-and-effect scenarios and visual aids.

The end product of this step is the development of a climate vulnerability theme (GIS layer) comparable to those developed for utilities, airfields, and transportation. This theme combines exposure information (data from Steps 2a and 2b) with sensitivity (the degree of risk to facilities, missions, and readiness) and adaptive capacity to provide a clear picture of potential vulnerability of the installation to climate and climate change.

Figure 12 outlines the geospatial data and narrative products for this step.

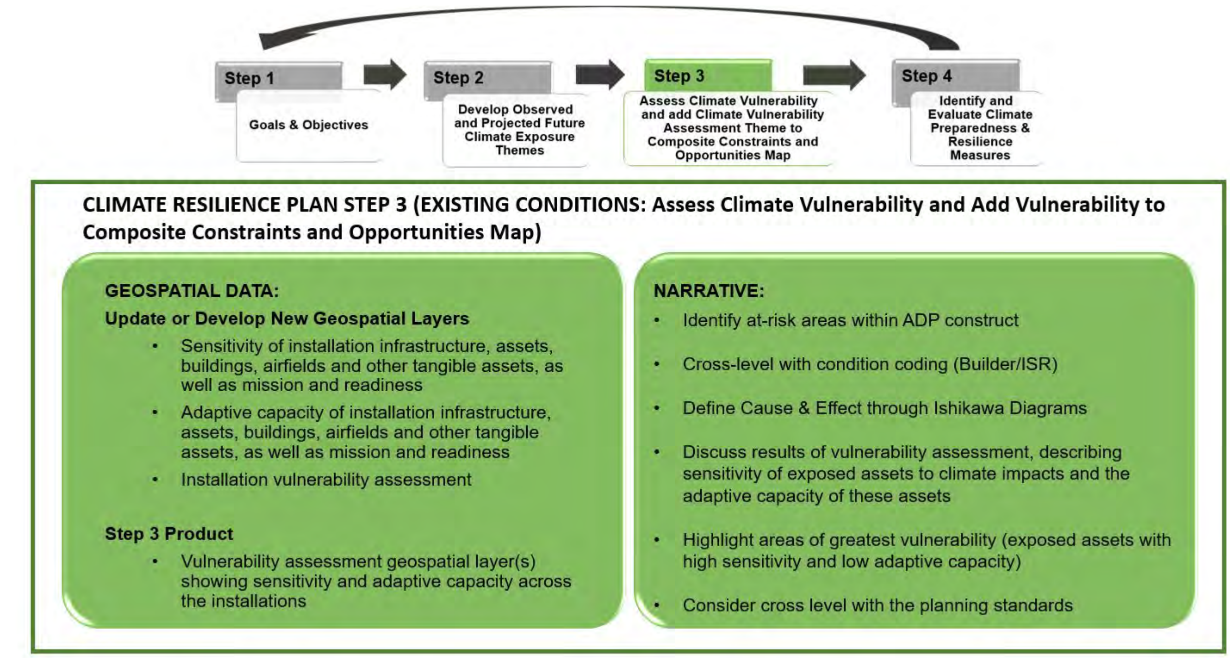


Figure 12: Geospatial data and narrative products for Step 3

2.3.1. Identifying Sensitive Areas

At this point in the ACRH, the Army planner has created several geospatial layers:

- An installation profile map (Step 1)
- A GIS layer showing nuisance weather impacts and the current climate resilience efforts on the installation to combat these impacts (Step 2a)
- A GIS layer showing extreme weather impacts and the current climate resilience efforts on the installation to combat these impacts (Step 2a)
- Two GIS layers for near-future (2050) lower and higher climate-change exposure scenarios (Step 2b)
- Two GIS layers for far-future (2085) lower and higher climate-change exposure scenarios (Step 2b)

Overlapping the GIS layers developed in Steps 1 and 2 will give a better understanding of areas sensitive to current or future climatic events. Current areas and infrastructure that are at the greatest risks of experiencing nuisance weather, weather extremes, and future climate change should be mapped and coded in a meaningful way that illustrates the current level of sensitivity. In the RPMP process, planners' code infrastructure for the Installation Status Report (ISR) is based on the following metrics: green for minor deficiencies, yellow for some facility deficiencies, red for significant facility deficiencies, and black for deficiencies that present significant obstacles (Figure 13).

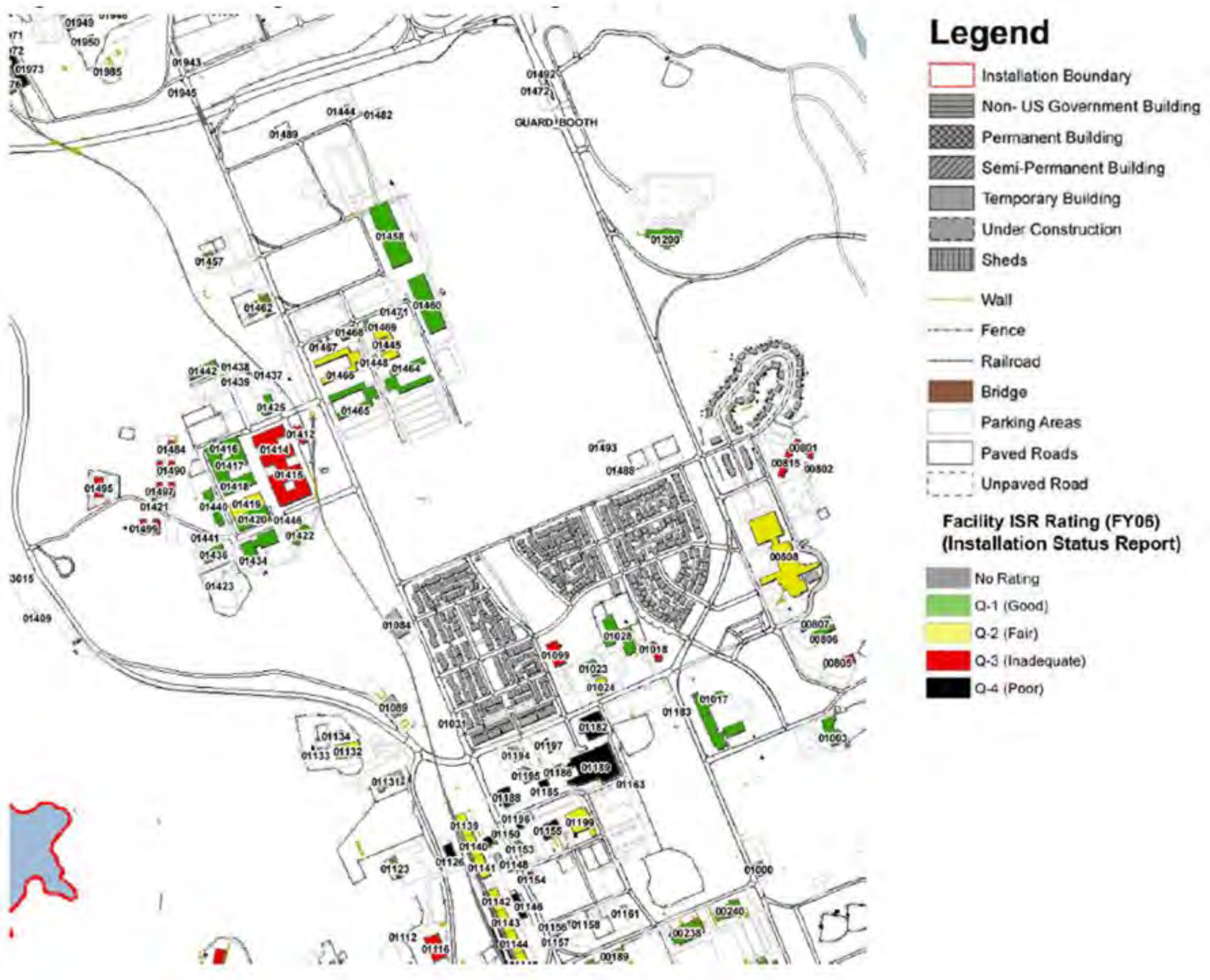


Figure 13: Example of a Facilities Map - ISR (Figure 4.4 in DA 2011)

Using a similar technique, Table 4 shows the ACRH recommended color coding for infrastructure and areas of the installation at the greatest risks of experiencing nuisance weather, weather extremes, and negative future climate change impacts. Definitions in the table are meant to serve as a guide and should not be considered rigid; each installation faces different climate resilience goals related to their specific mission area(s), geographic location, and size. This new color-coded GIS layer can be added to the installation profile map to quickly visualize the areas in greatest need of climate resilience measures.

Table 4: The ACRH color coding for infrastructure and areas of the installation based on sensitivity to nuisance weather, weather extremes, and future climate change hazards

Sensitivity	Color	Definition
None	Clear	There have been no nuisance climatic or weather impacts and no extreme weather impacts, nor is there expected to be any significant increase in exposure to climate hazards in the future.
Low	Yellow	**One or two of the following is true:** • There have been minor nuisance weather impacts. • There have been minimal impacts from extreme weather events. • There are minimal expected increases in exposure to climate hazards under one or two climate change scenarios. In any of the above options, there may already be climate resilience measures in place.
High	Red	**One of the following is true:** • All three options from the Low category are true. • There have been moderate to major nuisance weather impacts. • There have been moderate to major extreme weather event impacts. • There are minimal expected increases in exposure to climate hazards under three or more climate change scenarios. • There are moderate to extreme expected increases in exposure to climate hazards under one or more climate change scenarios.

Looking at the updated installation profile map with the color-coded sensitive areas, the Army planner is looking at only one piece of the sensitivity story (Figure 14). The next step is to identify the root causes through cause-and-effect relationships.

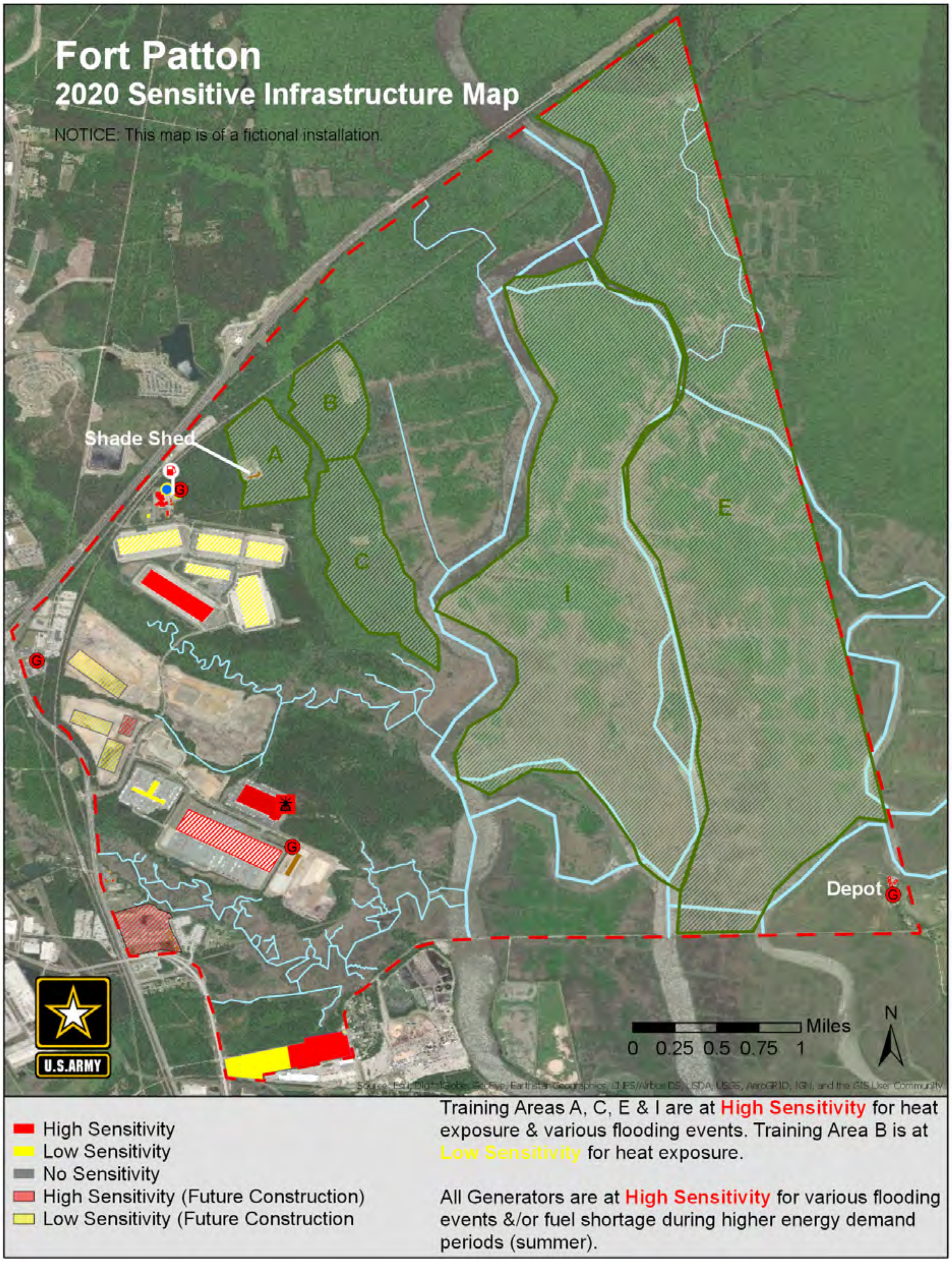


Figure 14: Example Installation Profile Map with the sensitivity color-coding GIS layer produced during Step 3

2.3.2. Cause and Effect

A large part of identifying the sensitivity of assets to climate hazards across the installation is identifying the root causes that contribute to the assets' exposure. The cause-and-effect relationship can help an Army planner identify natural and man-made constraints that are impacting climate resilience on the installation. There are several ways a planning team can go about identifying cause-and-effect relationships. The best way to start is with a problem statement (effect) and break down the causes by asking "Why?" questions.

One way to explore and build cause-and-effect relationships, from the USACE Risk-Informed Planning Manual (Yoe and Harper 2017), is the Ishikawa Diagram method. It is a great way to visually lay out the thought process behind cause-and-effect relationships. Starting with the risk-areas GIS layer created above, the Army planner should fill in the diagram as a cause-and-effect scenario (see Figure 15, row A).

The planner will need to identify all relevant factors that contribute to this effect. This is a good time to review the tables and GIS layers created in Steps 1 and 2. Next, the planner will need to identify what is causing the contributing factors. Causes can be obvious, or they may need to be broken down further to the root cause (see Figure 15, row B).

A completed example Ishikawa Diagram is shown in Figure 15, row C. The planner may start out with the premise that XX Creek causes flood damages to the barracks within XX installation. Why? Because of rainfall. Why is rainfall a factor? Because of increased runoff. Why is that a factor? Because of upstream development and climate change. This approach allows a sequence of questions that can get to root causes and identify both climate and non-climate factors contributing to climate exposure on an installation.

In Figure 15, row C, one root cause of increased runoff is upstream development on or off the installation. Identifying root causes gives a new level of constraints that may be out of the installation's control (like urban development upstream).

More examples of how a planning team can go about identifying cause-and-effect relationships can be found in the USACE Risk-Informed Planning Manual (Yoe and Harper 2017).

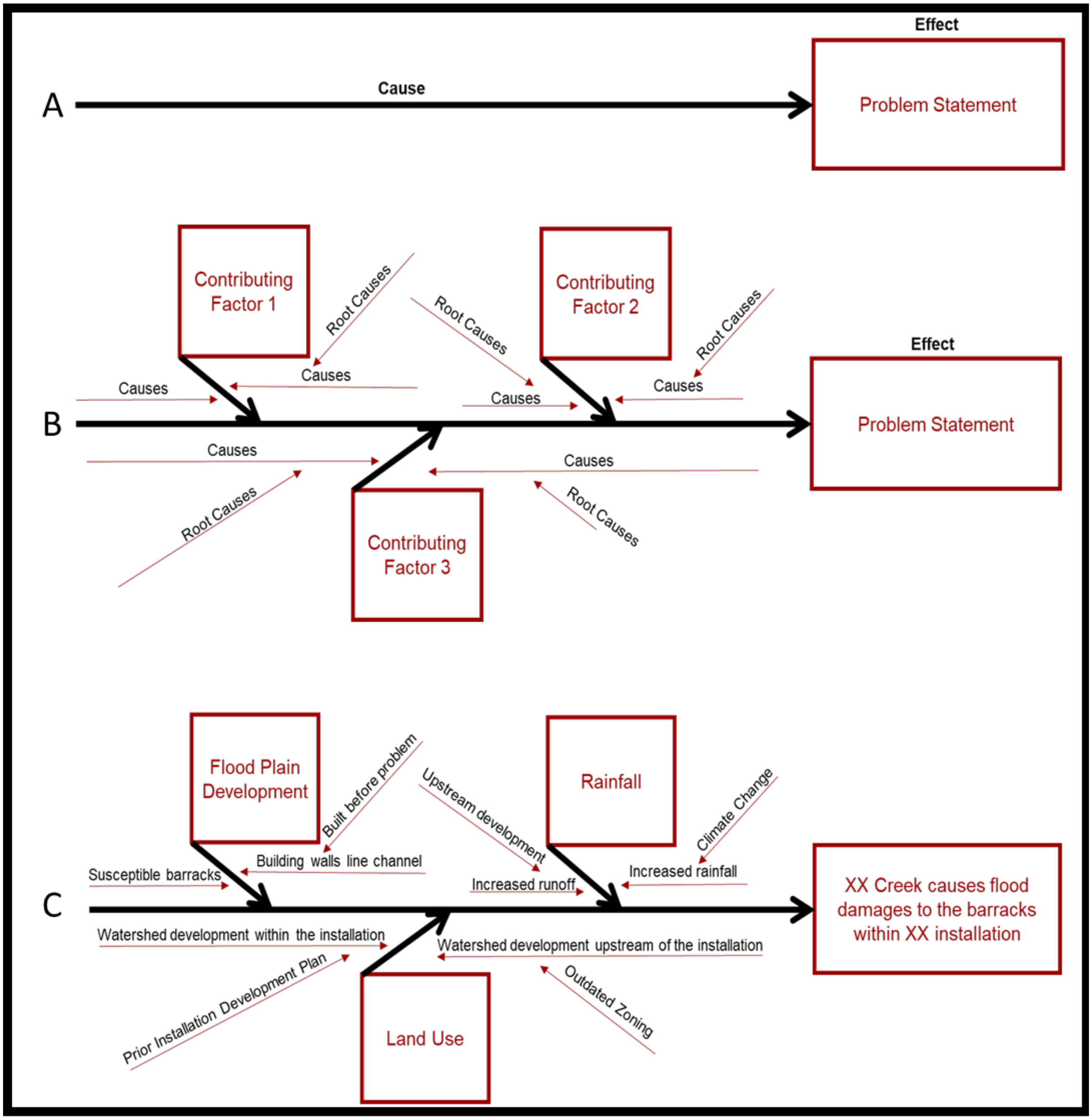


Figure 15: Building an Ishikawa Diagram to illustrate cause-and-effect relationships. Modified from the Planning Manual Part II – Risk-Informed Planning Figures 6.4 and 6.5 (Yoe and Harper 2017)

Developing good cause-and-effect relationships is essential to the success of an installation's climate resilience plan. A rich narrative description of these relationships provides a better understanding of the constraints to and opportunities for climate resilience climate resilience across the installation. This helps identify resilience measures that can reduce the risks of current and future climate impacts (Step 4).

2.3.3. Assessing Adaptive Capacity

By this step in the process, the Army planner should have a clear understanding of what kinds of climate extremes the installation is being or will be exposed to, and the degree of sensitivity of installation lands and infrastructure when exposed.

Next, the Army planner needs to assess adaptive capacity. This is an assessment of the ability of the installation to reduce the exposure of the asset. If the exposure is readily reduced—for example, reducing flood risk to a building by improving stormwater drainage—then the affected infrastructure or facility has high adaptive capacity. Other examples of high adaptive capacity include the capability to alter building designs to reduce energy consumption or restricting development within the installation's 100-year floodplain.

Adaptive capacity is considered low when exposure is not easily reduced. For example, if an airfield will become inundated 50% of the time due to sea level rise and measures such as sea walls and relocation are infeasible, adaptive capacity may be low.

The Army planner will review the cause-and-effect relationships behind the sensitivity color coding to add information about the adaptive capacity of an asset based on how difficult it may be for the installation to reduce the exposure of the asset at risk.

The color-coding scheme should be adjusted on the maps to capture this interplay between locations that are exposed, their sensitivity, and their adaptive capacity, as shown in Table 5. Table 5 builds on the information from Section 2.3.1 to show the extra level of information regarding adaptive capacity that can be added to the geospatial data layers.

2.3.4. Step 3 Product: The Climate Vulnerability Assessment Theme

Using GIS and the color coding in Table 5, the degree of exposure, sensitivity and adaptive capacity are easily assessed by the Army planner (Figure 16). This GIS data layer, showing exposure, sensitivity and adaptive capacity, constitutes the Climate Vulnerability Assessment Theme. This theme is the direct input into the installation planner's constraints and opportunities map.

Having identified assets and areas that are exposed to climate hazards in Steps 1 to 2, the Army planner can develop a strategy to address their installation's vulnerabilities in Step 3. The Army planner can use information from cause-and-effect analysis to initially screen potential management measures.

Table 5: Building on Table 4 from Section 2.3.1, the level of adaptive capacity associated with asset sensitivity can be coded as Low (solid) or High (hatched)

Sensitivity	Color	Definition	Adaptive Capacity
None	Clear	There have been no nuisance climatic or weather impacts and no extreme weather impacts, nor is there expected to be any significant increase in exposure to climate hazards in the future.	
Low	Yellow	**One or two of the following is true:** • There have been minor nuisance weather impacts. • There have been minimal impacts from extreme weather events. • There are minimal expected increases in exposure to climate hazards under one or two climate change scenarios. In any of the above options, there may already be climate resilience measures in place.	**High**
			Low
High	Red	**One of the following is true:** • All three options from the Low category are true. • There have been moderate to major nuisance weather impacts. • There have been moderate to major extreme weather event impacts. • There are minimal expected increases in exposure to climate hazards under three or more climate change scenarios. • There are moderate to extreme expected increases in exposure to climate hazards under one or more climate change scenarios.	**High**
			Low

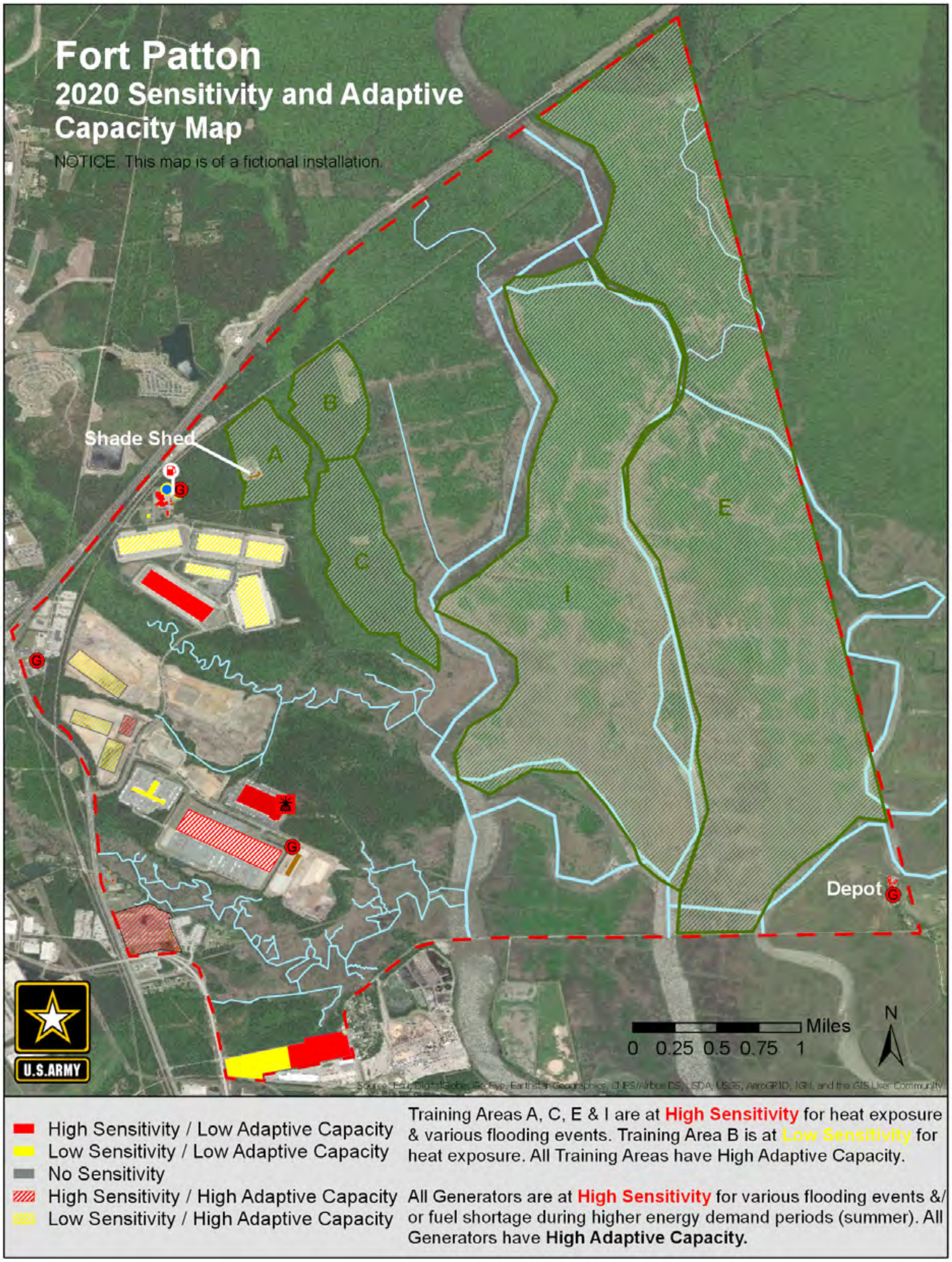


Figure 16: Example Installation Profile Map with the sensitivity and adaptive capacity GIS layers produced during Step 3

While working through Step 3, the Army planner should fill in a Vulnerability Assessment Table (Table 6), which will serve to annotate to the Climate Vulnerability Assessment Theme. Infrastructure and location identification should be the same on the installation profile map and the constraints and opportunities table. The table should have the following headers:

- Name: Location or infrastructure name on the installation profile map
- Exposure: Details of hazards affecting this area. Examples include *chronic flooding from king tides; damaged by 3 hurricanes since 2000; 2 future climate scenarios show increased exposure to fire hazard days,* etc.
- Sensitivity Level: None, Low, High
- Sensitivity: Details of factors affecting climate resilience. Examples include *location within a 100-year floodplain; issues outside the installation's footprint are leading to issues within the installation;* and *no space on the installation to expand endangered species habitat,* as well as information about how critical the resources are (*only power station on base, alternate housing available, building planned for demolition,* etc.)
- Adaptive Capacity Level: None, Low, High
- Climate Preparedness and Resilience Measures: List of measures that can be used to reduce risks and reach climate resilience goals; this column will be filled out in Step 4

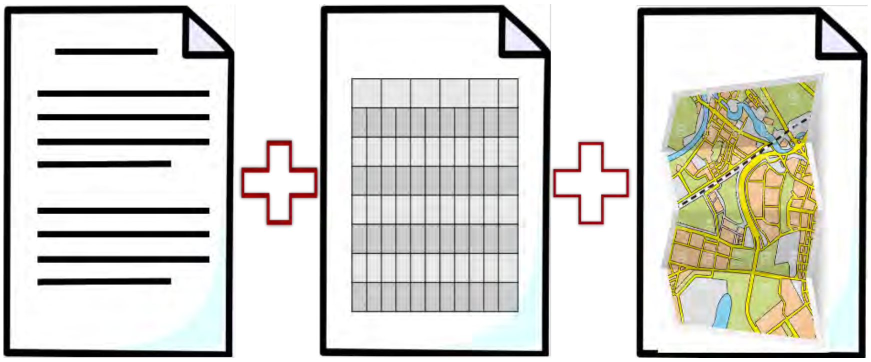
Table 6: Vulnerability Assessment Table example. Notice the amount of detail included in the table. This table should have enough detail to serve as a quick reference tool when viewing associated maps

Name	Exposure	Sensitivity Level	Sensitivity	Adaptive Capacity	Climate Preparedness and Resilience Measures
Areas A, C, E, and I	Heat	High	High heat and humidity levels during the summer half-year in the future may pose a significant health risk to troops.	High	Restrict use to cooler portions of the day during the summer half-year; take measures to ensure successful acclimation for troops rotating through base; improve infield health monitoring of troops.
Areas A, C, E, and I	Flooding	High	Flood risk to training areas increases with time, posing risk to troops.	High	Install flood warning system at stream crossings; develop plan to restrict vehicle traffic on saturated ground post-flood.
Building 45	Energy	High	High performance computing center's cooling demand is exacerbated by older, poorly insulated metal building.	Low	From energy demand perspective, current building is inadequate; in the future, unmet cooling demand may lead to computing infrastructure failure. Building needs to be replaced or facility relocated.
Building 45	Flooding	High	Future flooding and chronic flooding are incompatible with high performance computing function at this location.	Low	Building would be very costly to floodproof using either structural or nonstructural methods; facility would need to be relocated.

At the completion of Step 3, the Army planner will have a detailed understanding of the areas and infrastructure at risk from current and future climate events and change. The chief product of Steps 1 to 3 of the planning process is the Climate Vulnerability Assessment Theme, which consists of GIS layers and associated data with respect to:

- Exposure to current and historical nuisance and extreme weather events.
- Exposure to projected climate hazards.
- Sensitivity and adaptive capacity of installation infrastructure, assets, buildings, airfields, and other tangible assets, as well as mission and readiness.

This information can then be used to assist the planner in determining the installation's climate resilience goals.



2.3.5. Relating the ACRH Step 3 to Other Planning Processes

RPMP: The ACRH Step 3 aligns with the RPMP IDP. In this step, geospatial data on exposure are combined with information about risk and sensitivity, to develop the Climate Vulnerability Assessment Theme, which is an input into the composite constraints and opportunities map. The composite constraints and opportunities map is used to state the current condition of environmental features and operational/mission activities; provide a foundation for long-range planning; identify natural and man-made constraints; and identify and prioritize areas on the installation where development would be ideal, restricted or prohibited. This step relies on previously created GIS layers and the further analysis of those layers. This information can easily be incorporated into the composite constraints and opportunities map section of the IDP because IDP relies heavily on the geospatial analyses that help the Army planner identify the constraints to and the opportunities for climate resilience across the installation.

IEWP: The IEWP Guidance Requirements that correspond with ACRH Step 3 are:

3.2 Assess risks, potential mission impacts, security and resilience measures, and assess conservation or efficiency opportunities;

3.2.2 Conduct E&W risk assessment to document potential damage or loss of a vulnerable system as a consequence of an exposure to a threat.

INRMP: The ACRH Step 3 aligns with the second and third steps of the INRMP climate preparedness and resilience planning process.

In the second step, assessing climate vulnerabilities and risks, the planner is expected to assess exposure of target natural resources, and assess resulting impacts and risks to military missions. A part of the second step of the INRMP is identifying resources and infrastructure at risk of being impacted by climate change. Using the GIS layers created, planners can begin to assess the future climate change exposure of natural resources and the impacts to the installation's missions. Once risks are identified, planners can begin the process of setting priorities for climate preparedness and resilience and management.

In the third step, evaluating implications for INRMP goals and objectives, the planner should evaluate continued achievability of existing goals, and update climate-compromised goals and objectives. The GIS layers created in Step 3 of the ACRH process gives the Army planner a clear picture of the achievability of existing goals. For example:

An installation has a goal to maintain sea turtle nesting habitat along two miles of training beach. The ACRH analysis shows that the beach has a high risk of loss through coastal erosion due to sea level rise. The planner must now reevaluate the achievability of protecting the habitat and possibly look at the constraints (costs, laws, etc.) and opportunities (e.g., resilience measures to protect habitat and vital training areas) of meeting climate resilience goals.

At this stage, revisiting goals and objectives from the ACRH Step 1 may be necessary. The Army planner should be well positioned to create goals and objectives that address climate exposure to inform the INRMP process Step 4: Climate Preparedness and Resilience Measures.

Step 3 brings the knowledge and outputs from Steps 1 and 2 together to identify suitable climate preparedness and resilience measures. The ACRH provides a library of measures that can be used for climate risk reduction and resilience (Appendix C). The geospatial data and narrative products of this step are outlined in Figure 17.

2.4. Step 4: Choosing Climate Preparedness and Resilience Measures

The last step in the process is to identify climate preparedness and resilience measures that can be used to reduce the installation's vulnerability to climate change. The purpose of this step is to develop a catalog of measures that can be implemented as funding or other opportunities become available. As better data on climate exposure and vulnerability become available, this catalog of measures should be revisited.

Figure 17 outlines the geospatial data and narrative products for this step.

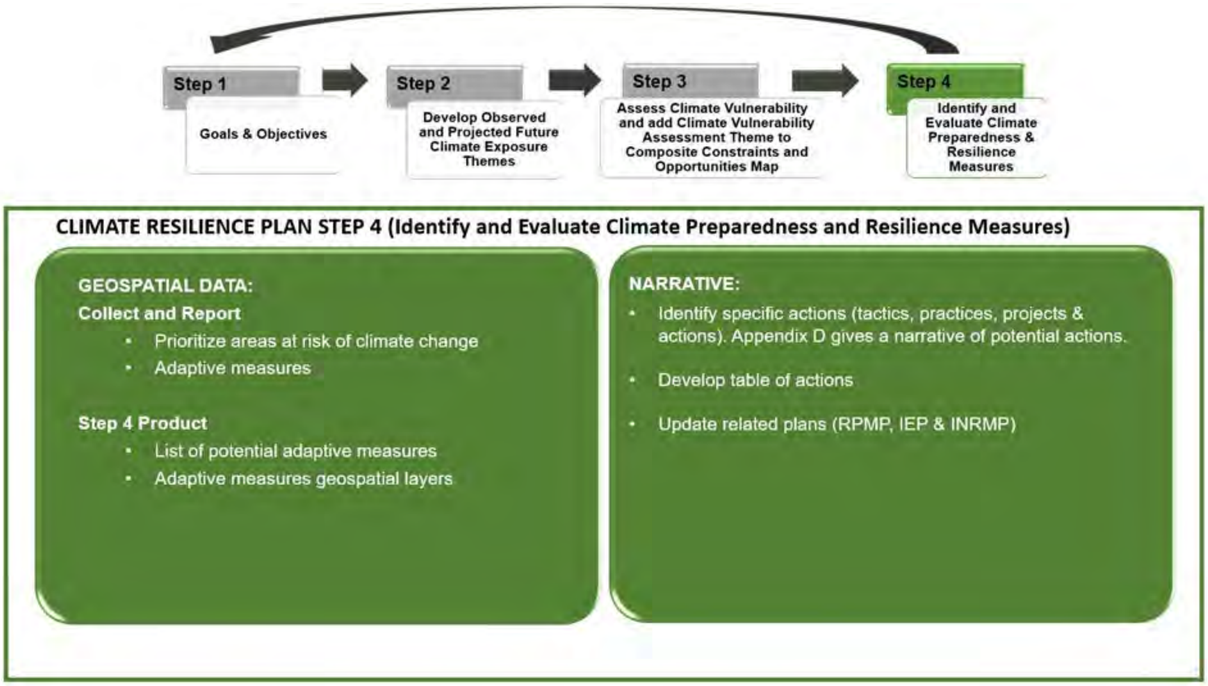


Figure 17: Geospatial data and narrative products for Step 4

The measures are organized by the hazard categories used in the ACAT. Within each hazard category, the measures are further divided into nonstructural, structural, and natural / nature-based features (NNBF).

Extensive information about resilience measures that absorb and adapt to disruptions for riverine coastal flooding has been developed over the past 10 years, spurred in part by hurricanes Katrina and Sandy and by an increase in observed sunny-day or chronic tidal flooding caused by sea level change (Sweet et al. 2014, Moftakhari et al. 2016). The range of measures, their suitability in different settings, and their pros and cons are well-documented [e.g. USACE 2013, City of New York 2013, USACE 2015a].

Coastal flood risk measures are characterized as structural (e.g., seawalls, coastal dikes, surge gates, river training structures, streambank protection, levee setbacks, culverts), nonstructural (e.g., zoning, evacuations, warning systems, dry floodproofing, wet floodproofing, elevating homes), and NNBF (e.g., engineered beaches and dunes, coral reefs, natural or man-made wetlands, and other features largely shaped by natural processes). Many of the same measures are applicable to riverine flood situations and other climate hazards as discussed later in this section.

Nonstructural: The USACE National Nonstructural Committee[4] defines nonstructural measures as “permanent or contingent measures applied to a structure and/or its contents that prevent or provide resistance to damage from flooding,” adding that they differ from structural measures in that they “focus on reducing the consequences of flooding instead of focusing on reducing the probability of flooding.”

Nonstructural measures often involve working with the local and state government to develop, implement and regulate. However, nonstructural measures can also be implemented on installations through policy change or educating the installation’s population. Physical measures include elevation, relocation, buyout/acquisition, dry floodproofing, and wet floodproofing. Nonphysical measures include warning systems, insurance (flood, fire, etc.), floodplain mapping, emergency preparedness plans, zoning, and risk communication. The USACE National Nonstructural Committee has developed several documents to assist in the planning and evaluation of nonstructural measures, including decision aids.

Structural: Structural measures involve any physical construction that reduces the probability of exposure to climate hazards. For example, a dam reduces flood risk by reducing the height of the flood and spreading the floodwaters out over a longer period of time. Therefore, the frequency with which floodwaters overtop a streambank and inundate the adjacent land is reduced. Levees, riprap, insulation, and storm water capture and reuse structures all count as structural measures.

Natural and Nature-Based Features: The USACE defines natural features as features that are created and evolving over time through the actions of physical, biological, geologic, and chemical processes operating in nature” or features “that may mimic characteristics of natural features but are created by human design, engineering, and constructions to provide specific services” (USACE 2013). Using NNBF for climate resilience has the added bonus of potentially increasing ecosystem goods and services on the installation.

[4] https://www.usace.army.mil/Missions/Civil-Works/Project-Planning/nnc/

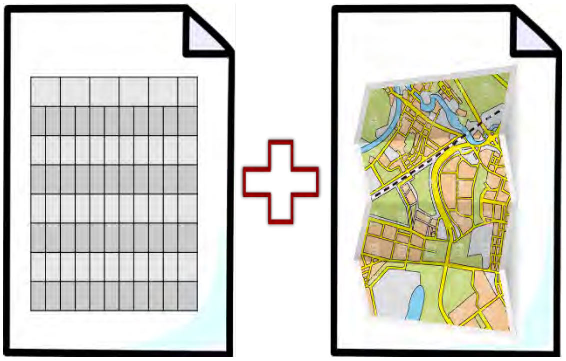
Though the term NNBF is recent, it does encompass a variety of long-established measures for which extensive technical guidance is available that enables estimates of engineering performance and reliability over the long term. These include engineered beaches and dunes, submerged artificial reefs, typical stream channel restoration, streambank protection, levee setbacks, stormwater detention basins, and grade control structures.

For other NNBF, information on long-term performance and reliability may be limited. Such features are better suited for high-frequency events such as high-tide flooding or as part of a layered approach including multiple lines of defense; they are currently less suited for resilience measures that require a quantitative cost-benefit analysis since performance information is lacking. In ten years or so, additional information on the engineering performance of such NNBF may become available to support their use in additional situations. The USACE Engineer Research and Development Center (ERDC) has produced information about NNBF (USACE 2015b and USACE 2018).

The list of climate preparedness and resilience measures in Appendix C can be used to complete the last column in the Vulnerability Assessment Table (Table 6). To achieve climate resiliency goals, only one measure may be needed or several measures may need to be bundled together to reduce risk. It is best to include several measures at first as the rest of the planning process will work on eliminating the measures due to a variety of reasons (cost, long-term ineffectiveness, etc.). It is important to note that Appendix C is not an exhaustive list; installations are encouraged to consider measures that are innovative and unique to their respective locations, risks, and climate resilience goals.

Some measures can be quickly shown as concepts on the installation profile map, such as potential locations of levees, sand dune construction, or open space preservation locations. These concept measures should be created in a separate GIS layer that can be used to further explore climate resilience across the installation (Figure 18).

2.4.1. Step 4 Products



At the completion of Step 4, the Army planner will have reviewed climate preparedness and resilience measures suited to addressing the climate resilience goals of the installation. Measures should be added to the Vulnerability Assessment Table to give a complete picture of the risks and the constraints and opportunities to reducing these risks. The opportunities will include the measures (single or bundled) chosen to reach climate resilience goals. The planner may also choose to show measures on the installation profile map via the creation of a measures GIS layer.

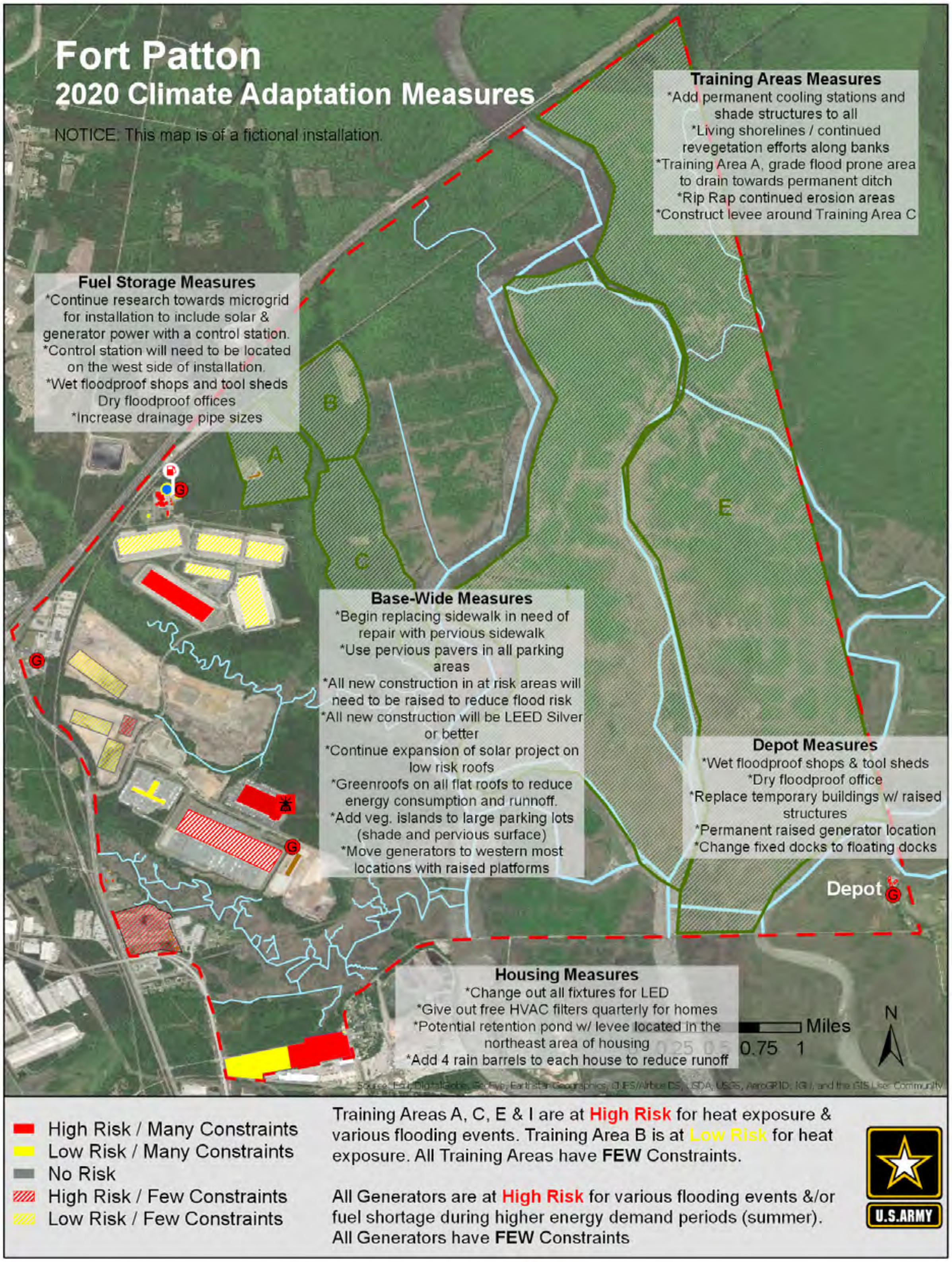


Figure 18: Example Installation Profile Map with the GIS layer produced during Step 4 showing concepts of climate adaptation measures

2.4.2. Relating ACRH Step 4 to Other Planning Processes

RPMP: The ACRH Step 4 aligns with the RPMP IDP**.** As discussed in previous sections, a part of the IDP is the construction of a composite constraints and opportunities map. Step 4 gives the Army planner the opportunity to expand on the opportunities and add an array of climate preparedness and resilience measures to the composite constraints and opportunities map. Another aspect of the IDP is the creation of the framework plan, a living document designed to be flexible and representative of the direction and location of future installation development. The framework plan is not constrained by funding or project requirements and thus provides a framework for change as projects are planned and completed over time. It is developed after considering alternatives (resilience measures). These measures are then viewed through a functional analysis process, a spatial analysis process, and lastly added to the framework plan. Many of the spatial products created throughout the ACRH process will be pulled into the framework plan.

Having completed all four steps, the planner is now ready to add information to the Capital Investment Strategy (CIS) with respect to:

- Actions necessary to ensure the resilience of existing infrastructure to climate change hazards.
- Measures necessary to ensure the resilience of planned or in-construction facilities and infrastructure to ensure resilience to climate change hazards.
- Proposed actions to ensure the resilience of future infrastructure to projected climate change hazards (such as identification of no-build zones due to future flood hazards), and funding to support work with installation partners and stakeholders to ensure resilience of off-installation infrastructure (roads, pipelines, powerlines, water supplies, housing).

The information added to the CIS should reflect anticipated timelines for action that take into account the projected time until the climate change hazard manifests as well as typical planning and coordination lead time. Monitoring for change and identifying thresholds for action should also be included in this strategy. While these actions are not capital investments, they are capital-preserving investments that should be sustained as part of the investment strategy for the installation.

IEWP: The IEWP Guidance Requirements that correspond with ACRH Step 4 are:

3.3.2 Provide scope of projects needed to support installation-specific energy and water goals and objectives, addressing a solution for closing a gap in installation mission requirements.

3.3.2.1 List Assured Access Projects, which provide a more dependable supply of energy and water to meet mission requirements during normal and emergency response operations. Address the following: 1) utility privatization projects; 2) utility procurement methodologies such as potential power purchases and/or rate negotiations, and potential future acquisition of water rights, supply contract, or state-issued permit modifications; 3) participation in utility offerings such as potential demand response, load curtailment, time-of-use, and rebates that are available.

3.3.2.2 List Infrastructure Condition Projects, which enhance the efficiency and condition of energy and water infrastructure.

3.3.2.3 List Critical Mission Sustainment Projects, which provide necessary energy and water to critical missions for a minimum of 14 days.

3.3.2.5 Identify and provide actions that improve the operation efficiency of existing systems and equipment without replacement, including landscape modification and equipment and building performance review.

The third step of the IEWP process is to generate solutions. This step requires the planner to scope best management practices and develop project concepts. Army planners should frame their solutions around their missions and findings from previous steps. When an IEWP planner reaches the third step, they should turn risks and opportunities into solutions and projects. This is the same thought process for choosing climate resilience measures from Appendix C in Step 4 of the ACRH process. Waiting until after all risks, constraints, and opportunities have been evaluated puts the Army planner in the best position to choose measures that will empower the installation to reach energy, water, and climate resilience goals.

With the nuisance weather, extreme weather, and future climate change scenarios documented and analyzed with water- and energy-specific goals in mind, developing an implementation plan is the next step for the Army planner. The ACRH has set the Army planner up to prioritize solutions with climate resilience at the forefront of the process, which is paramount when considering operations into the future and risk factors. The ACRH process also adds climate resilience measures to the cost-prioritization process, which broads the range of funding options to include:

- Real Property Maintenance (QRPA) – the principle funding source for real property maintenance, which supports new work/minor construction and repair or replacement projects.
- Army Energy and Utility (QUTM) – a funding source for utility upgrades and energy and water efficiency projects.
- MILCON – a military-construction funding strategy under which installations should use new construction design as a tool to influence energy, water, and installation resilience, provided that a plan to influence design standards has been drafted.

- Energy Resilience and Conservation Investment Program (ERCIP) – an Office of the Secretary of Defense (OSD)-managed MILCON appropriation for projects that improve energy resilience, increase energy efficiency, conserve water, and build renewable energy on military installations.
- Energy savings performance contract – an alternative procurement method that uses private sector expertise and capital for energy and water improvements. Contract costs are paid from verified savings resulting from contractor's actions over contract terms of up to 25 years.
- Utility energy service contract – an agreement negotiated directly with utilities or contractors competitively selected by the utility for financing the installation of improved E&W efficiency or demand reduction measures. Contract costs should be paid over time from the resulting savings or as a lump sum from available funds.
- Demand-side management programs – utility-sponsored programs that increase energy efficiency and water conservation, or the management of demand. They include load management techniques.

INRMP: The ACRH Step 4 aligns with the fourth step of the INRMP climate preparedness and resilience planning process, developing strategies and actions to reduce climate risks. This fourth step requires the planner to identify potential climate preparedness and resilience strategies and actions, evaluate the effectiveness/feasibility of possible strategies, and select priority risk reduction measures.

Strategies refers to the goals the Army planner laid out in Step 1 of the ACRH, such as reducing fire risk, reducing flood risk, and increasing energy efficiency across the installation. Actions are the climate resilience measures the planner chooses during Step 4, such as prescribed burning, elevating structures, or using landscaping to shade buildings. The ACRH Step 4 suggests the Army planner think creatively about risk reduction strategies; the fourth step of the INRMP process also encourages planners to think outside the box.

During INRMP's fourth step, the planner will use the climate resilience knowledge gained to understand the effectiveness and feasibility of strategies. Each installation will have to develop their own set of criteria for evaluating climate resilience goals, objectives, and resilience measures because each installation has different missions, priorities, and natural resource exposure to climate hazards. Once climate risk reduction strategies have been prioritized, the INRMP process will move into the project planning and funding acquisition stage.

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3. Conclusions and Next Steps

Climate change will continue to be a national security issue, with Army planners continuously needing to adapt their planning practices to this evolving threat. The ACRH is meant to serve as a guide and should not be considered rigid. Each installation is facing different climate resilience goals related to its specific mission area(s), geographic location, and size.

By completing Steps 1 to 4, at-risk areas for the installation's missions, infrastructure, and other aspects of the installation like threatened and endangered species habitat should be visually apparent on the maps and in the tables created. The level of constraints to reducing risks will be highlighted across the installation profile map. Opportunities for reducing risk will also be highlighted on the map. Step 4 is included in the ACRH as a resource to consider climate preparedness and resilience measures beyond what is normally considered on Army installations. In many cases, paring down resilience measures will require reviewing the overall RPMP and costs analyses.

The ACRH follows the best available actionable science. Upon completion of the four steps in the ACRH, Army planners will need to seek out further guidance specific to the individual installation's needs. Better information may be available in the future that enables more quantitative analysis of climate hazards at finer spatial and temporal scales—for example, when the next National Climate Assessment is released or when DoD updates its recommended sea level rise scenarios.

The information provided by the ACAT and the planning process outlined in this handbook is meant to provide a screening level assessment of climate vulnerability: at the scale of installation, it results in the identification of assets at risk, the factors that contribute to their vulnerability, and the information needed to reach a 10% design solution. The information is sufficient to address long-term planning decisions. In many cases, further implementation of a solution will require additional quantitative data on risk magnitudes, more accurate spatial information on projected hazard locations, and an improved timeline for monitoring performance of the built environment under changing conditions. The process outlined in this handbook is an essential first step in understanding whether such detailed assessments will be needed for a given planning decision.

USACE has developed guidance and webtools for considering climate change hazards to engineering decision-making[5]. While this guidance does not apply to military installations, it can provide examples of what the next steps might look like if the ACRH process indicates that an installation has substantial vulnerabilities. Other Federal agencies may also provide information that can serve as models for more in-depth planning in specific areas, including the U.S. Forest Service for forest management and wildfire information; the Natural Resources Conservation Service for avoiding and mitigating land degradation; the Federal Emergency Management Agency (FEMA) for disaster preparedness planning and recovery; and the National Park Service for assessing and mitigating hazards to cultural resources. Regional climate hubs within the US Department of Agriculture (USDA) and state agencies may provide important information and resources on land planning for climate resilience. Further information regarding climate change, climate change hazards affecting the DoD, and tools to aid in resilience planning are provided in Section 1.7 above.

The impacts of climate change on installations is uncertain and Army planners must think beyond their current weather or climate risk reduction measures to combat the threats of future climate change. The ACRH will aid Army planners in efficiently creating climate resilient installations now and in the future.

[5] https://www.usace.army.mil/corpsclimate/

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APPENDIX A: HAZARD AND INDICATOR DESCRIPTIONS

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A.1. Scenarios and Epochs

This tool divides the analysis into two scenarios (higher, lower) and three epochs (historical, 2050, and 2085), and enables comparisons among them.

The scenarios represent higher and lower amounts of temperature change and are tied to the representative concentration pathway (RCP) 4.5 and RCP8.5 used in the Fourth National Climate Assessment (USGCRP 2017). Changes in temperature lead to changes in how much precipitation falls, where it occurs, how fast land and sea ice melt, and therefore how much the seas rise (Table A.1). This tool uses a lower and a higher scenario of sea level (Hall et al. 2016).

The RCP scenarios are modeled futures that start by projecting changes in radiative forcing (heating, in units of Watts per meter squared (Wm^{-2})) in the upper atmosphere caused by the addition of greenhouse gases. The size of the number indicates the change in forcing by 2100: +4.5 and + 8.5 Wm^{-2}:

- RCP8.5 scenario represents a future where carbon dioxide and methane emissions continue to rise as a result of fossil fuel use, although the rate of this growth slows over the second half of the century, and is accompanied by a significant reduction in aerosols, and modest improvements in energy intensity and technology (Hayhoe et al. 2017). Atmospheric carbon dioxide levels rise from the current 400 parts per million (ppm) up to 936 ppm by the end of this century and contributing to a projected average global temperature increase of 5.4°–9.9°F (3°–5.5°C) by 2100 relative to the 1986–2005 average (Hayhoe et al. 2017). RCP8.5 represents the upper range of emissions based on the open literature but may not represent an actual upper limit on possible emissions. In this tool, the RCP8.5 scenario is considered the higher rate of change scenario.
- RCP4.5 scenario represents a future in which carbon dioxide and methane emissions rise at a slower rate, reaching only 528 ppm by 2100 and result in a projected average global temperature increase of 2° to 4.7°F (1.1° to 2.6°C) (Hayhoe et al. 2017). In the RCP4.5 scenario, radiative forcing stabilizes at 4.5 W/m^2 before 2100 on the assumption that a range of technologies and strategies are deployed that reducing greenhouse gas emissions. In this tool, the RCP4.5 scenario is considered the lower rate of change scenario.

Three epochs are used in the tool:

- The historical epoch is the period from 1950 to 2004 inclusive that was used to calibrate climate models. For the non-climate variables, a subset of this period may form the historical baseline based on the available data. There are no scenarios for the historical period, as this represents the existing condition to date.
- The 2050 epoch represents the 30-year climate interval 2035 to 2064. It represents the “near term” future. The tool divides the data for the 2050 epoch into “higher” and “lower” change scenarios as described above. In many instances, there is not much model diversity in projections to mid-century, so the 2050 “higher” and “lower” results may be similar.

- The 2085 epoch represents the 30-year climate interval 2070 to 2099. It represents the “far term” future. The tool divides the data for the 2085 epoch into “higher” and “lower” change scenarios as described above. In many instances, there is noticeable divergence in the results for the two scenarios, so the 2085 “higher” and “lower” results may be dissimilar.

Table A.1: Scenario inputs

Scenario Inputs	Lower Scenario	Higher Scenario
Temperature means/extremes	RCP4.5 ensemble mean	RCP8.5 ensemble mean
Precipitation means/extremes	RCP4.5 ensemble mean	RCP8.5 ensemble mean
Coastal Flood Extent	DoD Coastal Assessment Regional Scenario Working Group (CARSWG) DoD Regional Sea Level (DRSL) Global Lowest (0.2 m rise) Scenario	CARSWG DRSL Global Highest (2.0 m rise) Scenario
Riverine Flood Extent	1% AEP flood + 2 ft.	1% AEP flood + 3 ft.
Population[1]	EPA Integrated Climate and Land-Use Scenarios (ICLUS) SSP2	EPA ICLUS SSP5
Development/land use[2]	USGS FOREcasting SCEnarios of Land Use (FORE-SCE) B1 Scenario	USGS FORE-SCE A2 scenario

[1] For Alaska and Hawaii, projected population data were not available, so the values for the 2010 U.S. Census were used for all scenarios.

[2] For Alaska and Hawaii, projected land use data were not available, so current land use data from the Multi-Resolution Land Characteristics Consortium (www.mlrc.gov) National Land Cover Database (NLCD) was used for all scenarios.

A.2. WOWA Score Calculation

A weighted order weighted average (WOWA) is a multicriteria evaluation technique (Torra 1998) that makes it possible to use many different types of information in the creation of a single exposure index or score. The score takes into account both the contribution of individual indicators to the estimate of exposure and the risk preference of the decision-maker.

For a given hazard, each indicator is first assigned a weight that reflects an importance score, which is the best scientific estimate of the relative contribution each metric makes to the estimate of exposure (Figure A.1). For example, although vegetation adjacent to a building contributes to its exposure to wildfire, actual risk is very low if weather conditions are wet. Consequently, with respect to wildfire risk, the fire risk day indicator is given a larger contribution weight than the vegetation indicator in calculating exposure to wildfire. Importance weights are determined by subject matter experts and are a fixed value.

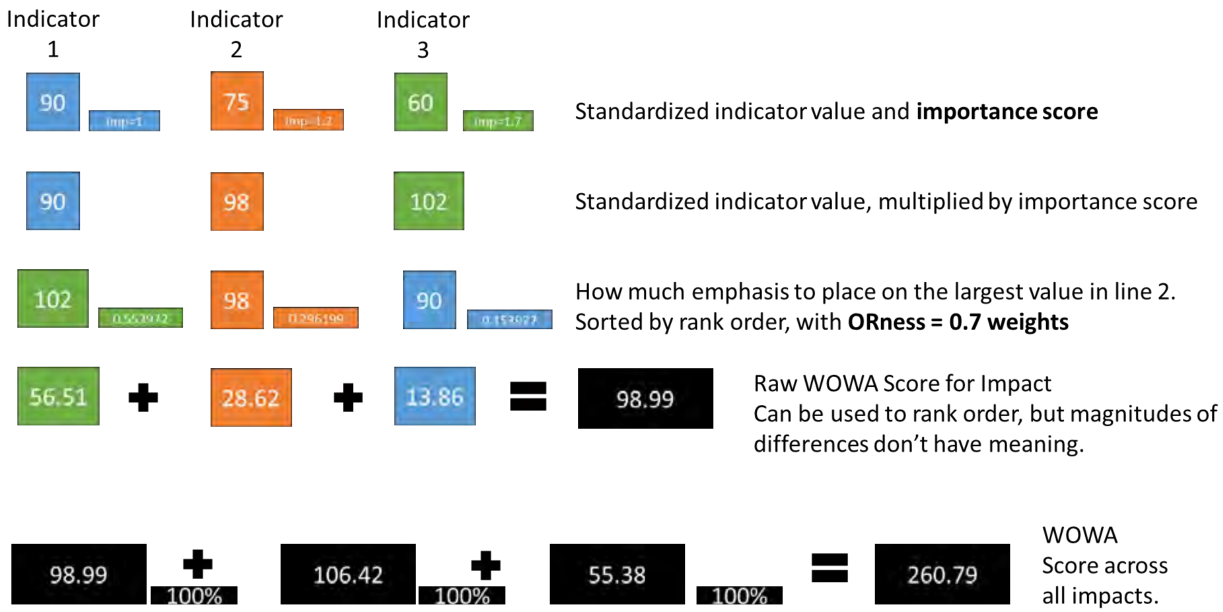


Figure A.1: Graphical representation of WOWA score calculation

Decision-maker risk preference is captured by ORness, a second weighting scheme that is applied to the importance-weighted metric values. ORness is a measure of the relative importance of large and small importance-weighted metric values to the final assessment of exposure (Blue et al., 2017; Runfola et al. 2017). ORness captures whether the decision-maker is risk-averse (highest contribution-weighted metric value drives the final exposure value, ORness=1) or risk-tolerant (all contribution-weighted metrics are included equally in determining the exposure value, ORness = 0.5). An intermediate risk preference, in which importance scales with the contribution-weighted metric values, is represented by an ORness of 0.7. The decision-maker can accept the default ORness value (0.7) or accept a different value.

The final exposure (WOWA) score for a base is the sum of the normalized ORness and contribution-weighted metric values for a given base. Database-wide, for a given hazard, the bases with the largest WOWA scores are considered to have the greatest exposure. High exposure coupled with installation-specific data showing high sensitivity and low adaptive capacity would be the basis for identifying an installation as highly vulnerable to a given hazard.

An important metric for understanding exposure is the indicator contribution. The indicator contribution is simply the fraction of an indicator's WOWA score relative to total WOWA score for a hazard at a given installation (Figure A.2). The contribution of a hazard is calculated similarly, where the denominator is the sum of the WOWA scores for the hazards at an installation, and the numerators are the individual hazard WOWA scores.

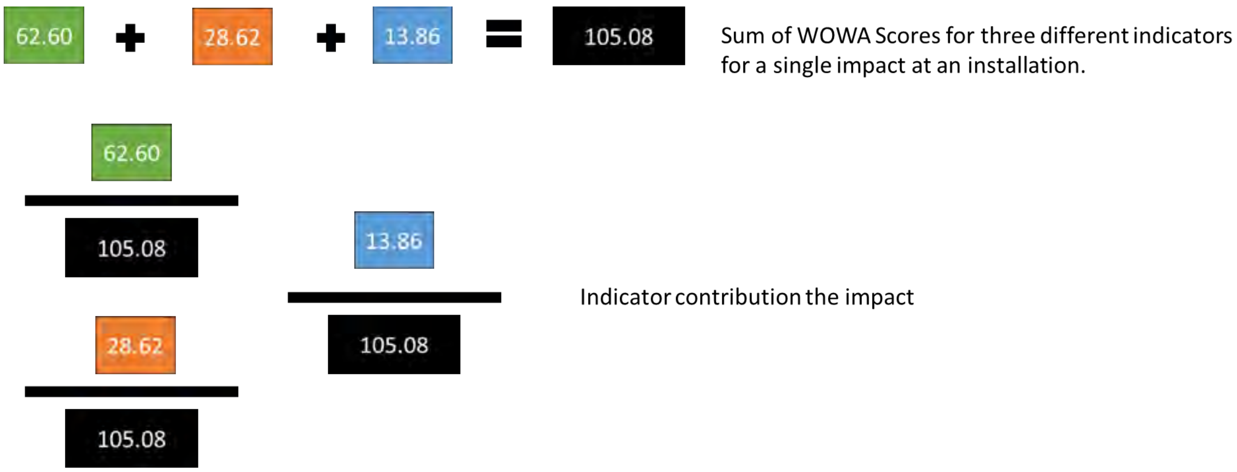
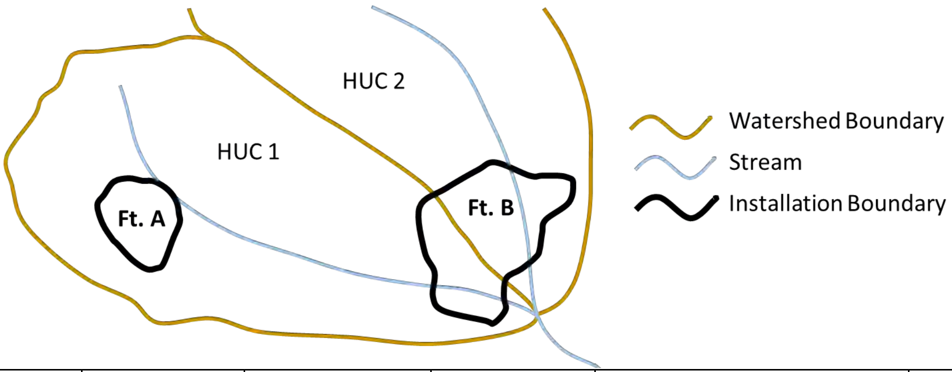


Figure A.2: Indicator contribution to an impact

A.3. Method for Assigning Watershed Values to Installations

Installations range in size from one or a few buildings to large training lands and bombing ranges. Because the resolution for most of the indicators used in this tool is far coarser than the footprint of smaller installations, a systematic way of assigning the indicator values to installations was needed. Unless otherwise indicated, indicator values were calculated as average values for USGS Hydrologic Unit Code (HUC) 8 watersheds, which are a reasonably good proxy for local conditions. The watersheds are large enough that spatial averaging can be used to reduce some of the data noise and yet provide a reasonably local climate signal.

As an example of how values were assigned, consider Forts A and B in the stylized graphic in Figure A.3. Fort A is located in watershed HUC 1, while Fort B is larger, and its boundary extends across portions of HUCs 1 and 2. The table underneath shows the proportion of the installation in each watershed (zero values are omitted). The table also shows the values for the high heat days indicator for each watershed. Since Ft. A is 100% in HUC1, it is assigned the indicator value for HUC1. The indicator value for Ft. B is the spatial average value across both HUCs.



Installation	HUC	HUC Area %	Indicator Value for HUC	Calculation	Indicator Value for Installation
Ft. A	1	100	24	1.0 x 24	24
Ft. B	1 2	40 60	25 26	(.4 * 25) + (.6*26)	25.6

Figure A.3: Method for assigning watershed indicator values to installations

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A.4. Climate Change Hazards and Indicators

The following sections provide an overview of the eight hazard categories used in the ACAT tool to evaluate installation exposure to climate change. For each hazard category, a summary of the observed and projected changes is provided, along with a description of how these changes are anticipated to affect military installations. This is followed by a description of each of the indicators used in the tool to assess exposure to that hazard.

Summary Table

Table A.2: Summary Table of indicators by hazard; with indicator number, name; units and National Standard View hazard weight

Indicator Number	Indicator Name	Units	Hazard Weight
Drought Hazard			
101	Flash Drought Frequency	Frequency (Occurrence/ year)	1.4
102	Drought Year Frequency	Percentage	1.2
105	Aridity	Unitless	1.5
106	Consecutive Dry Days	Days/year	1
108C	Mean Annual Runoff	Cubic feet per second (cfs)	1.5
Coastal Flooding Hazard			
201	Coastal Flood Extent	Percent of area	1.5
202	Coastal Erosion	Probability	1
Riverine Flooding Hazard			
301	Riverine Flood Extent	Percent of area	1.5
302C	Flood Magnification Factor	Unitless ratio	1.3
303	Maximum 1-Day Precipitation	Inches	1
304	Maximum 5-Day Precipitation	Inches	1
305	Extreme Precipitation Days	Days/year	1.4
Heat Hazard			
401	Days Above 95F	Days/year	1.1
402	5-Day Maximum Temperature	Degrees Fahrenheit	1.2
403	High Heat Days	Days/year	1.3
404	Frost Days	Days/year	1
405	High Heat Index Days	Days/year	1.7

Indicator Number	Indicator Name	Units	Hazard Weight
Energy Demand Hazard			
501	Heating Degree Days	Degree days	1.2
502	Cooling Degree Days	Degree days	1.7
503	5-Day Minimum Temperature	Degrees Fahrenheit	1.5
402	5-Day Maximum Temperature	Degrees Fahrenheit	1
Wildfire Hazard			
601	Fuel Abundance	Percent area	1.3
602	Ignition Rate	People/sq. mile	1.1
604	Fire Season Length	Days/year	1.7
101	Flash Drought Frequency	Frequency (Occurrence/ year)	1.5
604	Fire Season Length	Days/year	1.5
105	Aridity	Unitless	1.4
Land Degradation Hazard			
701	Soil Loss	Tons/acre/year	1.7
202	Coastal Erosion	Probability	1.2
702	Permafrost Hazard	Percent of area	1
Historical Extreme Conditions			
801	Tornado Frequency	Probability	1.4
802	Hurricane Frequency	Probability	1.7
803	Ice Storm Occurrence	Occurrence (presence, absence)	1.2
804	Historical Drought Frequency	Percent of weeks	1.1
805	Wildland Urban Interface	Percent of area	1.3
806	Hurricane Wind > 50 knots	Count/year	1.4
807	Hurricane Maximum Average Precipitation	Inches	1.5
808	Ice Jam Occurrence	Occurrence (presence, absence)	1.2

A.4.1. Drought Hazard

Droughts are meteorological, hydrologic, social, and economic events that can occur in all climate zones with hazards that can vary regionally, including reduced water supplies for municipal, industrial, or agricultural purposes, navigation, loss of soil by wind erosion or subsidence, saltwater intrusion into freshwater aquifers, decreased water quality, increased wildfire risk, and other more varied economic losses.

Drought frequency, duration, and severity primarily depend on temperature, wind, and precipitation patterns. Drought intensity can be exacerbated by high evaporation rates due to excessive temperatures, high winds, lack of cloudiness and/or low humidity, decreased soil moisture, and falling groundwater tables.

Drought can negatively hazard U.S. military installations in various ways. For example, dry conditions from drought limit stream flow in rivers thereby reducing water supplies in systems with riverine intakes. Additionally, droughts cause drying in vegetation, which is an initiating factor in wildfires and desertification processes. Specific to military readiness, droughts related to heat are correlated with the number of black flag days for training and can contribute to heat-related illnesses outlined by the U.S. Army Public Health Center[6].

Energy consumption may increase to provide additional cooling at installations during drought. Army (DA 2013) also noted that drought may result in reduced land carrying capacity for vehicle maneuvers and limits on low-level rotary wing flight operations, potential reductions in live-fire training, and greater competition for limited water resources.

Observed and projected future changes in these patterns mean that the droughts experienced in the past may no longer be adequate to estimate droughts in the future. The observed drought data for the U.S. in the 20th century does not reveal a clear drought trend due to spatial and topographical diversity (USGCRP 2017) though some regions of the U.S. have experienced record intensity of droughts and associated heat waves (USGCRP 2017).

Not all droughts develop and intensify slowly over many months. Fast-developing droughts, termed “flash droughts”, are distinguished by their rapid intensification (<2 months) and large reductions in soil moisture (Mo and Lettenmaier 2016). A flash drought may be short-lived or may develop into a long-term drought. Flash droughts can result from either a precipitation deficit, a temperature-increase-driven rise in PET, or both (Otkin et al. 2018). Because of their sudden onset, flash droughts can have very large impacts on agricultural yields, ecosystem health, and wildland fire risk if they occur in the growing season. In addition, for water supply systems with small storage volumes relative to inflow, flash droughts can result in rapid development of critical water shortages.

[6] https://phc.amedd.army.mil/topics/discond/hipss/Pages/Heat-Related-Illness-Prevention.aspx

Figure A.4: Drought may result in reduced rainfall and increased evaporation, resulting in reductions in water available in an installation's water supply reservoir

A.4.1.1. Future Drought

Projected changes for the future show that the duration, intensity, and frequency of droughts may increase in many parts of the U.S. Even while droughts are in progress, increased duration, intensity, and frequency of intense precipitation in some regions of the U.S. suggest potential for flooding that may occur during droughts as has already been observed in several parts of the U.S., including the Memorial Day floods in central Texas in 2015 (Di Liberto 2015) and September 2013 flood in central Colorado (Howard, 2013).

Researchers working in the western U.S. have emphasized the important role that rising temperatures may play in future droughts because of the role temperatures plays in evapotranspiration rates (Breshears et al. 2005). The Palmer Drought Severity Index (PDSI) (Palmer 1965) has historically been used to estimate drought in a way that takes into account both precipitation deficit and temperature-driven evapotranspiration effects. However, PDSI does not work across multiple scales, limiting its use in comparing drought across regions and for differentiating between short and long-term droughts that differ in their impacts on hydrological, ecological and agricultural practices (Vicente-Serrano and NCAR Staff 2015).

A.4.1.2. Indicators of Drought Exposure

Because drought is a regional, not local, phenomenon, these indicators are calculated for the HUC8 watershed. The installation value is the value for the watershed in which it is located, or if located across multiple HUC8 watersheds is the area-weighted average value. The following indicators (Table A.3) are used to assess the difference in drought risk in the future compared to today (see Appendix B: ACAT Indicator Fact Sheets for more information on how these indicators were calculated):

Table A.3: Indicators of drought used to assess drought exposure

Indicator	Importance Weight	Justification
ARIDITY (#105): Aridity is a change in the nature of an installation's climate towards increasingly drier conditions. Increases in aridity indicate essentially permanent reductions in water supply. It also indicates significant reductions in soil moisture and therefore changes in vegetation type and density, and wildfire risk. Importantly, changes in aridity are not strongly correlated with changes in any of the other drought variables.	1.5	This indicator is assigned a large weight because it is correlated with a permanent change in water availability at an installation.
MEAN ANNUAL RUNOFF (#108C): Mean Annual Runoff is the average annual discharge (volume of water) from the entire watershed upstream of an installation for the largest river in this watershed. Changes in this value are symptomatic of increases or reductions in annual surface water supply. Changes in water supply for large rivers may be independent of drought status at an installation.	1.5	This indicator is assigned the same weight as Aridity since climate change in the hydrologic source area may differ from that at the installation.
FLASH DROUGHT FREQUENCY (#101): This is related to the change in frequency of droughts that intensify quickly (< 2 months). Because of their sudden onset, flash droughts can have very large impacts on agricultural yields, ecosystem health, and wildland fire risk if they occur in the growing season. In addition, for water supply systems with small storage volumes relative to inflow, flash droughts can result in rapid development of critical water shortages. Increasing flash drought frequency increases risks.	1.4	This indicator is assigned a large weight because it represents an abrupt shift from wet to dry climate that carries with it an acute increase in wildfire risk.
DROUGHT YEAR FREQUENCY (#102): Drought Year Frequency is the average percentage of years in which a location is in moderate or more extreme drought. It is a reflection of year-to-year variability in drought status. This represents a longer-term threat to water supplies, ecosystem health and wildland fire risk and more sustained risk to installation mission and readiness.	1.2	This indicator is assigned a lower weight because longer term drought is often more predictable than flash drought, and because drought during the growing season results in less vegetative growth and, therefore, less wildfire risk compared to flash droughts.
CONSECUTIVE DRY DAYS (#106): Consecutive Dry Days is the mean annual maximum number of consecutive days with less than 0.01" (trace) of precipitation. It is an indicator of short-term variability in precipitation.	1	Changes in this indicator reflect increasing daily variability in precipitation that may result in minor disruptions to installation activities. This indicator is assigned the smallest weight.

A.4.2. Coastal Flooding Hazard

Coastal flooding results when ocean water inundates land that is not typically inundated during the annual tidal cycle. Flooding most commonly occurs in response to storm events when onshore winds push seawater up against the coast (storm surge), so that the water surface is elevated and salt water is pushed inland.

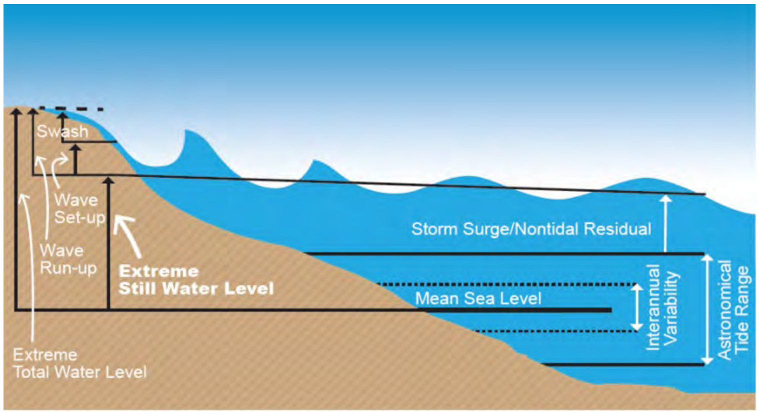

Figure A.5: Schematic of major components of coastal water levels

Coastal flooding is exacerbated by sea level rise, which is a significant problem for coastal regions across the world. Sea level rise is a direct result of climate change, as the ocean absorbs 90% of the increase in heat due to climate change. This added heat has increased sea surface temperatures that, in turn, has led to the thermal expansion of water: warmer water occupies a greater volume than colder water, leading to increases in sea surface elevation.

Increased air temperatures accelerate the melt of global land ice resulting in greater water volumes in the world's oceans. The rate of warming is greatest in polar regions (especially the Arctic). Land ice in polar regions (Greenland and Antarctica) has the potential to contribute many meters of water to the world's interconnected oceans. Mountain glaciers are also declining in size, but the total volume of water is significantly less.

Global mean sea levels have risen 7-8 inches since 1900, with about 3 inches since 1993 (Sweet et al. 2017). The rate of sea level rise now is greater than during any preceding century in at least 2800 years (Sweet et al. 2017).

Sea level change is not uniform globally (Sweet et al. 2017; Kopp et al 2015). Local topography, coastal bathymetry, the proximity and speed of ocean currents, and changes in sea water salinity (density) all influence local sea surface elevations. Also, the land surface itself may be rising or falling: for example, northern portions of the U.S. are still rebounding from the pressure exerted by ice sheets during the last Ice Age while the Mississippi Delta is gradually sinking under the weight of its sediment. Relative sea level (RSL) change is the sum of these and other influences on the local sea surface elevation in the vicinity of an installation.

Figure A.6: Coastal inundation extent for a typical coastal installation

RSL rise is potentially a significant problem for coastal installations and adjacent communities:

- It increases the frequency and inundation extent of flooding due to seasonal or daily high tides. In recent decades, tidally-influenced chronic flooding has become more frequent on all three U.S. coasts (Sweet et al. 2014).
- It magnifies the elevation of storm surges, increasing the extent of storm surge flooding and wave damage.
- It contributes to an increase in the rate of coastal erosion generally and specifically during storm events.
- It increases the hydrologic base level for rivers where they meet the ocean, exacerbating riverine flooding by increasing flood heights and amplifying flood heights during coincident events.
- In many regions, higher sea levels increase the exposure of coastal aquifers to salt water intrusion, a problem that becomes more acute if these aquifers are overdrawn.
- It may contribute to the flooding of port facilities and require additional elevation and maintenance of these facilities.

While RSL fall poses fewer hazards, it may:

- Cause rivers to incise their channels to match the sea level elevation at their mouth.
- Leave port facilities above the water line or out of the water altogether and decrease the depth of navigation channels.
- Cause declines in water table height and therefore affect coastal water supplies.

Additional projected effects of sea level rise include (Center for Climate and Security 2016):

- Loss or damage to mission essential infrastructure including coastal development, and energy and water infrastructure, and render portions of an installation inoperable for significant periods of time.
- Loss or degradation of mission capabilities.
- Loss of training and testing lands, including beaches and barrier islands.
- Loss of transportation means, facilities, and/or corridors.
- Loss of habitat and associated natural resources, including those that provide ecosystem services and natural barriers to disasters to the base and surrounding area.
- Increased potential for loss of life during extreme events.
- Increased potential for salt water intrusion resulting in aquifer salinization.

A.4.2.1. Indicators of Coastal Flood Exposure

Two indicators of coastal flood inundation exposure in ACAT are shown in Table A.4. See Appendix B: ACAT Indicator Fact Sheets for more information on how these indicators were calculated:

Table A.4: Indicators used to represent coastal flood exposure

Indicator	Importance Weight	Justification
COASTAL FLOOD EXTENT (#201): Coastal Flood Extent is the area of inundation given the 1% annual exceedance probability (AEP) coastal flood height. This reflects inundation during extreme events. The projected change in relative sea level data comes from the DoD's CARSWG DRSL database lowest and highest sea level scenarios. A simple bathtub model was used to translate these elevation changes into areas of inundation using a digital elevation model (DEM, topographic map). It can be correlated to the amount of potential damage resulting strictly from sea level rise.	1.5	This indicator is weighted highest. Changes in this indicator reflect changes in area inundated, which corresponds to areas where damages may be high and adaptation measures costly.
COASTAL EROSION (#202): Coastal Erosion is an indicator of the susceptibility of an undeveloped coastline to erosion due to changing sea level and wave action. Coastal Erosion is the probability of erosion based on data from the USGS Coastal Vulnerability Index database. THIS INDICATOR IS STATIC (does not change with time).	1	This indicator is weighted lowest. Coastal erosion is a significant problem in some areas, but the affects may be reduced or eliminated through structural and nonstructural measures.

Figure A.7: Example of CVI erosion probability values at an installation

A.4.3. Riverine Flooding Hazard

Increases in precipitation, especially increases in the magnitude and/or frequency of extreme precipitation events, are projected in most portions of the U.S. under a warming climate. Two important changes occur as temperatures increase: evaporation rates increase, which means more water is available for the atmosphere to hold and soil moisture is reduced (exacerbating drought); and the atmosphere itself can hold more water (6-7% more per degree Celsius (1.8°F)) before the air becomes saturated and precipitation commences, which results in higher moisture content particularly for air masses that originate over the ocean.

Temperature increases in the winter half of the year (October through April) that are likely in many regions of the country affect how much precipitation falls as snow (and runs off in the spring and summer) and how much falls as rain (and runs off in the winter months, when many reservoirs are unable to store this volume due later-in-the-season flood risk concerns) (Easterling et al. 2017).

These changes are already occurring, particularly at high latitudes (Figures A.8 and A.9). End of season snow water equivalent (SWE, the amount of water actually in a watershed's snowpack in the spring) has declined since 1980 in the western U.S. due to spring warming (Pederson et al. 2013).

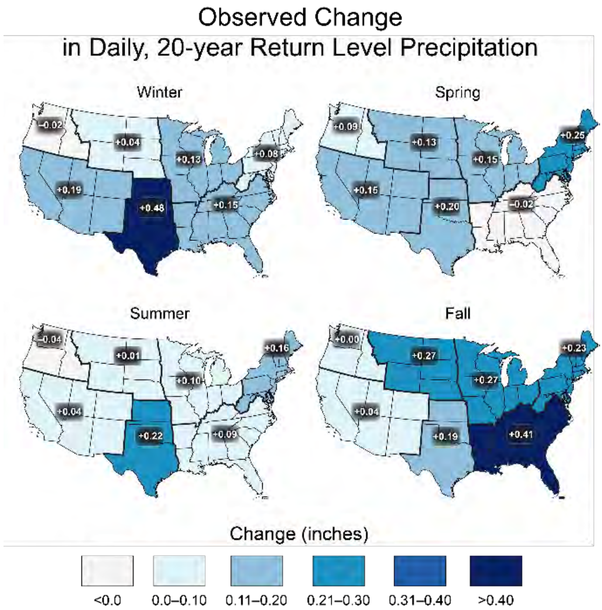

Figure A.8: Observed changes in precipitation for the 1 day, 20-year return interval storm for CONUS between 1948 and 2015. (Easterling et al. 2017: Fig 7.2)

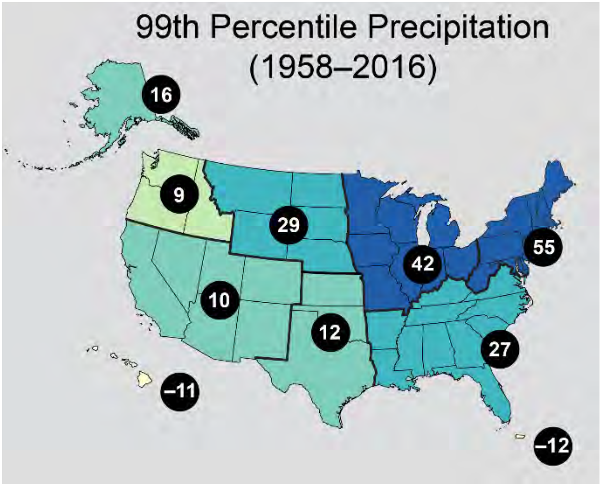

Figure A.9: Observed percent change in the amount of precipitation falling in extreme precipitation events (Easterling et al. 2017: Fig 7.4)

Figure A.10: Flooding, Norfolk, Virginia (photo courtesy U.S. Navy)

The most important consequence of excess precipitation is flooding. Flooding can occur when rivers overflow their banks or when precipitation is so heavy that the existing drainage / flood runoff system is overwhelmed (also called urban flooding). Flooding may be a slow-moving disaster, such as the gradual downstream movement of spring runoff flood peak, or very rapid, as when extreme quantities of precipitation falling in one area over a relatively short amount of time produces a flash flood.

Extreme events in relatively small areas can still cause significant damages: a storm at an installation in the desert Southwest in August 2013 caused $64 million in damages to more than 160 facilities, 8 roads, a bridge and 11,000 linear feet of fencing and also damaged an adjacent training area (GAO 2014). Compound flood events, such as a stalled tropical storm dumping rain on previously saturated ground, can produce floods in areas that have not previously flooded.

Flood risk management system maintenance costs may increase, and system upgrades to handle the additional flood waters may be necessary (Wehner et al. 2017). Deployment of National Guard and Reserve units and other DoD personnel for flood fighting and flood relief missions (Mullick 2018) may increase in frequency and mission duration in the future, affecting the timing of, and manpower and resources available for, other military activities. Standing floodwaters may increase the available habitat for mosquitos, thereby facilitating the spread of disease, and may spread toxic waste and sewerage (e.g., Hayden et al. 2013).

A.4.3.1. Indicators of Riverine Flood Exposure

The indicators used to represent flood are shown in Table A.5. See Appendix B: ACAT Indicator Fact Sheets for more information on how these indicators were calculated.

Table A.5: Indicators used to represent riverine flood risk exposure

Indicator	Importance Weight	Justification
FLOOD EXTENT (RIVERINE) (#301): The current flood extent for the installation boundary is based on Federal Emergency Management Agency (FEMA) National Flood Hazard Layer for the 1% annual exceedance probability (AEP) event, or 2-D hydrologic and hydraulic modeling on a 10 m. digital elevation model where FEMA data are lacking. Projected changes in flood extent were modeled by adding 2 ft (for 2050) and 3ft (for 2085) freeboard to the current elevation of the 1% AEP event, and mapping the area of inundation that would result. This indicator is a measure of the potential extent of damage due to inundation during a flood event.	1.5	This indicator is given the highest weight because percent of area in a floodplain is considered the strongest indicator of current and future flood risk. This indicator is an indicator of regional flood risk that integrates both direction precipitation and flooding during snowmelt runoff.
EXTREME PRECIPITATION DAYS (#305): This refers to the average annual number of days in which precipitation in the future is projected to exceed the amount that occurred 1% of the days in the historic period. This provides an indication of future increases in precipitation intensity that is relative to current conditions: the definition of an extreme precipitation day will be different in different areas of the U.S. This can be used to assess how frequently heavy precipitation events may disrupt on- and off-base activities, and potentially overwhelm existing flood risk management infrastructure. Larger numbers indicate increased exposure.	1.4	This indicator is given the next highest weigh because it reflects a dual threat. Extreme precipitation events carry two different implications for flood hazard: it can influence flood risk at the watershed scale, but also pose an immediate flash flood risk for an installation.

Indicator	Importance Weight	Justification
FLOOD MAGNIFICATION FACTOR (#302): Flood magnification factor is the percent change in flood runoff (daily flow exceeded 10% of the time) in the future compared to the historic period. Values greater than 1 indicate an increase in flood flows in the future while values less than 1 indicate a decrease. Flood factor is calculated for the watershed upstream of the downstream-most point on the installation. Larger numbers indicate increased exposure.	1.3	This indicator is an important descriptor of how much larger the largest riverine floods may be in the future relative to today. It has important implications for flood risk management. It is rated slightly less in importance than Flood Extent (Riverine) and Extreme Precipitation Days because the information carried in this indicator partially duplicates the information of those two indicators.
MAXIMUM 1-DAY PRECIPITATION (#303): This is the average annual maximum 1-day precipitation total for each epoch-scenario. The intensity of the 1-day event is a particularly good metric for estimating changes in flash and urban flooding exposure. Larger numbers indicate increased exposure.	1	Because this indicator is highly correlated with Maximum 5-Day Precipitation, the weights of both were adjusted down so that local precipitation does not contribute excessively to flood risk compared to other indicators.
MAXIMUM 5-DAY PRECIPITATION (#304): This is the average annual maximum precipitation total for any 5-day period. Unlike 1-day precipitation, this indicator takes into account the effect of saturated soils on exacerbating flood risk by increasing the share of precipitation that runs off once the soil is saturated. Larger numbers indicate increased exposure.	1	Because this indicator is highly correlated with Maximum 1-Day Precipitation, the weights of both were adjusted down so that local precipitation does not contribute excessively to flood risk compared to other indicators.

Figure A.11: Example of flood extent mapping, showing the area of an installation impacted by the 1% and 0.2% AEP

A.4.4. Heat Hazard

Rising temperatures pose a direct and measurable risk to human health. Small increases in average temperature can result in significant increases in the frequency of temperature extremes, as well as contribute to increases in precipitation intensity and quantity, reductions in winter snowpack, increases in global mean sea level, increases in evapotranspiration, and changes to other processes. Average temperatures at the earth's surface in the contiguous U.S. have risen between 1.2°F and 1.8°F since 1900 (Vose et al. 2017). Although this seems like a small amount, it represents a significant increase in the amount of heat energy driving the earth's climate system, resulting in a variety of important and ongoing changes to drought, wildfire, precipitation location and amount, snowpack volume, wind strength, and through melting of land ice, sea level rise.

The rate of warming varies by geography, with higher rates of warming in Alaska, the Northwest, the Southwest, and the Northern Great Plains. Warming has been least in the Southeast. Rates of warming have varied by season, with greater warming in winter than in summer. The rate of warming in the last decade appears to be accelerating, with the most recent average rate of 0.512°F per decade based on satellite observations. The National Oceanic and Atmospheric Administration estimates 2019 is the second-warmest year on record after 2016[7].

Humans regulate body temperature (thermoregulation) under warm conditions through the evaporation of sweat. Warm temperatures below body temperature and low humidity levels are optimal for thermoregulation. Increases in heat and humidity make thermoregulation more difficult, especially under conditions typical of military activity, including wearing heavy clothing and carrying heavy packs.

Heat causes greater number of deaths from natural disasters in the U.S., exceeding the rate from tornados, floods, and hurricanes (NOAA 2019). A recent study shows that rising temperatures have already led to a dramatic increase in the annual rate of heat stroke or heat exhaustion among active-duty service members at U.S. military bases, from 1,766 in 2008 to 2,792 in 2018 (Barnes et al. 2019a; Hasemyer 2019, Figure 1). Across all the services globally, 11,452 service members were affected in 2014-2018; installations with the greatest number of heat-related illnesses and deaths are in the U.S. South and Southeast, where high temperatures coincide with humidity levels (Hasemyer 2019).

[7] https://www.wunderground.com/article/news/climate/news/2019-12-16-second-warmest-november-globally-2019-likely-second-warmest-year

Four Army installations accounted for more than one-third of all heat illnesses observed: Fort Benning, GA (n=1,504); Fort Bragg, NC (n=1,108); Fort Campbell, KY (n=694); and Fort Polk, LA (n=610) (Barnes et al. 2019b). MCB Camp Lejeune/Cherry Point, NC (n=738) also made the top five installations for heat-related illnesses in the U.S. (Barnes et al. 2019b). Although the rate of illness was greater in recruits, the rate of illness was similar among individuals regardless of where in the U.S. they came from (Barnes et al. 2019b). Less than 8% of the total cases occurred OCONUS, including Iraq and Afghanistan (Barnes et al. 2019b). The effects of increasing heat require increased attention in planning for operations, soldier training and preparation, and weapons employment (Hasemyer 2019).

Climate change is anticipated to increase heat-related health problems, with even small climate changes resulting in increases in illness and death (USGCRP 2016). Increases in temperature are anticipated to have significant effects on military training and testing, including an increase in the number of 'black flag' (suspended outdoor training) or fire hazard days (limiting activities like live-fire training); increase in the need for operational health surveillance, as well as higher rates of heat-related mortality and morbidity; and reassessment of weapons system operations and deployment (including changes to soldier readiness due to changes in the availability or timing of days when conditions are suitable).

Higher temperatures may also affect pilot readiness (DA/U.S. Air Force 2003). Acquisition and supply chains may also be affected (DoD 2014 Adaptation Roadmap). In addition, higher temperatures significantly increase the opportunity for vector-borne diseases: higher winter temperatures reduce winter vector mortality rates, while higher spring-fall temperatures extend the length of the breeding season allowing for multiple reproductive cycles (USGCRP 2016).

Consequently, warming temperatures have already allowed for the expansion of the geographic range and seasonal risk from vector-borne diseases (e.g., Lyme, spotted fever, anaplasmosis, and West Nile virus in the U.S.) in the U.S. (Beard et al. 2016). Climate change also has the potential to enable expansion of disease into the U.S. from adjoining regions as climate conditions become more favorable for the disease vectors (e.g., mosquitos, fleas, ticks) (Beard et al. 2016).

The DoD and DA use the Wet Bulb Globe Temperature (WBGT) to regulate outdoor activity during hot and humid weather. However, there are several input variables to the WBGT that can only be measured in the field, but not reliably derived from climate model outputs. Thus, in addition to metrics that reflect rising temperatures explicitly, this tool relies on the National Weather Service's Heat Index (NWS 2011) to capture the combined effect of temperature and humidity on outdoor activity.

The Heat Index captures the effects of heat humidity on human health under the assumption that the person is in the shade, and not being cooled due to wind and cloud cover (all variables WBGT can take into account). The following tables compare the two indices (https://www.weather.gov/ict/WBGT):

Table A.6: Comparison between WBGT and Heat Index values for sample weather conditions

Temperature °F	Dew Point Temperature °F	Relative Humidity %	Sky %	Wind mph	Heat Index °F	WBGT °F
90	65	42	05	03	92	89
90	65	42	05	13	92	83
90	65	42	65	13	92	81
90	70	52	10	06	96	88
90	70	52	60	06	96	86
90	70	52	60	13	96	85
100	70	39	10	13	108	90
100	70	39	10	5	108	94
100	70	39	65	05	108	91

Table A.7: Comparison between WBGT and Heat Index

	WBGT	Heat Index
Measured in the sun	X	
Measured in the shade		X
Uses Temperature	X	X
Uses Relative Humidity	X	X
Uses Wind	X	
Uses Cloud Cover	X	
Uses Sun Angle	X	

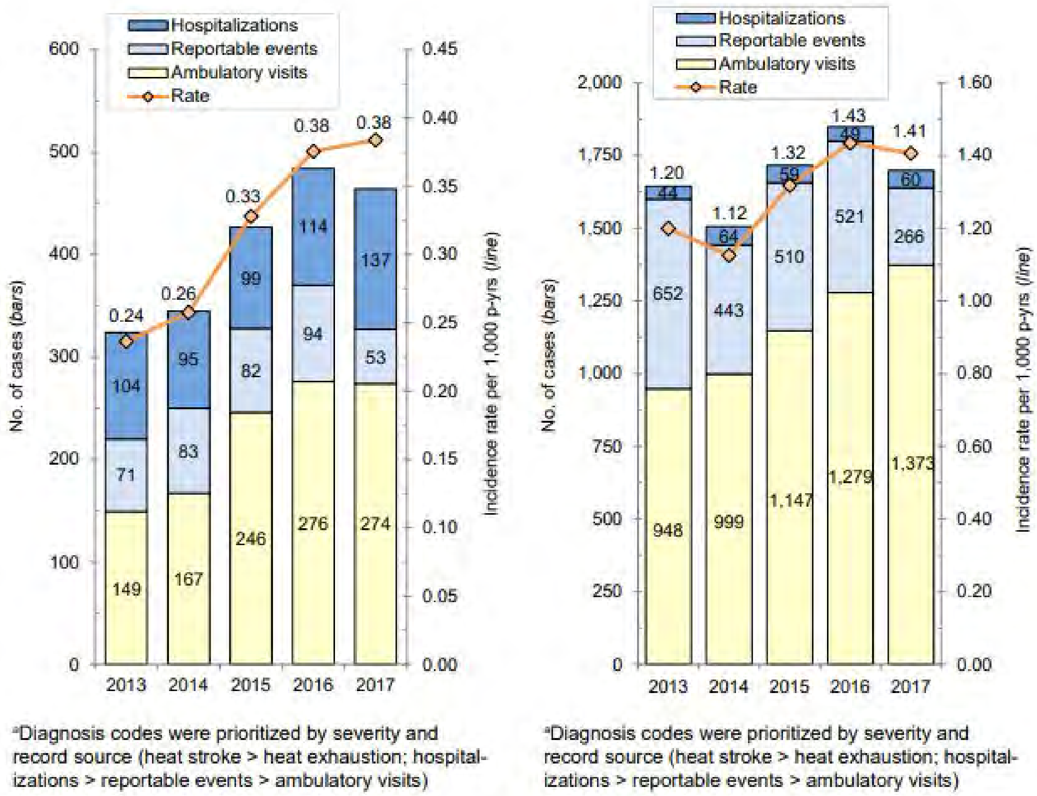

Figure A.12: Incident cases and incidence rates of heat stroke (left) and heat exhaustion (right), active component, U.S. Armed Forces (2013-2017) (https://apps.dtic.mil/sti/pdfs/AD1071315.pdf)

Infrastructure is significantly at risk from changes in both high and low temperatures (Muench and Van Dam 2015). High temperatures enhance chemical weathering of cement and other materials and may warm or fracture asphalt and pavement. Freezing temperatures, especially in the presence of water, induce mechanical damage through the freeze-thaw process.

In some regions, warmer winter temperatures may result in an increase in frequency of winter days above freezing and winter nights below, which could increase the frequency of freeze-thaw damage. This is important for installations because all of these changes have the potential to significantly increase the maintenance requirements for runways and roads to remain operable (DoD 2014).

Increasing temperatures directly or indirectly drive all the hazards in assessed in ACAT and discussed in the ACRH. Changes in mean and extreme temperatures play a significant direct role in shaping installation mission suitability by making it more difficult to affecting outdoor training activities and airfield operations. These same factors also impact installation sustainability through effects on building heating and cooling demands, damage to infrastructure, and stresses on natural resources.

In ACAT, the Heat Hazard area focuses narrowly on the effects of change on temperature extremes, with the broader consequences of these higher temperatures reflected in all the other hazard areas. Temperature extremes have a critical impact on human health in the context of outdoor activity. Rising temperatures affect human health by increasing the frequency and severity of heat waves, and other extreme events; by expanding the areas where vector and waterborne infectious diseases occur; impacting air and water quality; and increasing stresses to mental health and well-being (Vose et al. 2017; DoD 2014). Conversely, warmer winter temperatures may have an ameliorating effect on human health through reductions in exposure to cold.

A.4.4.1. Indicators of Heat Exposure

Indicators of Heat Exposure used in ACAT capture the changing rate of exposure to high temperature extremes with the potential to limit outdoor training and other readiness activities are shown in Table A.8. See Appendix B: ACAT Indicator Fact Sheets for more information on how these indicators were calculated.

Table A.8: Indicators used to represent heat exposure

Indicator	Importance Weight	Justification
HIGH HEAT INDEX DAYS (#405): High humidity levels lower evaporation rates. The National Weather Service Heat Index[8] accounts for the way that temperature and humidity interact to impair thermoregulation. Index values ≥ 90°F indicate a threshold where hazards are likely to impact outdoor training activities by limiting the amount of activity, shifting more of that activity to cooler parts of the day, and significantly increasing health risk.	1.7	This indicator is given the highest weight, because direct heat-related morbidity and mortality are significant concerns with direct if seasonal impacts on readiness; these are exacerbated by high humidity conditions, which is captured by the heat index.
HIGH HEAT DAYS (#403): This reflects the gain in heat compared to current high temperatures. It identifies the locally significant, historical high temperature threshold (the high temperature that is exceeded only 1% of the time at a given location) and assesses how frequently this threshold will be exceeded in the future.	1.3	This indicator is given the second largest weight because it addresses the magnitude of the most extreme temperatures, which can damage infrastructure and impede aircraft operations.
5-DAY MAXIMUM TEMPERATURE (#402): This indicates gain in maximum temperature. A 5-day window marks a significant impact on training and readiness schedules.	1.2	This indicator is given the third largest weight because of the potential impact on training schedules of a sustained high heat event.
DAYS ABOVE 95°F (#401): This is a count of the average number of days where the maximum temperature (daytime high) exceeds 95°F. This threshold is significant because it marks the point at which air temperature is approximately equal to body temperature, which makes it difficult for people to shed heat.	1.1	This compares extremes relative to a common threshold to facilitate comparison across regions. It is given a lower weight in part because there is information overlap between this indicator and others.
FROST DAYS (#404): A Frost Day is a day in which the minimum temperature gets below freezing (32°F), and therefore infrastructure may be subject to freeze-thaw cycles, and some forms of construction need to be suspended.	1	This is given the lowest weight because this risk is anticipated to decline with time as winter temperatures warm, so it contributes less to exposure over time.

[8] The DoD standard is the Wet Bulb Globe Temperature, but calculation of this index requires data that is not available from climate models.

A.4.5. Energy Demand Hazard

Rising temperatures are expected to affect both energy demand and supply. Warmer winter temperatures may reduce demand for heating, although cold extremes are anticipated to continue to occur, resulting in spikes in demand for energy for heating. Higher summer temperatures are anticipated to drive up energy demand for cooling residential, municipal, industrial, agricultural, and other buildings.

This rising demand is anticipated to strain the U.S. energy grid at the same time that transmission is reduced due to reductions in powerline and transformer capacities, higher surface water temperatures in waters used to cool power plants and nuclear reactors, reduced renewable and thermo electric energy generating capacity, and at least regional reductions in water available for power generation, including hydropower and biofuels (Zamuda et al. 2018).

Rising energy demand will also reduce summer air quality by increasing the release of pollutants and the formation of smog (Zamuda et al. 2018), with the potential for impacts on soldier health and ability to train outdoors. Indirect impacts on energy demand include storm damage to facilities, powerlines and transformers; riverine and coastal flooding impacts on power generation and transmission infrastructure, including improperly-sited backup and emergency power generation equipment; flood damage to energy waste (coal ash, nuclear waste) stored on-installation or upstream; and drought impacts on water available for cooling and power generation (Zamuda et al. 2018).

The DoD Roadmap (DoD 2014) identifies two areas of climate change concern related to energy: changing building heating and cooling demand, which impacts installation energy intensity and operation costs; and disruption to and competition for reliable energy supplies.

Higher temperatures will increase demand for energy resources, and therefore make blackouts and power supply disruptions more common (Zamuda et al. 2018). For installations obtaining energy from regional sources, higher temperatures are also projected to drive up electricity costs not only by increasing demand but also by reducing the efficiency of power generation and delivery (Zamuda et al. 2018). Energy expenditures for counties in the U.S. South and Southwest may increase by 10 to 20% by 2085 (Hsiang et al. 2017).

A significant amount of water is used in all phases of energy generation, including fossil fuel extraction, electricity generation, facility cooling and hydropower. While extraction water use may occur far away from electricity generation, generating facilities tend to be more regional or local. Consequently, the large quantities of water needed for energy generation will compete with domestic, municipal, other industrial and agricultural water uses (Lane et al. 2017). Reductions in water supply are of direct concern because this can lead to brownouts and blackouts.

Because energy risk is a regional problem, variables in this category are calculated at the watershed (HUC8) scale in ACAT, and the value for the installation represents the value of the watershed(s) in which the installation is located.

A.4.5.1. Indicators of Energy Demand and Performance Exposure

Because energy risk is a regional problem, variables in this category are calculated at the watershed (HUC8) scale in ACAT, and the value for the installation represents the value of the watershed(s) in which the installation is located. The indicators used to represent energy risk are shown in Table A.9. See Appendix B: ACAT Indicator Fact Sheets for more information on how these indicators were calculated.

Table A.9: Indicators used to indicate the changes in energy demand and performance exposure

Indicator	**Importance Weight**	**Justification**
COOLING DEGREE DAYS (#502): A Cooling Degree Day is the accumulated time above 65°F, the temperature above which buildings need to be cooled, as the sum of how many degrees above this threshold it gets each day. This indicator is a measure of the average sum of cooling degree days per year for each epoch-scenario. Higher numbers indicate increased exposure.	1.7	This has the largest weight because it represents the change in the total energy demand for cooling and therefore necessary added energy capacity.
5-DAY MAXIMUM TEMPERATURE (#504): This is a proxy (indirect) for peak summertime cooling energy demand. It is the average annual maximum temperature over 5 sequential days for each epoch-scenario. Larger numbers indicate increased exposure.	1.5	This gets the second largest weight because it represents critical peak energy demand during the highest heat events, and shortfalls in this area may result in brownouts/blackouts, and spikes in heat-related mortality and morbidity.
HEATING DEGREE DAYS (#501): A Heating Degree Day is the accumulated time below 65°F, the temperature below which buildings need to be heated, as the sum of how many degrees below this threshold it gets each day. This indicator is a measure of the average sum of heating degree days per year for each epoch-scenario. Higher numbers indicate increased exposure.	1.2	This has a lower weight because the aggregate demand for heating can likely be met with existing capacity in most areas in a warming world.
5-DAY MINIMUM TEMPERATURE (#503): This is a proxy (indirect) for peak wintertime heating energy demand. It is the average annual minimum temperature over 5 sequential days for each epoch-scenario. Larger numbers indicate increased exposure.	1	Cold spells and extreme cold are anticipated to continue to occur, but to occur less frequently and therefore this represents the lowest energy demand risk.

A.4.6. Wildfire Hazard

Wildfires are uncontrolled fires that originate on or cross onto undeveloped areas, regardless of cause (human or natural). Wildfires pose a significant and increasing threat to structures and communities intermingled with or immediately adjacent to vegetated areas (termed “wildlands”, which encompasses all undeveloped areas, including military ranges, grasslands, shrublands, barren lands, woodlands, and forests).

Over the 20th Century, aggressive fire suppression policies (Pyne 1982) have enabled forest tree densities to increase and understory canopies to thicken, greatly facilitating the development of larger, high-intensity wildfires across the U.S. Whereas wildfires in unoccupied regions (such as the boreal forests of Alaska, Canada and Siberia) can be allowed to burn until the snows fall, fire suppression efforts are at their maximum when homes, businesses, and lives are at stake (Todd and Jewkes 2006).

Development in and adjacent to forested areas has expanded rapidly since the 1990s (Martinuzzi et al. 2015), resulting in a sharp increase in wildfire size and damages, as well as an increase in human ignitions. Finally, in the Western U.S. where the topic has received the greatest attention, warming temperatures over the last thirty years have contributed to an increase in the number of large wildfires (>1,000 acres) from approximately 140 per year in the 1980s to approximately 250 per year in the period 2000-2012, and a greater than 2 month increase in the wildfire season (Union of Concerned Scientists 2013).

Figure A.13: Battling a wildfire on Fort Sill (https://www.army.mil/article/55355/wind_drought_feed_fires_on_fort_sill)

Wildfire may pose a significant risk to military bases (Beavers 2007), can impact the timing and type of training activities on a given base (Galbraith 2011), and can divert military resources to firefighting activities (e.g., Anonymous 2013). There are numerous examples of live-fire training igniting wildfires during dry conditions with both on- and off-base impacts (e.g., Panzino 2018; Galbraith 2011).

Finally, managing smoke from wildfires both on and off base is a significant concern (Mickler 2014). Exposure to smoke outdoors (or even indoors if building air is unfiltered) can cause or exacerbate existing health problems (asthma, bronchitis, cardiovascular problems). Land managers can reduce fire risk through actions that reduce vegetation density (thinning, prescribed fires, grazing, and managing low-intensity wildfires) in wetter parts of the year, limit ignitions (closing lands to human use, limiting live-fire and fireworks) under dry conditions favorable for wildfire, and creating non-vegetation fire buffer zones between structures and wildlands.

Wildfire has three key components: climatological conditions favorable for ignition and spread; the presence of wildland vegetation, especially dense and multi-canopied vegetation; and a natural or human source of ignition.

Wildland vegetation is a necessary pre-cursor to wildfire, but vegetation alone is insufficient if conditions are wet. Climatological conditions favorable for wildfire must also exist, and these include high temperatures, strong winds, unstable air, low precipitation, and low relative humidity (Baker 2009). These conditions are responsible for reducing fuel moisture (Abatzoglou and Williams 2016; Westerling 2016), facilitating both wildfire ignition and spread (Baker 2009).

In the context of fire planning, wildland vegetation are known as “fuels”. Fuels can be classified by time-lag fuel moisture class, which approximate the time it takes for the fuel to come close to equilibrium with atmospheric conditions. The flammability of fuels is directly related to the duration of hot, dry atmospheric conditions: the longer hot, dry conditions persist, the greater the share of the vegetation is dry enough to ignite and the easier it is for fire to spread.

Consequently, drought conditions carry significant fire risk (Littell et al. 2016). Of particular concern are alternating wet-dry conditions, in which wet years with abundant new growth (fine fuels) are followed by dry years where this new growth dries out (Baker 2009; Scasta et al. 2016). However, while short term drought is highly correlated with area burned, long-term droughts (> 4 months) are not (Riley et al. 2013).

Even if fuels are available and weather conditions are favorable, a source of ignition is necessary. The most common sources are lightning and human activity. Increasingly, humans have come to dominate the wildfire regime by altering land cover (Syphard et al. 2017), by causing the majority of ignitions (Balch et al. 2017; Nagy et al. 2018), and by fire suppression activities that allow understory canopy layers to increase, resulting in larger future fires.

Of particular concern has been the increase in development along the wildland-urban interface (WUI), that area in which development is occurring on parcels adjacent to or interspersed with, forests and grasslands (Radeloff et al. 2005; Martinuzzi et al. 2015). The WUI simultaneously increases ignitions (by bringing human activities to the forest) and increases the consequences of wildfire (because wildfires pose the most immediate hazard to people who live in the WUI).

Climate change is anticipated to worsen wildfire conditions in many areas of the U.S. (Wehner et al. 2017): warmer temperatures are likely to increase evaporation and change precipitation patterns, while at the same time increase periods of drought in many locations (Stein et al. 2013). While drought may exacerbate wildfire risk, it may also reduce water availability to fight fires (Stein et al. 2013).

A.4.6.1. Indicators of Wildfire Exposure

Because wildfire is a local, not regional phenomenon, some of these indicators are calculated for the installation area and lands immediately adjacent (in a 1 mile buffer zone); climatological indicators are calculated at the HUC8 watershed, and the installation value is the value for the watershed in which it is located, or if located across multiple HUC8 watersheds is the area-weighted average value; demographic data are calculated as the area-weighted sum for the county(-ies) in which the installation lies. The indicators are used to represent wildfire risk are shown in Table A.10. See Appendix B: ACAT Indicator Fact Sheets for more information on how these indicators were calculated.

Table A.10: Indicators used to represent wildfire exposure

Indicator	Importance Weight	Justification
FIRE SEASON LENGTH (#604): Fire Season Length is the average annual number of days in which the Keetch-Byram Drought Index (KBDI) is >600, indicating long-term arid conditions and dry coarse fuels. Vegetation becomes more flammable under prolonged dry conditions. The KIBDI captures the accumulated moisture deficit for a given region over the course of a year. Values for the index decrease when precipitation occurs, and increase with number of days since the last precipitation event. An index value of 600 or greater indicates a prolonged period of aridity, which gives time for vegetation and soils to dry out. Consequently, the number of days with KBDI > 600 indicates the share of the year in which vegetation is already very dry and wildfires readily ignite and spread.	1.7	This indicator is given the highest weight, because weather conditions that dry fuels and make them prone to ignition and wildfire spread are the most important factor in determining exposure to wildfire risk.
FLASH DROUGHT FREQUENCY (#101): This indicates the change in frequency of droughts that intensify quickly (< 2 months). Because of their sudden onset, flash droughts can have very large impacts on agricultural yields, ecosystem health, and wildland fire risk if they occur in the growing season. In addition, for water supply systems with small storage volumes relative to inflow, flash droughts can result in rapid development of critical water shortages. Increasing flash drought frequency increases risks.	1.5	This indicator is given a large weight because it represents an abrupt shift from wet climate that promotes new vegetative growth to a dry climate that carries with it an acute increase in wildfire risk that may impact training activities.
FUEL ABUNDANCE (#601): Fuel refers to vegetation that is unmanaged (e.g., not irrigated), which responds in concert with weather conditions. Fuel Abundance is the percent area of an installation and a 1-mile buffer around the installation that is in unmanaged wildland vegetation. THIS INDICATOR IS STATIC FOR ALASKA AND HAWAII.	1.3	This indicator is given a low weight, because fuels rely on dry conditions to promote the ignition and spread of wildfires.
IGNITION RATE (#602): Humans are a major cause of wildfire ignition when they conduct activities in and close to vegetated areas (e.g., camping, grilling, operating machinery, smoking, burning trash and also military training activities). Ignition Rate is the population density in proximity to an installation. Human-caused ignitions are assumed to scale with the density of people in the vicinity of wildland vegetation, and therefore the frequency with which people use that space for recreation and other activities. THIS INDICATOR IS STATIC FOR ALASKA AND HAWAII.	1.1	Humans are only one cause of wildfire ignitions, and that rate varies regionally, and is easily modulated through access management on public lands. Consequently, this gets the lowest weight.

A.4.7. Land Degradation Hazard

Land Degradation refers to long-term changes in land use, land cover, soil moisture, permafrost and other processes that result in soil loss, reduced soil fertility, coastal erosion, land subsidence, a reduced ability of the land to support native plants and animals, and reduced agricultural yields (FAO 2000). Major factors in land degradation are soil water erosion, wind erosion, loss of nutrients, physical deterioration, and salinization (Dunstan et al. 2004). Processes that enhance degradation also increase erosion by wind and water, resulting in changes to regional hydrology, increased sediment loads in streams and water bodies, increased atmospheric dust, and replacement of native vegetation by non-native weedy species.

Exposure to land degradation may be partly determined by climate variation and change in addition to human activities (Bationo et al. 2006). The main climatic factors influencing soil erosion are rainfall (amount, frequency, duration, and intensity), and wind (direction, strength, and frequency of high-intensity winds), coupled with drying-out of the soil (Bullock 2005).

In Arctic regions, increased air temperatures result in increase in soil temperature, leading to significant increases in the depth of annual permafrost melt or permanent permafrost loss (Luber et al. 2018). Wildfire, by destroying vegetation cover, weakening surface soils, and increasing soil direct heating and drying by the sun, is a significant accelerator of land degradation in many regions.

Land degradation is a significant problem for installations. Many kinds of degradation result in loss of vegetative cover, increasing erosion from extreme precipitation events that can limit off-road transit by military vehicles and personnel (U.S. Army 2013). Bare ground, when dry, may become a significant dust source (Pu and Ginoux 2017) that restricts air and ground travel, fouls machines of all types, penetrates building interiors, and poses health challenges.

Drought and soil bareness are expected to contribute to an increase in dustiness in portions of the U.S. over the 21st century (Pu and Ginoux 2017). In mountainous regions, blowing dust that lands on snow fields may accelerate snow melt, which may contribute to increases in spring runoff, and reductions in water availability in late summer.

In coastal regions, sea level rise and increased storm surge will not only inundate land, but will alter harbor topography and bathymetry, may increase the likelihood of saltwater intrusion into freshwater aquifers, contribute to coastal soil salinization, and increase water table height (USACE 2013). In the Arctic, loss of sea ice contributes to coastal erosion by decreasing the protective barrier formed by ice shoving and pushing, increasing fetch, and therefore enabling larger and more powerful waves to develop.

Thawing of permafrost (soil at or below the freezing point of water (32°F) for two or more years) weakens soils, further accelerating coastal erosion. Permafrost thawing also leads to the ground sinking (subsidence) (Kokelj and Jorgenson 2013), which can damage infrastructure of all kinds, including roads, training ranges, pipelines, transmission lines, bridges, and buildings (Markon et al. 2018), and can lead to significant changes to surface hydrologic patterns (Jorgenson et al 2013; Olefeldt et al. 2016, Rawlins et al. 2019).

Land use is the major non-climate contributor to land degradation. Installations have discretion over land use patterns and the disturbance of surface soils and vegetation. Numerous best-practices exist to mitigate disturbance and prevent erosion during construction, and during routine activities. However, changes in climate impact these decisions by making the land more susceptible to erosion once disturbed, introducing new disturbance processes, and increasing the frequency and intensity of extreme climate events responsible for land degradation.

For all indicators, baseline data exists on current land status with respect to degradation, but the information is limited to the current state of the indicator. If there are additional causes of land degradation – such as repeated vehicular traffic or increased runoff due to adjacent development – these are unlikely to be captured in the base condition. These are factors that may be relevant for the sensitivity assessment and should be discussed there.

Because land degradation is a problem with both regional and local components, the indicators used to assess this hazard are calculated at two scales: climate components (e.g., aridity, length of fire season) are computed at the HUC8 level while land-surface-specific components (soil loss, coastal erosion, and permafrost loss) are computed for the installation footprint.

A.4.7.1. Indicators of Land Degradation Exposure

Indicators are used to represent exposure to land degradation are shown in Table A.11. See Appendix B: ACAT Indicator Fact Sheets for more information on how these indicators were calculated.

Table A.11: Indicators used to represent land degradation exposure

Indicator	Importance Weight	Justification
SOIL LOSS (#701): This indicator reflects the changes in the rate of surface erosion due to changes in precipitation intensity and land use. It is calculated using the Revised Universal Soil Loss Equation (RUSLE). Increases in soil loss not only result in erosion and gully formation of the land surface, but eroded sediment accumulates in stream channels and reservoirs, resulting in reductions in reservoir capacity, changes in the performance of flood risk management infrastructure, and affects to in stream habitat.	1.7	This indicator is given the highest weight because it takes into account factors that both enhance erosion and combat erosion, changes in this indicator show a long-term shift in this balance that indicate long-term, landscape-wide changes in erosion rate with implications for use of a wide range of outdoor landscapes.
FIRE SEASON LENGTH (#604): Fire Season Length is the average annual number of days in which the Keetch-Byram Drought Index (KBDI) is >600, indicating long-term arid conditions and dry coarse fuels. Vegetation becomes more flammable under prolonged dry conditions. The KIBDI captures the accumulated moisture deficit for a given region over the course of a year. Values for the index decrease when precipitation occurs and increase with number of days since the last precipitation event. An index value of 600 or greater indicates a prolonged period of aridity, which gives time for vegetation and soils to dry out. Consequently, the number of days with KBDI > 600 indicates the share of the year in which vegetation is already very dry and wildfires readily ignite and spread.	1.5	This indicator is given the next highest value because it is unpredictable in location, time and severity, but the effects on land surface degradation can be severe and long-lasting.
ARIDITY (#105): Aridity is a change in the nature of an installation's climate towards increasingly drier conditions. Increases in aridity indicate essentially permanent reductions in water supply. It also indicates significant reductions in soil moisture and therefore changes in vegetation type and density, and wildfire risk. Importantly, changes in aridity are not strongly correlated with changes in any of the other drought variables.	1.4	This indicator is given a medium weight because a shift to a more arid climate reduces vegetative cover, which increases exposure to erosion, while at the same time slowing the rate at which the land surface recovers from disturbance (such as a military training exercise).
COASTAL EROSION (#202): Coastal Erosion is an indicator of the susceptibility of a coastline to erosion due to wave action. It is affected primarily by exposure to wave action (largely a function of fetch) and by the nature of the ground at a given location (e.g., sandy vs. rocky). Coastal Erosion is the probability of erosion based on data from the USGS Coastal Vulnerability Index database. It is a proxy for potential damage during storm events for more vulnerable coastlines. This indicator is static (does not change with time).	1.2	Coastal erosion is a significant problem in some areas, but the affects may be reduced or eliminated through structural and nonstructural measures. Consequently, this indicator is given a lower weight.
PERMAFROST HAZARD (#702): Permafrost Hazard Potential is the percent of the installation at significant risk for damage to infrastructure due to permafrost thaw. This indicator reflects the mitigating effects of multiple factors, including soil substrate, on the consequences of permafrost thaw. For example, while fine-sediment deposits may subside or be subject to liquefaction as permafrost thaws, gravelly substrates may retain most or all of their engineering performance characteristics. The former location would have a much higher hazard potential than the later, based on this index.	1	While this is a significant hazard for a small number of installations located in the Arctic, it is not a concern for the majority of locations and therefore is given the lowest weight.

A.4.8. Historical Extreme Conditions

In addition to the specific climate hazards described above, the tool includes information on exposure to the several historical extreme events as shown in Table A.12. These data sets provide a background to current exposure to a range of hazards. Because most planning processes ask planners to differentiate between existing and future conditions, these indicators were grouped together to facilitate development of the existing conditions assessment portion of the planning processes. Indicators shown in Table A.12 were selected based in part on the availability of nationally-consistent, complete and authoritative data. See Appendix B: ACAT Indicator Fact Sheets for more information on how these indicators were calculated.

Table A.12: Indicators used to represent historic extremes

Indicator	Importance Weight	Justification
HURRICANE FREQUENCY (#802): Hurricane Frequency is the mean annual probability of being impacted by a hurricane, defined as being within 200 km buffer around the hurricane track.	1.7	This indicator is given the highest weight, because hurricanes combine widespread high damage and life-safety loss with unpredictability. The results of hurricanes can be substantial disruption to mission and readiness.
HURRICANE MAXIMUM AVERAGE PRECIPITATION (#807): Hurricane Maximum Average Precipitation is the maximum average annual precipitation from hurricane events experienced in any portion of an installation's HUC8 watershed across all storms.	1.5	Hurricane precipitation is assigned the second highest weight because of high damages and life-safety risk, even for category 1 and 2 storms, and post-tropical storms.
TORNADO FREQUENCY (#801): Tornado Frequency is the average annual probability of a tornado occurring on or in the HUC8 watershed(s) of an installation.	1.4	Tornadoes are assigned a middle weight, because although they can result in widespread damage and life safety risk, they have a relatively small footprint.
HURRICANE WIND GREATER THAN 50 KNOTS (#806): Hurricane Wind > 50 knots is the maximum frequency with which any portion of an installation's HUC8 watershed was impacted by hurricane winds greater than 50 knots.	1.4	Similarly, hurricane wind damage causes damage and life safety risk, but for a much narrower area than precipitation.
WILDLAND URBAN INTERFACE (#805): Wildland Urban Interface (WUI) is the percent of installation classified as wildland-urban interface or intermix, according to the USDA WUI map. For Alaska and Hawaii, WUI was mapped based on the USDA methodology.	1.3	The mix of vegetation and structures is given a lower weight because while it supports wildfires that can cause costly destruction of property, this exposure can be reduced through known adaptation measures (e.g., zoning, wildfire codes).
ICE STORM OCCURRENCE (#803): Ice Storms is a presence-absence indicator identifying places in the U.S. where freezing rainstorms have occurred that have significantly impacted above-ground infrastructure.	1.2	This indicator is given a lower weight. Ice storms are can cause significant damage to some above ground infrastructure, such as transmission lines and communications equipment. Ice storms can also inhibit transportation due to hazardous road conditions. Not all locations are subject to ice storms.
ICE JAM OCCURRENCE (#808): Ice Jam Occurrence is a presence-absence indicator identifying places in the U.S. where ice jams have occurred in an installation's HUC8 watershed(s).	1.2	Similarly, while ice jams can increase seasonal flood risk, and are unpredictable in time and place, they are also an infrequent, if sometimes significant, cause of damage.
HISTORICAL DROUGHT FREQUENCY (#804): Historical Drought Frequency is the percent of weeks in the historic period when any part of an installation was categorized as in severe (D2), extreme (D3) or exceptional (D4) drought as determined by the National Integrated Drought Information System (NIDIS) historical records.	1.1	Drought is a significant source of damage to agriculture and reductions in water supply. This gets the lowest rate because it is expected that existing water installation water supply infrastructure takes historical drought frequencies into consideration in sizing and operations.

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APPENDIX B: ACAT INDICATOR FACT SHEETS

101 FLASH DROUGHT FREQUENCY

USACE CLIMATE PREPAREDNESS AND RESILIENCE

HIGH INDICATOR VALUE
Higher exposure due to more frequent flash drought occurrence

LOW INDICATOR VALUE
Lower exposure due to less frequent flash drought occurrence

THIS INDICATOR MEASURES HOW OFTEN RAPID ONSET ("FLASH") DROUGHTS OCCUR

BACKGROUND

- Flash Drought Frequency is the average number of times per year in which rapid-onset drought occurs, characterized by a sharp drop in precipitation over a three-month period. It is measured using the 1-month Standardized Precipitation Evaporation Index (SPEI).
- Drought is a reduction in the amount of water available for use and can occur in any climate.
- A flash drought is the rapid onset of more arid conditions, such as the failure of expected summer rains.
- Flash droughts can not only lead to unexpected water shortages, but can contribute to wildfire risk (as new growth and soils rapidly dry out) and excess heat stress (because high pressure systems associated with all droughts bring clear sunny skies and hotter temperatures).

CALCULATION

- Drought is measured using the Standardized Precipitation Evaporation Index (SPEI)[1] with the Thornthwaite potential evapotranspiration (PET) approximation[2,3] and uses monthly temperature and precipitation data.
- For each epoch-scenario, Flash Drought Frequency is the average number of times per year in which the 1-month SPEI drops from above -1 to below -1.5 in a 3-month window [for example, from -0.5 in March to -1.75 in May].
- Continuous drought is counted as a single drought episode.

[1]Vicente-Serrano S.M., S. Beguería, J.I. López-Moreno (2010). A Multi-scalar drought index sensitive to global warming: The Standardized Precipitation Evapotranspiration Index - SPEI. Journal of Climate 23: 1696-1718.
[2]Beguería, S., S.M. Vicente-Serrano, F. Reig, B. Latorre (2014). Standardized Precipitation Evapotranspiration Index (SPEI) revisited: parameter fitting, evapotranspiration models, kernel weighting, tools, datasets and drought monitoring. International Journal of Climatology, 34: 3001-3023.
[3]Thornthwaite, C. W. (1948). An approach toward a regional classification of climate. Geographical Review, 38(1), 55-94.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS: Daily precipitation from 32 CMIP5 GCM model runs downscaled using the LOCA method	Average number of flash droughts per year	**CONUS:** 1/16 degree (6 km)	Daily
AK, HI: 25 CMIP5 GCMs downscaled via the BCSD method for daily temperature and precipitation data		**AK, HI:** 1/8 degree (12 km)	

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Frequency (occurrence/year)	Drought, Wildfire	1.4 Drought, 1.5 Wildfire

102 DROUGHT YEAR FREQUENCY

HIGH INDICATOR VALUE
Higher exposure due to more frequent drought

LOW INDICATOR VALUE
Lower exposure due to less frequent drought

THIS INDICATOR MEASURES HOW OFTEN YEAR-LONG DROUGHTS OCCUR

BACKGROUND

- Drought Year Frequency is the average percentage of years in which a location is in moderate or more extreme drought status as measured using the 12-month Standardized Precipitation Evaporation Index (SPEI).
- Drought is a reduction in the amount of water available for use and can occur in any climate.
- Droughts can lead to significant water shortages in all sectors (municipal, agricultural, industrial, energy, environment), and can contribute to increased wildfire risk and heat stress (because temperatures are higher during drought).

CALCULATION

- Drought is measured using the Standardized Precipitation Evaporation Index (SPEI)[1] with the Thornthwaite potential evapotranspiration (PET) approximation[2,3] and uses monthly temperature and precipitation data. For each epoch-scenario, this is the percent of years in which the 12-month SPEI is < -1 (moderate drought).

[1]Vicente-Serrano S.M., S. Beguería, J.I. López-Moreno (2010). A Multi-scalar drought index sensitive to global warming: The Standardized Precipitation Evapotranspiration Index - SPEI. Journal of Climate 23: 1696-1718.

[2]Beguería, S., S.M. Vicente-Serrano, F. Reig, B. Latorre (2014). Standardized Precipitation Evapotranspiration Index (SPEI) revisited: parameter fitting, evapotranspiration models, kernel weighting, tools, datasets and drought monitoring. International Journal of Climatology, 34: 3001-3023.

[3]Thornthwaite, C. W. (1948). An approach toward a regional classification of climate, Geographical Review, 38(1), 55-94.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS: Daily precipitation from 32 CMIP5 GCM model runs downscaled using the LOCA method	Average frequency with which drought years occur	**CONUS**: 1/16 degree (6 km)	Daily
AK, HI: 25 CMIP5 GCMs downscaled via the BCSD method for daily temperature and precipitation data		**AK, HI**: 1/8 degree (12 km)	

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Percentage	Drought	1.2

105 ARIDITY

LOW INDICATOR VALUE
Higher values indicate a more humid climate, and therefore a reduced exposure due to an increase in precipitation relative to potential evapotranspiration

HIGH INDICATOR VALUE
Lower values indicate an increasingly arid climate due to a decrease in precipitation relative to potential evapotranspiration

THIS INDICATOR MEASURES WHETHER THE CLIMATE ON AVERAGE IS BECOMING DRIER OR MORE HUMID

BACKGROUND

- Aridity is a change in the overall water balance of the climate towards increasingly drier conditions. Aridity is a long-term reduction in climatic wetness in a region. It has significant impacts on soil moisture, vegetation type and density, available water supply, and wildfire risk.
- Aridity may increase if precipitation decreases, if increases in temperature lead to increases in potential evapotranspiration (PET), or both.

CALCULATION

- Aridity is the average annual precipitation-potential evapotranspiration (P/-PET)[1] calculated using the Thornthwaite PET approximation[2] and monthly temperature and precipitation data.
- A number greater than or equal to 0.65 indicates a humid climate while a number less than 0.65 indicates an arid climate. A decrease in value over time, even if all values are greater than 0.65, indicates an increasingly arid climate.

1) For each model, compute annual P, and annual PET values by summing the monthly values.

2) From the annual P and annual PET, compute the Aridity Index (P/PET)[2] for each year in each model.

3) For each epoch-scenario, compute the mean aridity index values across all models. This will be the aridity indicator.

[1] UNEP [United Nations Environment Program]. 1992. World Atlas of Desertification. eds. N. Middleton and D.S.G. Thomas. United Nations Environment Program, London.

[2] Thornthwaite, C. W. (1948). An approach toward a regional classification of climate. Geographical Review, 38(1), 55-94.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS: Daily precipitation from 32 CMIP5 GCM model runs downscaled using the LOCA method	The overall dryness of a location's climate, as a ratio between precipitation and potential evapotranspiration	**CONUS:** 1/16 degree (6 km)	Daily
AK, HI: 25 CMIP5 GCMs downscaled via the BCSD method for daily temperature and precipitation data		**AK, HI:** 1/8 degree (12 km)	

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Unitless	Drought, Land Degradation	1.5 Drought, 1.4 Land Degradation

106 CONSECUTIVE DRY DAYS

USACE CLIMATE PREPAREDNESS AND RESILIENCE

HIGH INDICATOR VALUE
Higher values indicate greater exposure due to longer number of consecutive dry days

LOW INDICATOR VALUE
Lower values indicate reduced exposure due to shorter durations between precipitation events

THIS INDICATOR IS THE NUMBER OF DRY DAYS BETWEEN RAIN EVENTS

BACKGROUND

- Consecutive Dry Days is the mean annual maximum number of consecutive days with less than 0.01" of precipitation. It is a measure of the length of time between precipitation events. For some parts of the U.S., an interval of two or three weeks might be unusual, whereas in others, whole seasons might routinely not record precipitation greater than a trace (0.01 inch).
- A location's drought preparedness is typically scaled to expected dry period length; consequently an increase in consecutive dry days might result in water supply stress, increased fire risk (which would affect training activities), agricultural crop loss resulting in local or regional economic stress for agricultural communities adjacent to installations, and risk to threatened and endangered species[1].

CALCULATION

- This is the average maximum number of consecutive dry days across models for a given epoch-scenario.
- For each model trace, determine maximum number of consecutive days with less than 0.01" (trace) of precipitation.
  - Compute area average value by HUC8 (so reduce gridded value to one value) for each year in a model run.
  - For that model, for each epoch-scenario (e.g., 2050 Low), select the maximum value from among the area average HUC8 values.
  - Across all models in a given epoch-scenario, select the mean value.

[1]Wuebbles, D. J., Fahey, D. W., & Hibbard, K. A. (2016). The Climate Science Special Report (CSSR) of the Fourth National Climate Assessment (NCA4). AGUFM, 2016, GC34D-04.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS: Daily precipitation from 32 CMIP5 GCM model runs downscaled using the LOCA method	Average longest number of days between rainfall events	**CONUS**: 1/16 degree (6 km)	Daily
AK, HI: Daily precipitation from 25 CMIP5 model runs downscaled using the BCSD method		**AK, HI**: 1/8 degree (12 km)	

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Days per year	Drought	1

108C MEAN ANNUAL RUNOFF

USACE CLIMATE PREPAREDNESS AND RESILIENCE

LOW INDICATOR VALUE
Lower values indicate increased exposure to water stress because there is less water available on average

HIGH INDICATOR VALUE
Higher values indicate reduced exposure to water stress because there is more water available on average

THIS INDICATOR MEASURES ALL WATER DISCHARGED IN SURFACE STREAMS WITHIN A WATER SHED

BACKGROUND

- Mean Annual Runoff is the average annual discharge (volume of water) from the entire watershed upstream of the downstream-most boundary of the installation for the largest river in this watershed. This is an estimate of unregulated flows, meaning the effects of water storage and flood releases are not taken into account.
- This indicator reflects the renewable freshwater supply in a given basin[1,2].
- Freshwater supply is important not only for drinking water, but also for industrial production, combatting wildfire, maintaining plantings for shade (to reduce building cooling costs), providing water for ecosystem services, generating electricity through hydropower, and providing cooling water for thermoelectric generation. Rising demand may affect freshwater supply availability as well, and should be evaluated for each installation.
- Changes to demand are not included in this indicator.

CALCULATION

- Mean annual runoff is the average volume of water discharged by streams in a given year. This is an estimate of unregulated flows, meaning the effects of water storage and flood releases are not taken into account.
- Cumulative mean annual runoff includes the discharge of streams that originate upstream of a given watershed. For larger stream networks, headwaters regions may respond differently to climate change than downstream reaches.
- Use modeled routed runoff values (CONUS) or modeled surface runoff (AK, HI) specific to each future scenario.
- For indicator 108C, use cumulative runoff values from each model trace (CONUS) or the sum of the contributing watershed runoff (AK, HI).
- Calculate the mean annual runoff value for each model trace.
- Calculate the median annual runoff value across all model traces to obtain a single indicator value for each HUC-8 watershed.

[1]Milly, P. C., Dunne, K. A., and A. V. Vecchia. 2005. Global Pattern of Trends in Streamflow and Water Availability in a Changing Climate. Nature. 438(7066): 347-350.
[2]Doll, P., and H. M. Schmied. 2012. How is the Impact of Climate Change on River Flow Regimes Related to the Impact on Mean Annual Runoff? A Global-Scale Analysis. Environmental Research Letters. 7(1): 014037.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS: Daily precipitation from 32 CMIP5 GCM model runs downscaled using the LOCA method translated into surface runoff using a Variable Infiltration Capacity (VIC) model[3] and routed to channel segments via the MizuRoute algorithm[4]	Projected mean annual runoff in a given watershed, including all upstream watersheds (C, cumulative)	**CONUS**: 1/16 degree (6 km)	Daily
AK, HI: Daily precipitation from 25 CMIP5 model runs downscaled using the BCSD method, translated into surface runoff using a Variable Infiltration Capacity (VIC) model[3]. No flow routing available		**AK, HI**: 1/8 degree (12 km)	

[3]Liang, X., D. P. Lettenmaier, E. F. Wood, and S. J. Burges (1994). A simple hydrologically based model of land surface water and energy fluxes for general circulation models, J. Geophys. Res., 99(D7), 14415–14428, doi:10.1029/94JD00483.

[4]Mizukami, N., Clark, M. P., Sampson, K., Nijssen, B., Mao, Y., McMillan, H., Viger, R. J., Markstrom, S. L., Hay, L. E., Woods, R., Arnold, J. R., and Brekke, L. D.: mizuRoute version 1: a river network routing tool for a continental domain water resources applications, Geosci. Model Dev., 9, 2223–2238, https://doi.org/10.5194/gmd-9-2223-2016, 2016.

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
cfs (cubic feet per second)	Drought	1.5

U.S. ARMY

201 SEA LEVEL PERCENT AREA FLOODING

USACE CLIMATE PREPAREDNESS AND RESILIENCE

LOW INDICATOR VALUE
Lower percentage of land within the 1% coastal floodplain indicates lesser vulnerability to infrastructure damage, human safety, and mission

HIGH INDICATOR VALUE
Higher percentage of land within the 1% coastal floodplain indicates greater vulnerability to infrastructure damage, human safety, and mission

THIS INDICATOR MEASURES HOW MUCH OF AN INSTALLATION MAY BE FLOODED AS SEA LEVELS RISE

BACKGROUND

- The sea level flooding indicator represents the extent of flooding from coastal inundation over time as sea levels change.
- It is the sea surface elevation during coastal storm events (the 1% annual exceedance probability (AEP) coastal water levels).
- It is calculated from the 1% AEP coastal water levels provided in the DoD Regional Sea Level (DRSL) database, as developed by the DoD's Coastal Assessment Regional Scenario Working Group (CARSWG)[1]. The 1% AEP water levels are developed from tide gauge data near the installation.
- Higher values suggest higher vulnerability relative to other sites.

CALCULATION

- Installation footprint elevation shape files (DEM) are intersected with 1% AEP coastal water levels from the CARSWG DRSL database. Installation area and 1% AEP inundation area are computed to derive percent of installation area.
- The 1% AEP's were developed for the lowest to highest sea level change scenario for future years 2050 and 2085 and are computed by interpolating between the 2035, 2065, and 2100 1% AEP installation specific values in the CARSWG DRSL database.
- 1% AEP are in NAVD88 or LMSL. Datum adjustments for coastal water records for installations in U.S. Ocean Island States were converted to NAVD88.

[1]Hall, J.A., S. Gill, J. Obeysekera, W. Sweet, K. Knuuti, and J. Marburger (2016). Regional Sea Level Scenarios for Coastal Risk Management: Managing the Uncertainty of Future Sea Level Change and Extreme Water Levels for Department of Defense Coastal Sites Worldwide (U.S. Department of Defense, Strategic Environmental Research and Development Program, 2016), 43. https://www.serdp-estcp.org/content/download/38961/375873/version/3/file/CARSWG+SLR+FINAL+April+2016.pdf

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
1% AEP coastal water levels from the DoD Regional Sea Level (DRSL) database, as developed by the DoD's Coastal Assessment Regional Scenario Working Group (CARSWG)[1]	Base year, lowest to highest sea level change scenario for years 2035, 2065 and 2100 1% AEP installation specific values from CARSWG. Base year refers to the year 1992, which is the current National Tidal Datum Epoch (1983-2001)	1km	Base and projected

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Percent of Area	Coastal Flooding	1.5

202 COASTAL EROSION

USACE CLIMATE PREPAREDNESS AND RESILIENCE

LOW INDICATOR VALUE
Lower values indicate the shoreline is not highly susceptible to erosion

HIGH INDICATOR VALUE
Higher values indicate the shoreline is susceptible to coastal erosion

THIS INDICATOR MEASURES THE LIKELIHOOD THAT COASTAL EROSION WILL RESULT IN SHORELINE LOSS AND DAMAGE TO INFRASTRUCTURE

BACKGROUND

- Coastal Erosion is a measure of a coastline's susceptibility to erosion due to wave action. Coastal Erosion is the probability of erosion based on data from the USGS Coastal Vulnerability Index database[1].
- Infrastructure and property damage in coastal locations results from a variety of processes, important among which is erosion due to wave action. Wave action is a function of wind energy, which is greater in more exposed locations (e.g., seaward side of a barrier island) than in sheltered locations (e.g., landside of a barrier island). However, even under high wave action, erosion is minimal if the shoreline is hardened, for example because it is a rocky cliff or a developed, urban shoreline. Erosion is maximized if the shoreline is sandy or otherwise unconsolidated. Consequently, a shoreline's susceptibility to erosion is a combination of exposure to wave action and the degree to which the substrate is vulnerable to that action.
- Coastal erosion is an important consideration for some installations, and may result in significant damage to infrastructure, loss of land area, and potentially disruption of access to portions of an installation. It is important to recognize that sea level rise will exacerbate erosion in areas that are currently susceptible. However, in other areas, flood damage from sea level rise may not be accompanied by a significant increase in erosion susceptibility.
- THIS IS A STATIC INDICATOR.

CALCULATION

- For each epoch-scenario, this is the maximum probability of erosion based on data from the USGS Coastal Vulnerability Index (CVI)[1] for each installation. Coastal Erosion is the probability of the shoreline erosion rate exceeding one of two thresholds (1-2 m/year; and >2 m/year), with higher values indicating greater exposure. The coastal erosion indicator is the sum of the probabilities of exceeding each threshold. Larger numbers indicate greater risk. This indicator is constant through time.
  1) For coastal installations, the value for each installation is the maximum probability of erosion value within the installation footprint, or if one is not present, an immediately adjacent area with visually comparable shoreline characteristics (sandy vs. rocky/built).
  2) If the USGS CVI database indicates coastal vulnerability but no probability of erosion value is available, this location is assigned a value of 0.01 (nominal erosion probability).
  3) If none of the above conditions obtain, the probability of erosion is assigned a value of 0.
  4) For non-coastal installations, the value is set to 0 (no risk of coastal erosion).

[1]Gutierrez, B.T., Plant, N.G., Pendleton, E.A., and Thieler, E.R. (2014). Using a Bayesian Network to predict shore-line change vulnerability to sea-level rise for the coasts of the United States: U.S. Geological Survey Open-File Report 2014–1083, 26 p., http://dx.doi.org/10.3133/ofr20141083.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS, AK, HI: USGS Coastal Vulnerability Index[1] (CVI). Data were downloaded from: USGS Map service: Coastal Vulnerability to Sea-Level Rise	Probability of coastal erosion	.5 km	2014

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Probability	Coastal Flooding, Land Degradation	1 Coastal Flooding, 1.2 Land Degradation

301 FLOOD EXTENT

USACE CLIMATE PREPAREDNESS AND RESILIENCE

HIGH INDICATOR VALUE
Higher values indicate a larger portion of an installation is subject to riverine flooding

LOW INDICATOR VALUE
Lower values indicate a smaller portion of an installation is subject to riverine flooding

THIS INDICATOR MEASURES HOW MUCH OF AN INSTALLATION MAY BE FLOODED DUE TO CHANGES IN RIVERINE FLOOD MAGNITUDES

BACKGROUND

- Flood Extent is the percent of the installation area that may be inundated during the 1% annual exceedance probability (AEP) riverine flood event. The current riverine flood extent is based on the 1% AEP. Future extents are based on adding 2ft (low) and 3ft (high) to the flood elevations and estimating the resulting extent of flooding.
- This indicator adopts the +2ft value as the mid-century Epoch value, and the +3ft scenario as the late-century Epoch value, and for each Epoch, uses the same value for the High and Low Scenarios.
- Floods pose myriad hazards to installations. Floodwaters pose a significant life-safety and public health risk, damage buildings and infrastructure, and spread pollutants and hazardous waste across the landscape[1]. Ponding water may provide a breeding ground for mosquitos and other disease vectors. Saturated ground may inhibit range use and access, and contribute to land degradation.

CALCULATION

- Where available, historical inundation areas are based on the Federal Emergency Management Agency (FEMA) National Flood Hazard Layer (NFHL) 1% annual exceedance probability inundation maps. Where not available, a 2D Hydrologic Engineering Center-River Analysis Tool (HEC-RAS) model was developed based on 10-m DEM data and the 1% precipitation depths from the NOAA Atlas 14 and Atlas 2 precipitation datasets to delineate historical floodplains.
- For both cases, future flood levels were approximated using the freeboard approach in which 2ft and 3ft were added to the computed water surface elevation using GIS processing, and the floodplains were delineated based on these new elevations.
- The percent of installation inundated under each of these three scenarios was then determined.

[1]Madani, K., and J. R. Lund. 2010. Estimated Impacts of Climate Warming on California's High-Elevation Hydropower. Climatic Change. 102(3-4): 521-538.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
FEMA National Flood Hazard Layer (NFHL) data: https://www.fema.gov/national-flood-hazard-layer-nfhl USGS 10-m DEM elevation data: https://prd-tnm.s3.amazonaws.com/index.html?prefix=StagedProducts/Elevation/13/ArcGrid/ NOAA Atlas 14 Precipitation: https://hdsc.nws.noaa.gov/hdsc/pfds/ NOAA Atlas 2 Precipitation: https://hdsc.nws.noaa.gov/hdsc/pfds/other/mt_pfds.html	Percent of installation inundated by the 1% AEP flood event	10-m	Variable, dependent on when FEMA NFHL was developed. For areas where 1% AEP water surface elevations were determined using 2D modeling, best available data at time of production were used

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Percent of area	Riverine Flooding	1.5

302C FLOOD MAGNIFICATION FACTOR

LOW INDICATOR VALUE
Values less than 1 indicate a decrease in flood risk in the future because the largest floods get smaller

HIGH INDICATOR VALUE
Values greater than 1 indicate an increase in flood risk in the future because the largest floods get larger

THIS INDICATOR MEASURES HOW MUCH BIGGER THE 10% ACE FLOOD EVENT WILL BE IN THE FUTURE RELATIVE TO THAT FLOOD EVENT TODAY

BACKGROUND

- This indicator measures the change in flood runoff and is a ratio of the monthly local or cumulative runoff exceeded 10 percent of the time in the future compared to this value in the historic period. The flood magnification factor represents how flood flow is predicted to change in the future.[1]
    - In watersheds with indicator values greater than 1, flood flow is predicted to be greater for that epoch-scenario compared to the present.
    - In watersheds with indicator values less than 1, flood flow is predicted to be less for that epoch-scenario compared to the present.
- Increases in flood flow can have adverse effects on species not adapted to such changes. For example, increased flood flow levels can lead to river bed scour, which reduces egg-to-fry survival rates of salmon in the Pacific Northwest[2].
- Increased flood flow levels may also result in energy spills at hydropower plants, when there is neither sufficient storage capacity nor turbine capacity. Energy spills may be especially prevalent in winter and early spring, when increased flood flow levels may occur[3].
- Higher values suggest higher vulnerability relative to other watersheds.

CALCULATION

- Use modeled routed runoff values for CONUS or modeled surface runoff for AK, HI specific to each future scenario.[4]
- Calculate the 10% annual exceedance probability (AEP) flood runoff for the base period (1950-2004), and a future scenario (2035-2064 or 2070-2099).
    - For indicator 302C, use cumulative flood runoff values in the base and future periods.
- Divide the future value of flood runoff by the base period value to obtain the flood magnification factor. Base period values are set to 1.

[1] Vogel, R.M., Yaindl, C. and Walter, M. (2011), Nonstationarity: Flood Magnification and Recurrence Reduction Factors in the United States1. JAWRA Journal of the American Water Resources Association, 47: 464-474. doi:10.1111/j.1752-1688.2011.00541

[2] Mantua, N., I. Tohver, and A. Hamlet. 2010. Climate Change Impacts on Streamflow Extremes and Summertime Stream Temperature and Their Possible Consequences for Freshwater Salmon Habitat in Washington State. Climatic Change 102(1-2): 187-223.

[3] Madani, K., and J. R. Lund. 2010. Estimated Impacts of Climate Warming on California's High-Elevation Hydropower. Climatic Change. 102(3-4): 521-538.

[4] CMIP-5 output is available for download online at: http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS: 32 LOCA CMIP5 daily precipitation data translated into surface runoff using a Variable Infiltration Capacity (VIC) model[5] and routed to channel segments via the MizuRoute algorithm.[6]	Change in the magnitude of large flood events (10% annual exceedance probability floods)	**CONUS**: 1/16 degree (6 km)	Daily
AK, HI: 25 BCSD CMIP5 daily precipitation data translated into surface runoff using a Variable Infiltration Capacity (VIC) model.[4]		**AK, HI**: 1/8 degree (12 km)	

[5] Hamman, J. J., Nijssen, B., Bohn, T. J., Gergel, D. R., and Mao, Y.: The Variable Infiltration Capacity model version 5 (VIC-5): infrastructure improvements for new applications and reproducibility, Geosci. Model Dev., 11, 3481-3496, https://doi.org/10.5194/gmd-11-3481-2018, 2018.

[6] Mizukami, N., Clark, M. P., Sampson, K., Nijssen, B., Mao, Y., McMillan, H., Viger, R. J., Markstrom, S. L., Hay, L. E., Woods, R., Arnold, J. R., and Brekke, L. D.: mizuRoute version 1: a river network routing tool for a continental domain water resources applications, Geosci. Model Dev., 9, 2223–2238, https://doi.org/10.5194/gmd-9-2223-2016, 2016.

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
unitless	Riverine Flooding	1.3

303 MAXIMUM 1-DAY PRECIPITATION

HIGH INDICATOR VALUE
Higher values indicate greater exposure due to increases in flood risk

LOW INDICATOR VALUE
Lower values indicate smaller exposure due to reduced flood risk

THIS INDICATOR MEASURES THE CHANGE IN THE LARGEST 1-DAY RAINFALL EVENT

BACKGROUND

- The Maximum 1-Day Precipitation is the average annual maximum 1-day precipitation amount (inches). It is a measure of precipitation intensity.
- Precipitation intensity is an important contributor to flooding, particularly in urban areas. The faster rain falls, the more rapidly the uppermost layers of soil saturate, which reduces the ability of the ground to absorb the rainfall and leads to a greater runoff for a given amount of precipitation.
- The net result of increased precipitation intensity is higher flood peaks that occur more rapidly, and a reduction in the amount of rainfall that penetrates the sub-surface to the rooting depth of plants.

CALCULATION

- This is the average annual maximum daily precipitation amount.
- Compute area average value by HUC8 (so reduce gridded value to one value) for each year in a model run.
- For that model, for each epoch-scenario (e.g., 2050 Low), select the maximum value from among the area average HUC8 values.
- Across all models in a given epoch-scenario, select the median value.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS: Daily precipitation from 32 CMIP5 GCM model runs downscaled using the LOCA method	Maximum precipitation in a 24-hour period	**CONUS**: 1/16 degree (6 km)	Daily
AK, HI: Daily precipitation from 25 CMIP5 model runs downscaled using the BCSD method		**AK, HI**: 1/8 degree (12 km)	

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Inches	Riverine Flooding	1

304 MAXIMUM 5-DAY PRECIPITATION

USACE CLIMATE PREPAREDNESS AND RESILIENCE

HIGH INDICATOR VALUE
Higher values indicate greater exposure due to increases in flood risk

LOW INDICATOR VALUE
Lower values indicate smaller exposure due to reduced flood risk

THIS INDICATOR MEASURES THE CHANGE IN THE PRECIPITATION THAT FALLS IN A MULTI-DAY STORM EVENT

BACKGROUND

- The Maximum 5-Day Precipitation is the average annual maximum 5-day precipitation total (inches).
- Multi-day rainfall quantity is an important contributor to flooding. The more rain that falls, the greater the soil saturation, especially if this rain falls steadily rather than episodically.
- Saturated soils are unable to absorb additional rain, resulting in high rates of runoff during subsequent day precipitation events.
- The net result of increased multi-day precipitation is higher, longer-duration flood peaks, extensive areas of saturated ground, and ponded water that may increase breeding grounds for mosquitos and other pathogens. The flushing of waste and toxic material into streams is a significant concern for large area, multi-day precipitation events.

CALCULATION

- This is the annual maximum precipitation over a 5-day window.
- Compute area average value by HUC8 (so reduce gridded value to one value) for each year in a model run.
- For that model, for each epoch-scenario (e.g., 2050 Low), select the maximum value from among the area average HUC8 values.
- Across all models in a given epoch-scenario, select the median value.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS: Daily precipitation from 32 CMIP5 GCM model runs downscaled using the LOCA method	Maximum total precipitation in a 5-day period (multi-day storm event)	**CONUS**: 1/16 degree (6 km)	Daily
AK, HI: Daily precipitation from 25 CMIP5 model runs downscaled using the BCSD method		**AK, HI**: 1/8 degree (12 km)	

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Inches	Riverine Flooding	1

U.S.ARMY

305 EXTREME PRECIPITATION DAYS

HIGH INDICATOR VALUE
Higher values indicate greater exposure due to increases in flood risk

LOW INDICATOR VALUE
Lower values indicate smaller exposure due to reduced flood risk

THIS INDICATOR MEASURES HOW OFTEN RAINFALL IN FUTURE STORMS EXCEEDS THAT IN THE MOST EXTREME STORMS HISTORICALLY FOR A GIVEN LOCATION

BACKGROUND

- Extreme Precipitation Days is the average annual number of days that precipitation in a future epoch-scenario is greater than what would have been considered an extreme precipitation day historically (the historic period 1% annual chance event storm).
- This indicator gets at the projected frequency of storms in the future that would be extreme compared to today's extreme storms for a given area.
- This captures relative future risk, which is important because flood risk infrastructure is sized to current risks in a given area.

CALCULATION

- This is a count of the average annual number of extreme precipitation days. Compute area average value by HUC8 (so reduce gridded value to one value) for each year in a model run.
- For that model, for each epoch-scenario (e.g., 2050 Low), select the mean value from among the area average HUC8 values.
- Across all models in a given epoch-scenario, select the mean value.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS: Daily precipitation from 32 CMIP5 GCM model runs downscaled using the LOCA method	Number of days with precipitation greater than the amount that fell during extreme (1% annual chance exceedance) precipitation events historically	**CONUS**: 1/16 degree (6 km)	Daily
AK, HI: Daily precipitation from 25 CMIP5 model runs downscaled using the BCSD method		**AK, HI**: 1/8 degree (12 km)	

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Days/year	Riverine Flooding	1.4

401 DAYS ABOVE 95°F

USACE CLIMATE PREPAREDNESS AND RESILIENCE

HIGH INDICATOR VALUE
Higher values indicate greater vulnerability due to the greater number of days over 95°F

LOW INDICATOR VALUE
Lower values indicate less vulnerability due to the fewer number of days over 95°F

THIS INDICATOR IS THE AVERAGE NUMBER OF DAYS WITH HIGH TEMPERATURES GREATER THAN 95°F

BACKGROUND

- Days Above 95°F is the average annual number of days in which the high temperature exceeds 95°F.
- When air temperatures exceed 95°F, the human body has a very difficult time cooling itself. Consequently, outdoor activity may need to be restricted when daytime temperatures exceed 95°F.
- High heat conditions are also associated with increasing demand for energy for cooling, and may lead to problems associated with aircraft performance.
- Heat stress is also experienced by plants and animals, and has been associated with mass mortality events in the natural world as well.
- This is an estimate of how often days are projected to exceed this temperature in the future.

CALCULATION

- This is a count of the average annual number of days with temperatures above 95°F.
- Compute area average value by HUC8 (so reduce gridded value to one value) for each year in a model run.
- For that model, for each epoch-scenario (e.g., 2050 Low), select the median value from among the area average HUC8 values.
- Across all models in a given epoch-scenario, select the mean value.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS: Daily temperature from 32 CMIP5 GCM model runs downscaled using the LOCA method	Number of days in which the daytime high temperature is greater than 95°F	**CONUS**: 1/16 degree (6 km)	Daily
AK, HI: Daily temperature from 25 CMIP5 model runs downscaled using the BCSD method		**AK, HI**: 1/8 degree (12 km)	

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Days/year	Heat	1:1

402 5-DAY MAXIMUM TEMPERATURE

USACE CLIMATE PREPAREDNESS AND RESILIENCE

HIGH INDICATOR VALUE
Higher values indicate hotter temperatures and greater heat stress exposure

LOW INDICATOR VALUE
Lower values indicate cooler temperatures and less heat stress exposure

THIS INDICATOR IS THE AVERAGE TEMPERATURE OF THE HOTTEST FIVE-DAY PERIOD OF THE YEAR

BACKGROUND

- The 5-Day Maximum Temperature is the average annual highest 5-day average temperature.
- The value of the annual maximum 5-Day Maximum Temperature is a measure of how hot the hottest 5-day period is.
- Sequential high heat days are associated with increased heat-related morbidity and mortality.
- High temperatures are especially problematic for individuals who move between areas, such as recruits and individuals in the National Guard and Reserve.

CALCULATION

- This is the annual 5-day period with the highest temperature.
- Compute area average value by HUC8 (so reduce gridded value to one value) for each year in a model run (historic, 8.5, 4.5).
- For that model, for each epoch-scenario (e.g., 2050 RCP8.5), select the maximum value from among the area average HUC8 values.
- Across all models in a given epoch-scenario, select the median value.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS: Daily temperature from 32 CMIP5 GCM model runs downscaled using the LOCA method	Greatest average daytime high temperature over a 5-day period	**CONUS**: 1/16 degree (6 km)	Daily
AK, HI: Daily temperature from 25 CMIP5 model runs downscaled using the BCSD method		**AK, HI**: 1/8 degree (12 km)	

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Degrees Fahrenheit	Heat, Energy	1.2, 1.5

403 HIGH HEAT DAYS

HIGH INDICATOR VALUE
Higher values indicate hotter temperatures and greater heat stress exposure

LOW INDICATOR VALUE
Lower values indicate cooler temperatures and less heat stress exposure

THIS INDICATOR MEASURES HOW OFTEN FUTURE TEMPERATURES EXCEED THAT OF THE MOST EXTREME HISTORICAL HIGH TEMPERATURE FOR A GIVEN LOCATION

BACKGROUND

- High Heat Days is the average number of days in which temperatures exceed the 99th percentile temperature in the historic baseline period.
- This indicator shows how frequent temperatures that are considered extreme today will occur in the future.
- High heat days are associated with increased heat-related morbidity and mortality.
- High temperatures are especially problematic for individual who move between areas, such as recruits and individuals in the National Guard and Reserve.

CALCULATION

- This is the annual number of days with the maximum temperature greater than the 99th percentile in the historic baseline period.
- Compute area average value by HUC8 (so reduce gridded value to one value) for each year in a model run.
- For that model, for each epoch-scenario (e.g., 2050 Low), select the mean value from among the area average HUC8 values.
- Across all models in a given epoch-scenario, select the mean value.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS: Daily temperature from 32 CMIP5 GCM model runs downscaled using the LOCA method	Number of days with high temperatures greater than the extreme (1% annual chance exceedance) high temperature event historically	**CONUS**: 1/16 degree (6 km)	Daily
AK, HI: Daily temperature from 25 CMIP5 model runs downscaled using the BCSD method		**AK, HI**: 1/8 degree (12 km)	

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Days/year	Heat	1.3

404 FROST DAYS

HIGH INDICATOR VALUE
Higher values indicate greater exposure to frost impacts

LOW INDICATOR VALUE
Lower values indicate less exposure to frost impacts

THIS INDICATOR IS A MEASURE OF HOW OFTEN THE OVERNIGHT TEMPERATURE DROPS BELOW FREEZING

BACKGROUND

- Frost Days is the average annual number of days in which the minimum temperature is below freezing (32°F). This is a measure of how frequently overnight temperatures drop below freezing.
- Freezing temperatures, especially in fall and spring, are associated with damage to infrastructure and to agricultural crops.
- Reductions in frost days are an indication of significant warming in the winter half year (October to March).

CALCULATION

- This is the average annual number of frost days.
- Compute area average value by HUC8 (so reduce gridded value to one value) for each year in a model run.
- For that model, for each epoch-scenario (e.g., 2050 Low), select the median value from among the area average HUC8 values.
- Across all models in a given epoch-scenario, select the mean value.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS: Daily temperature from 32 CMIP5 GCM model runs downscaled using the LOCA method	Average annual number of days in which the minimum temperature is below freezing (32°F)	**CONUS**: 1/16 degree (6 km)	Daily
AK, HI: Daily temperature from 25 CMIP5 model runs downscaled using the BCSD method		**AK, HI**: 1/8 degree (12 km)	

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Days/year	Heat	1

405 HIGH HEAT INDEX DAYS

USACE CLIMATE PREPAREDNESS AND RESILIENCE

LOW INDICATOR VALUE
Lower values indicate reduced exposure to hot, humid days in which outdoor activity may have to be curtailed

HIGH INDICATOR VALUE
Higher values indicate greater exposure to hot, humid days in which outdoor activity may have to be curtailed

THIS INDICATOR IS A COMBINED MEASURE OF TEMPERATURE AND HUMIDITY STRESS

BACKGROUND

- High Heat Index Days is the average annual number of days where Heat Index Values are ≥ 90°F for a portion of the day (extreme caution or higher).
- The U.S. National Weather Service developed the Heat Index[1] to capture the joint impact of both temperature and humidity on human health.
- Because humans rely on the evaporation of sweat for cooling, they are vulnerable to heat stress either during high heat conditions, or when high humidity levels retard the evaporation of sweat.
- For CONUS, both projected temperature and relative humidity data are derived from the LOCA CMIP5 dataset. For AK and HI, projected relative humidity values were not available at the time of this study, and this indicator uses historical climatology values for monthly relative humidity.

CALCULATION

- This is the average annual number of days in which the Heat Index values equal or exceed 90°F for at least a portion of the day (extreme caution or higher).
- Compute area average value by HUC8 (so reduce gridded value to one value) for each year in a model run.
- For that model, for each epoch-scenario (e.g., 2050 Low), select the median value from among the area average HUC8 values.
- Across all models in a given epoch-scenario, select the mean value.

[1] NWS. 2011. Meteorological Conversions and Calculations: Heat Index Calculator. NWS 2016. Storm Data Preparation. National Weather Service Instruction 10-1605 (16 July 2018) https://www.nws.noaa.gov/directives/sym/pd01016005curr.pdf

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS: Daily temperature and relative humidity from 24 CMIP5 GCM model runs downscaled using the LOCA method	Average number of days for which the Heat Index is ≥90°F, indicating dangerously hot and humid conditions	**CONUS:** 1/16 degree (6 km)	Daily
AK, HI: 25 CMIP5 GCMs downscaled via the BCSD method for daily temperature; daily specific humidity from Oakridge National Laboratory's DayMet archive (daymet.ornl.gov)		**AK, HI:** 1/8 degree (12 km)	

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Days/year	Heat	1.7

501 HEATING DEGREE DAYS

USACE CLIMATE PREPAREDNESS AND RESILIENCE

LOW INDICATOR VALUE
Lower values indicate overall warmer conditions (especially overnight) and a reduced energy demand for heating buildings

HIGH INDICATOR VALUE
Higher values indicate overall colder winter conditions and greater energy demand for heating buildings

THIS INDICATOR MEASURES THE ENERGY REQUIRED FOR HEATING BUILDINGS

BACKGROUND

- Heating Degree Days is the average annual sum of the number of degrees that every day's average temperature is below 65°F, and therefore buildings must be heated.
- A heating degree day is a measure of the total energy demand needed to heat a building.
- Climate change is anticipated to increase temperatures in all seasons, including overnight temperatures. Consequently, it is anticipated that energy demand for heating will be reduced in the future.

CALCULATION

- This is the annual sum of the number of degrees that every day's average temperature is below 65°F.
- Compute area average value by HUC8 (so reduce gridded value to one value) for each year in a model run.
- For that model, for each epoch-scenario (e.g., 2050 Low), select the median value from among the area average HUC8 values.
- Across all models in a given epoch-scenario, select the mean value.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS: Daily temperature from 32 CMIP5 GCM model runs downscaled using the LOCA method	Average annual number of heating degree days	**CONUS**: 1/16 degree (6 km)	Daily
AK, HI: Daily temperature from 25 CMIP5 model runs downscaled using the BDSD method		**AK, HI**: 1/8 degree (12 km)	

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Degree days	Energy	1.2

502 COOLING DEGREE DAYS

USACE CLIMATE PREPAREDNESS AND RESILIENCE

LOW INDICATOR VALUE
Lower values indicate overall cooler summer conditions and reduced energy demand for cooling buildings

HIGH INDICATOR VALUE
Higher values indicate overall warmer summer conditions and greater energy demand for cooling buildings

THIS INDICATOR MEASURES THE ENERGY REQUIRED FOR COOLING BUILDINGS

BACKGROUND

- Cooling Degree Days is the average annual sum of the number of degrees that every day's average temperature is above 65°F and therefore buildings must be cooled.
- A cooling degree day is a measure of the total energy demand needed to cool a building.
- Climate change is anticipated to increase temperatures in all seasons, including overnight temperatures. Consequently, it is anticipated that energy demand for cooling will increase in the future.

CALCULATION

- This is the annual sum of the number of degrees that every day's average temperature is above 65°F.
- Compute area average value by HUC8 (so reduce gridded value to one value) for each year in a model run.
- For that model, for each epoch-scenario (e.g., 2050 Low), select the median value from among the area average HUC8 values.
- Across all models in a given epoch-scenario, select the mean value.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS: Daily temperature from 32 CMIP5 GCM model runs downscaled using the LOCA method	Average annual number of cooling degree days	**CONUS**: 1/16 degree (6 km)	Daily
AK, HI: Daily temperature from 25 CMIP5 model runs downscaled using the BCSD method		**AK, HI**: 1/8 degree (12 km)	

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Degree days	Energy	1.7

503 5-DAY MINIMUM TEMPERATURES

USACE CLIMATE PREPAREDNESS AND RESILIENCE

LOW INDICATOR VALUE
Lower values indicate increased exposure to cold weather

HIGH INDICATOR VALUE
Higher values indicate reduced exposure to cold weather

THIS INDICATOR MEASURES THE AVERAGE LOW TEMPERATURE OF THE COLDEST FIVE-DAY PERIOD OF THE YEAR

BACKGROUND

- The five-day minimum temperature is the coldest five-day period in the year, and represents the coldest stretch of winter temperatures.
- Climate change is anticipated to result in higher temperatures year-round, including winter.
- Consequently, the value of the 5-day minimum temperature is likely to increase over time in most regions.

CALCULATION

- This variable represents the average annual coldest five-day period.
- Compute area average value by HUC8 (so reduce gridded value to one value) for each year in a model run.
- For that model, for each epoch-scenario (e.g., 2050 Low), select the minimum value from among the area average HUC8 values.
- Across all models in a given epoch-scenario, select the mean value.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS: Daily temperature from 32 CMIP5 GCM model runs downscaled using the LOCA method	Coldest annual average minimum daily temperature for a five day period	**CONUS**: 1/16 degree (6 km)	Daily
AK, HI: Daily temperature from 25 CMIP5 model runs downscaled using the BCSD method		**AK, HI**: 1/8 degree (12 km)	

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Degrees Fahrenheit	Energy	1

601 FUEL ABUNDANCE

LOW INDICATOR VALUE
Lower values indicate a smaller share of the installation and adjoining lands are in native vegetation

HIGH INDICATOR VALUE
Higher values indicate a greater share of the installation and adjoining lands are in native vegetation

THIS INDICATOR MEASURES HOW MUCH OF THE INSTALLATION AND IMMEDIATELY ADJACENT LAND IS IN NATIVE VEGETATION

BACKGROUND

- Fuel Abundance refers to the percent area of an installation including a 1-mile buffer around the installation boundary that is in natural vegetation. Including a small buffer around the installation accounts for the presence of vegetation that may facilitate the uncontrolled movement of fires on to or off of an installation.
- Wildfire has three key components: abundant vegetation that can serve as fuel; dry climate conditions that contribute to fuel flammability; and natural or human source of ignition.
- This indicator measures the abundance of fuel in the immediate vicinity of the installation which serve as an ignition source or which can carry a fire onto the installation from adjoining areas.
- Native vegetation (as compared to agriculture and ornamental vegetation) does not receive supplemental water and is therefore more likely to ignite and burn when conditions are dry.
- Wetland areas were included in the count because if they dry out, they can become a fuel source; however, tidal wetlands (as in Hawaii) are excluded because sea levels are not responsive to drought conditions.
- For this indicator, projected changes in land use and land cover were available for CONUS, but not for AK or HI. THIS INDICATOR IS STATIC FOR ALASKA AND HAWAII.

CALCULATION

- This is assessed as the percent of area in Wildland vegetation on the installation and within a 1-mile buffer around the installation. **CONUS:** Wildland vegetation is defined as the following land use categories: 3-mech-disturbed National forests; 8-deciduous forest; 9-evergreen forest; 10-mixed forest; 11-grassland; 12-shrubland.
- **ALASKA:** Wildland vegetation is defined as the following land use categories: 41-Deciduous forest; 42-Evergreen forest; 43-Mixed forest; 51-Dwarf scrub; 52-Shrub; 71-Grassland; 72-Sedge/herbaceous; 74-Moss; 90-Woody wetland; 95-Herb wetland.
- **HAWAII:** Wildland vegetation is defined as the following land use categories: 8-Grassland; 9-Deciduous forest; 10-Evergreen forest; 11-Mixed forest; 12-Shrub.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS: USGS EROS FOREcasting SCEnarios of Land-Cover Backcast (1992 baseline)[1] Future: 2050, 2085 (SRES B1, A2)[2]	Projected change in land cover in the vicinity of the installation	**CONUS**: 250m	**CONUS**: 1992, 2050, 2085
AK: Multi-Resolution Land Characteristics Consortium (www.mlrc.gov) National Land Cover Database (NLCD), 2016 Alaska Product (NLCD_2016_Land_Cover_AK_20200213.img)		**AK**: 30m	**AK**: 2016
HI: Multi-Resolution Land Characteristics Consortium (www.mlrc.gov) National Land Cover Database (NLCD), 2011 Hawaii – Ouahu Product (hi_oahu_2011_ccap_hr_land_cover20140619.img), 2001 Hawaii – Hawaii Product (hi_landcover_wimperv_9-30-08_se5.img)		**HI**: 30m	**HI-Oahu**: 2011 **HI-Hawaii**: 2001

[1]Sohl, T. L., R. Reker, M. Bouchard, K. Sayler, J. Dornbierer, S. Wika, R. Quenzer, and A. Friesz. 2016. Modeled historical land use and land cover for the conterminous United States. Journal of Land Use Science DOI: 10.1080/1747423X.2016.1147619.
[2]Sohl, T. L., K. L. Sayler, M. A. Bouchard, R. R. Reker, A. M. Friesz, S. L. Bennett, B. M. Sleeter, R. R. Sleeter, T. S. Wilson, M. Knuppe, and T. Van Hofwegen. 2014. Spatially explicit modeling of 1992 to 2100 land cover and forest stand age for the conterminous United States. Ecological Applications 24:1015-1036. DOI: 10.1890/13-1245.1011

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Percent of area	Wildfire	1.3

602 IGNITION RATE

HIGH INDICATOR VALUE
Higher values indicate a greater risk of wildfire ignition

LOW INDICATOR VALUE
Lower values indicate a reduced risk of wildfire ignition

THIS INDICATOR MEASURES THE DENSITY OF PEOPLE ON AND ADJACENT TO THE INSTALLATION, AND PROVIDES AN INDIRECT MEASURE OF WILDFIRE IGNITIONS DUE TO HUMAN ACTIVITY

BACKGROUND

- Ignition Rate is the population density in proximity to an installation. Human-caused ignitions are assumed to scale with the density of people in the vicinity of wildland vegetation, and therefore the frequency with which people use that space for recreation and other activities.
- Humans are a major cause of wildfire ignition when they conduct activities in and close to vegetated areas (e.g., camping, grilling, operating machinery, smoking, burning trash and also military training activities).[1,2,3]
  - Population density in the vicinity of an installation is a proxy (indirect) measure of human activity in naturally vegetated areas.
  - Changes in wildfire ignition rates are assumed to covary with population density.
- Projected future population data are available for CONUS but not AK or HI. THIS INDICATOR IS STATIC FOR ALASKA AND HAWAII.

CALCULATION

- Population density, and therefore ignition rate, is calculated as:
  - Determine the population density of every county (population /area), for all five epoch-scenarios (CONUS) or just 2010 (AK, HI).
  - Intersect this data with HUC8 watershed boundaries to determine the average population density for each HUC8.
  - For each installation, compute the area weighted average population density of the HUC8 watershed(s) for the installation. This is the indicator value.

[1]Balch, J. K., Bradley, B. A., Abatzoglou, J. T., Nagy, R. C., Fusco, E. J., Mahood, A. L. (2017). Human-started wildfires expand the fire niche across the United States, Proceedings of the National Academy of Sciences USA, 114(11), 2946-2951, doi:10.1073/pnas.1617394114

[2]Nagy, R., Fusco, E., Bradley, B., Abatzoglou, J. T., Balch, J. (2018). Human-related ignitions increase the number of large wildfires across US ecoregions. Fire, 1(1), 4. doi:10.3390/fire1010004

[3]Syphard, A.D., J.E. Keeley, A.H. Pfaff and K. Ferschweiler (2017). Human presence diminishes the importance of climate in driving fire activity across the United States. PNAS 114 (52) 13750-13755, DOI: 10.1073/pnas.1713885114

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS: EPA ICLUS V2-1-1 population data for 2010 (Base Epoch), SSP2 (Low Scenario) and SSP5 (High Scenario) (https://catalog.data.gov/dataset/iclus-v2-1-1-population-projections)	Projected change in population density in the vicinity of the installation	County-level information	**CONUS**: 2010, 2050, 2080
AK, HI: US 2010 Census data (www.census.gov)			**AK, HI**: 2010

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
People/sq. mile	Wildfire	1.1

604 FIRE SEASON LENGTH

HIGH INDICATOR VALUE
Higher values indicate greater wildfire risk

LOW INDICATOR VALUE
Lower values indicate reduced wildfire risk

THIS INDICATOR MEASURES HOW OFTEN SUSTAINED HOT AND DRY CONDITIONS CONTRIBUTE TO THE FLAMMABILITY OF NATIVE VEGETATION ON OR ADJACENT TO AN INSTALLATION

BACKGROUND

- Fire Season Length is the average annual number of days in which the Keetch-Byram Drought Index[1,2] (KBDI) is >600, indicating long-term arid conditions and dry coarse fuels.
- Vegetation becomes more flammable under prolonged dry conditions. The KIBDI captures the accumulated moisture deficit for a given region over the course of a year. Values for the index decrease when precipitation occurs, and increase with number of days since the last precipitation event. An index value of 600 or greater indicates a prolonged period of aridity, which gives time for vegetation and soils to dry out.
- Consequently, the number of days with KBDI > 600 indicates the share of the year in which vegetation is already very dry and wildfires readily ignite and spread.

CALCULATION

- For each model and HUC8, calculate the daily KBDI using the KDBI routine in ClimInd.R[3] , which computes KBDI using the corrections of Alexander (1990).
- Calculate the average annual number of days with KBDI >600 by model and HUC8.
- For each model-epoch-scenario, compute the median number of days KDBI>600.
- For each epoch-scenario, compute the mean number of days KBDI>600 across all models.

[1] Alexander, M.E. (1990). Computer Calculation of the Keetch-Byram Drought Index – Programmers Beware! Fire Management Notes. 51(4): 23-25. (https://cfs.nrcan.gc.ca/pubwarehouse/pdfs/11084.pdf)
[2] Keetch, J.J., and G. Byram (1968). A drought index for forest fire control. Res. Paper SE-38. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 32 pp. (Revised 1988)
[3] https://rdrr.io/cran/ClimInd/src/R/kbdindex.R

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS: 32 CMIP5 GCMs downscaled using the LOCA method for daily temperature and precipitation data	This is the average annual number of days in which extreme weather conditions favor the ignition and spread of wildfires because both fine and coarse fuels have dried out	**CONUS**: 1/16 degree (6 km)	Daily
AK, HI: 25 CMIP5 GCMs downscaled via the BCSD method for daily temperature and precipitation data		**AK, HI**: 1/8 degree (12 km)	

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Days/Year	Wildfire, Land Degradation	1.7 Wildfire, 1.5 Land Degradation

701 SOIL LOSS

HIGH INDICATOR VALUE
Higher values indicate increased exposure to soil loss via surface runoff

LOW INDICATOR VALUE
Lower values indicate decreases exposure to soil loss via surface runoff

THIS INDICATOR MEASURES THE RATE OF SOIL EROSION GIVEN CHANGES IN PRECIPITATION INTENSITY, SOIL TYPE, SLOPE, AND LAND USE

BACKGROUND

- Soil loss can result from many processes, but chief among these are precipitation intensity (how fast precipitation falls) and land use (how dense the vegetation is and therefore its ability to protect the ground surface from erosion). Both of these variables affect the ability of raindrops to dislodge soil particles, and surface runoff to transport these particles to stream channels.
- Soil loss is important because degraded lands impact accessibility to training ranges (if large gullies form), and may increase sediment loads in rivers resulting in the accumulation of sediment in channels and in reservoirs, reducing both the effectiveness of flood risk infrastructure and the capacity of reservoirs to hold water.

CALCULATION

- Soil loss due to surface erosion was calculated using the Revised Universal Soil Loss Equation (RUSLE)[1,2,3]. Soil loss is calculated as a product of: R*C*K*LS*P:
  - R= how erosive precipitation is (derived from intensity)
  - C = vegetation density (derived from land use land cover data)[4]
  - K = soil K-factor (how cohesive the soil is)
  - LS = a factor representing topographic steepness based on topographic data
  - P = a factor representing erosion control measures

[1]Wischmeier, W., and D. Smith. 1978. Predicting rainfall erosion losses: a guide to conservation planning. U.S. Department of Agriculture, Agriculture Handbook No. 537, online at https://www.ars.usda.gov/SP2UserFiles/ad_hoc/36021500USLEDatabase/AH_537.pdf . accessed 30 June 2016.

[2]Renard, K., and J. R. Freimund. 1994. Using monthly precipitation data to estimate the R-factor in the revised USLE. Journal of Hydrology 157:287-306.

[3]Renard, K., G. Foster, G. Weesies, D. McCool, and D. Yoder. 1997. Predicting soil erosion by water. A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture, Agriculture Handbook No. 703.

[4]Sleeter, B. M., T. L. Sohl, M. A. Bouchard, R. R. Reker, C. E. Soulard, W. Acevedo, G. E. Griffith, R. R. Sleeter, R. F. Auch, K. L. Sayler, S. Prisley, and Z. Zhu. 2012. Scenarios of land use and land cover change in the conterminous United States: Utilizing the special report on emission scenarios at ecoregional scales. Global Environmental Change 22:869-914.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS: Daily precipitation from 32 CMIP5 GCM model runs downscaled using the LOCA method. USGS EROS FOREcasting SCEnarios of Land-Cover Backcast (1992 baseline).[1] Future: 2050, 2085 (SRES B1, A2)[2]. USDA soil K-factor data; Open Topography Digital Elevation Model (DEM) 90-m data.	Projected annual rate of soil loss due to surface runoff	**CONUS**: 1/16 degree (6 km)	Daily
AK, HI: Daily precipitation from 25 CMIP5 model runs downscaled using the BCSD method. European Soil Data Centre Global Soil Erosion dataset.[3]		**AK, HI**: 1/8 degree (12 km)	

[1]Sohl, T. L., R. Reker, M. Bouchard, K. Sayler, J. Dornbierer, S. Wika, R. Quenzer, and A. Friesz. 2016. Modeled historical land use and land cover for the conterminous United States. Journal of Land Use Science DOI: 10.1080/1747423X.2016.1147619.

[2]Sohl, T. L., K. L. Sayler, M. A. Bouchard, R. R. Reker, A. M. Friesz, S. L. Bennett, B. M. Sleeter, R. R. Sleeter, T. S. Wilson, M. Knuppe, and T. Van Hofwegen. 2014. Spatially explicit modeling of 1992 to 2100 land cover and forest stand age for the conterminous United States. Ecological Applications 24:1015-1036. DOI: 1010.1890/1013-1245.1011.

[3]Panagos P., Borrelli P., Meusburger K., Yu B., Klik A., Lim K.J., Yang J.E, Ni J., Miao C., Chattopadhyay N., Sadeghi S.H., Hazbavi Z., Zabihi M., Larionov G.A., Krasnov S.F., Garobets A., Levi Y., Erpul G., Birkel C., Hoyos N., Naipal V., Oliveira P.T.S., Bonilla C.A., Meddi M., Nel W., Dashti H., Boni M., Diodato N., Van Oost K., Nearing M.A., Ballabio C., 2017. Global rainfall erosivity assessment based on high-temporal resolution rainfall records. Scientific Reports 7: 4175. DOI: 10.1038/s41598-017-04282-8. [https://esdac.jrc.ec.europa.eu/content/global-soil-erosion]

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Tons/Acre/Year	Land Degradation	1

702 PERMAFROST

USACE CLIMATE PREPAREDNESS AND RESILIENCE

LOW INDICATOR VALUE
Lower values indicate a smaller share of the installation's land may be affected by permafrost thawing, resulting in infrastructure damage

HIGH INDICATOR VALUE
Higher values indicate a larger share of the installation's land may be affected by permafrost thawing, resulting in infrastructure damage

THIS INDICATOR MEASURES THE PERCENT OF THE INSTALLATION WHERE PERMAFROST THAW MAY RESULT IN INFRASTRUCTURE DAMAGE

BACKGROUND

- Permafrost Hazard Potential is the percent of the installation rated as low[1] or higher on the consensus geohazard index indicating significant risk for damage to infrastructure for a given location. It indicates how much of an installation's infrastructure may be at risk due to permafrost thaw.
- This index captures the mitigating effects of multiple factors, including soil substrate, on the consequences of permafrost thaw. For example, while fine-sediment deposits may subside or be subject to liquefaction as permafrost thaws, gravelly substrates may retain most or all of their engineering performance characteristics. The former location would have a much higher hazard potential than the later based on this index. It is assumed that the current hazard of existing permafrost is zero, so this indicator addresses the question of the hazard posed if existing permafrost thaws.
- Hjort et al. (2018) combined information about permafrost ground temperature (MAGT) and active layer thickness (ALT)[2] with additional environmental variables (e.g., climate, soils, water, land cover) and infrastructure data (roads, bridges, etc.) to calculate Northern Hemisphere infrastructure risk (low, moderate, high) due to near surface (<15 m) permafrost thaw for the periods 2041–2060 and 2061–2080.
- This index is a conservative estimate of potential impacts to infrastructure as a result of permafrost thaw.[3]

CALCULATION

- Installation boundary shapefiles were intersected with the gridded data from Karjalainen et al. (2019), and the percent of installation by consensus geohazard index for infrastructure built on permafrost for the periods of analysis:
    - Historic baseline: 2000-2014. Baseline permafrost has a default hazard value of 0.
    - 2050 epoch: 2041 to 2060.
    - 2085 epoch: 2061 to 2080.
- For both the 2050 and 2085 epochs, the Low scenario derived from climate data for the lower atmospheric concentration (relative concentration pathway 2.6) multiple model ensemble climate, and while data for the High scenario was developed using the higher atmospheric concentration (relative concentration pathway 8.5) multiple model ensemble climate data.
- The data were aggregated into percent of installation with non-zero hazard (combining the area of hazards in categories 1, 2, and 3).

[1]Aalto, J., O. Karjalainen, J. Hjort, and M. Luoto. 2018. Statistical Forecasting of Current and Future Circum-Arctic Ground Temperatures and Active Layer Thickness. Geophysical Research Letters 45:4889–4898.
[2]Hjort, J., O. Karjalainen, J. Aalto, S. Westermann, V. E. Romanovsky, F. E. Nelson, B. Etzelmuller, and M. Luoto. 2018. Degrading permafrost puts Arctic infrastructure at risk by mid-century. Nature Communications 9.
[3]Karjalainen, O., J. Aalto, M. Luoto, S. Westermann, V. E. Romanovsky, F. E. Nelson, B. Etzelmuller, and J. Hjort. 2019. Circumpolar permafrost maps and geohazard indices for near-future infrastructure risk assessments. Scientific Data 6.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
Circumpolar raster grid data[4] from PANGAEA archive at https://doi.pangaea.de/10.1594/PANGAEA.893881	The percent of each installation where thawing permafrost has the potential to damage infrastructure	30 arc-second resolution (~1 km^2)	Epoch averages Base: 2000-2014; 2050: 2041-2060; 2085: 2061-2080
[4]Karjalainen, Olli; Aalto, Juha; Luoto, Miska; Westermann, Sebastian; Romanovsky, Vladimir E; Nelson, Frederick E; Etzelmüller, Bernd; Hjort, Jan (2018): Circumpolar raster grids of permafrost extent and geohazard potential for near-future climate scenarios. PANGAEA, https://doi.org/10.1594/PANGAEA.893881			

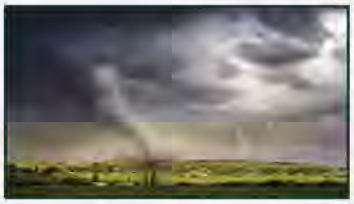
THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Percent of area	Land Degradation	1

801 TORNADO FREQUENCY

HIGH INDICATOR VALUE
Higher values indicate greater tornado risk

LOW INDICATOR VALUE
Lower values indicate lesser tornado risk



THIS INDICATOR MEASURES HOW OFTEN TORNADOES HAVE OCCURRED ON OR NEAR AN INSTALLATION

BACKGROUND

- Tornado Frequency is the average annual probability of a tornado occurring on or in the HUC8 watershed(s) of an installation.
- THIS IS A STATIC INDICATOR.

CALCULATION

- **CONUS**: For each tornado track, the path of the tornado is represented by a 5 km buffer around this track. A high resolution grid (0.01 decimal degrees or ~1km) was created for CONUS, and for each cell in the grid, tornado frequency was computed as the number of buffered tracks that overlap the cell.
  - Intersect the gridded tornado frequency data with the HUC8 watershed boundaries.
  - For each HUC8, assign the value of the cell with the largest number of tornadoes within the analysis period (1994-2018).
  - Divide by the length of the period of record (25 years inclusive) to get the annual Tornado Frequency.
  - Each installation is assigned the HUC8 value. If an installation boundary crosses into multiple HUC8 watersheds, select the maximum HUC8 value.
- **AK, HI**: For each county, determine the number of tornadoes that have been recorded. Divide this by the period of record (1996-2019) to determine the frequency defined as occurrences/year. The installation is assigned the value for the county in which it is located. If the installation boundary spans more than one county, assign the maximum of the county values to the installation.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS: Tornado track data for the period 1994-2018 was obtained from the NOAA National Weather Service Storm Prediction Center Tornado, Hail and Wind Database (https://www.spc.noaa.gov/gis/svrgis/)	Frequency with which tornadoes have occurred on an installation or within its immediate HUC8 watershed	**CONUS**: 0.01 degree (~ 1 km)	Daily
AK, HI: NOAA Storm Events Database[1] (https://www.ncdc.noaa.gov/stormevents/ftp.jsp)		**AK, HI**: County	

[1] NOAA National Centers for Environmental Information. 2020. NCDC Storm Events Database. https://www.ncdc.noaa.gov/stormevents/

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Probability	Historical Extreme Conditions	1.4

802 HURRICANE FREQUENCY

USACE CLIMATE PREPAREDNESS AND RESILIENCE

HIGH INDICATOR VALUE
Higher values indicate greater hurricane risk

THIS INDICATOR MEASURES HOW OFTEN HURRICANES HAVE IMPACTED AN INSTALLATION AND ITS ADJACENT WATERSHED

LOW INDICATOR VALUE
Lower values indicate lesser hurricane risk

BACKGROUND

- Hurricane Frequency is the mean annual probability of being impacted by a hurricane, defined as being within 200 km buffer around the hurricane track.
- The hurricane track data comes from the International Tropical Cyclone Best Track Dataset (IBTrACS, https://www.ncdc.noaa.gov/ibtracs/) (Knapp et al. 2010). This is a static indicator based on data from the period 1970-2017.
- THIS IS A STATIC INDICATOR.

CALCULATION

- A particular location is determined to have been impacted by a given tropical cyclone if it falls anywhere within the 200 km buffer about the storm track.
- For a given location, count the number of times in the period 1970-2017 that it has fallen within the buffer zone of the tropical cyclone best track.
- Divide this count by the number of years in the period (48 years) to get the annual tropical cyclone density for each location.
- Each HUC8 watershed is assigned the largest precipitation value for any grid cell falling in that watershed.
- Each installation receives the value for the HUC8 watershed in which it is located. If the boundary crosses more than one watershed, the maximum value across HUC8 watersheds is assigned to the installation.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS, AK, HI: International Tropical Cyclone Best Track Dataset (IBTrACS, https://www.ncdc.noaa.gov/ibtracs/).[1] This is a static indicator based on data from the period 1970-2017	Frequency with which hurricanes have passed over or very close to (within 200 km of) an installation over the period 1970-2017	0.25 degree	Daily

[1]Knapp, K. R., M. C. Kruk, D. H. Levinson, H. J. Diamond, and C. J. Neumann, 2010: The International Best Track Archive for Climate Stewardship (IBTrACS): Unifying tropical cyclone best track data. Bulletin of the American Meteor. Society, 91, 363-376. doi:10.1175/2009BAMS2755.1

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Probability	Historical Extreme Conditions	1.7

803 ICE STORM OCCURRENCE

USACE CLIMATE PREPAREDNESS AND RESILIENCE

HIGH INDICATOR VALUE
Ice storms have occurred historically

LOW INDICATOR VALUE
Ice storms are not known to have occurred historically

THIS INDICATOR MEASURES WHETHER AN ICE STORM HAS OCCURRED WITHIN THE VICINITY OF AN INSTALLATION

BACKGROUND

- Ice Storms are a presence-absence indicator identifying places in the U.S. where freezing rain storms have occurred that have significantly impacted above-ground infrastructure.
- Ice storms, also known as damaging freezing rain storms, are storms in which freezing rain occurs, resulting in ice accumulation on standing structures. Ice storms can be a significant source of damage to above-ground infrastructure both on installations and affecting supporting utilities and other infrastructure in adjacent communities. Damage from ice storms averages approximately $313 million per year[1], and for the period 1996-2012 was associated with 95 fatalities and 331 direct injuries in the U.S.[2] Ice storms are significantly more likely to result in a federal disaster declaration than any other kind of winter storm[1], and damage not just infrastructure, buildings and roads, but also result in lost productivity over the days during which power and other utilities are restored and streets are cleared of downed trees, transmission lines, and other debris.
- THIS IS A STATIC INDICATOR.

CALCULATION

- The Ice Storms database provides a record of the location of ice storms affecting above ground infrastructure in the U.S. The data are highly variable in completeness through time. Therefore, this metric is a presence-absence metric.
- Merge all storm polygons in GIS to determine the extent of all recorded ice storms.
- Tabulate intersection with HUC8 polygons, assigning to each HUC8 watershed the maximum value of the intersection (1 for occurred, 0 for did not occur).
- For each watershed assign the maximum value of the HUC8 watershed(s) in which the installation is located, identifying those installations where ice storms affected either the installation itself or infrastructure and access provided to the installation from surrounding communities.

[1] Zarnani A., P. Musilek, X. Shi, X. Ke, and H. He (2012). Learning to predict ice accretion on electric power lines. Engineering Applications of Artificial Intelligence 25: 609–617. doi: 10.1016/j.engappai.2011.11.004

[2] Degelia, S. K., J. I. Christian, J.B. Basara, T. J. Mitchell, D.F. Gardner, S.E. Jackson, J.C. Ragland, and H. B. Mahan (2016). An overview of ice storms and their impact in the United States. International Journal of Climatology 36(2016):2811-2822

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS, AK, HI: USACE Cold Regions Research and Engineer Laboratory Ice Storms Database, http://rsgisias.crrel.usace.army.mil/ice/icegis.html[3]	Whether or not an ice storm is recorded to have ever occurred within the same watershed as the installation	Latitude and longitude values for ice storm events are of variable accuracy, based on descriptions in references sources	1946-2014

[3] Jones, K.F., R. Thorkildson and J.N. Lott (2002). The development of the map of extreme ice loads for ASCE Manual 74, Electrical Transmission in a New Age, Omaha, ASCE, Reston Virginia, pp 9-31

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Occurrence (presence, absence)	Historical Extreme Conditions	1.2

804 HISTORICAL DROUGHT FREQUENCY

USACE CLIMATE PREPAREDNESS AND RESILIENCE

HIGH INDICATOR VALUE
Higher values indicate greater drought risk

LOW INDICATOR VALUE
Lower values indicate lesser drought risk

THIS INDICATOR MEASURES THE FREQUENCY OF EXTREME AND EXCEPTIONAL DROUGHT CONDITIONS WITHIN AN INSTALLATION'S WATERSHED

BACKGROUND

- Historical Drought Frequency is the percent of weeks in the historic period when any part of an installation was categorized as in severe (D2), extreme (D3), or exceptional (D4) drought as determined by the National Integrated Drought Information System (NIDIS) Gridded Annual US Drought Monitor data.[1,2]
- NIDIS drought values range from D0 (no drought) through D4 (exceptional drought). The data are weekly values for the period 2000 and 2018. Each installation was assigned a weekly value that represents the most extreme drought value for the installation for that week. Then the total number of weeks in the highest three categories (D2= severe, D3=extreme, D4=exceptional) was summed. Historical drought frequency is then determined as the percent of all weeks in D2, D3, and D4 drought for the period 2000 to 2018. Higher values indicate greater exposure to drought.
- THIS IS A STATIC INDICATOR.

CALCULATION

- To calculate this indicator:
  - Data on the weekly drought status was obtained from the NIDIS Drought Monitor website. These determinations are based on both meteorological data and expert elicitation.
  - For the period January 2000 through December 2018, gridded data on the weekly occurrence of Severe Drought (D2), Extreme Drought (D3), and Exceptional Drought (D4) were obtained.
  - For each HUC8 watershed, the assigned value is the maximum number of weeks in D2, D3, or D4 drought of any portion of that watershed.
  - This indicator is the total number of weeks in D2, D3, or D4 drought divided by the total number of weeks in the period of record.
  - Each installation is assigned the value of the HUC8 watershed in which it is located. If the installation spans multiple watersheds, the installation is assigned the maximum value across these watersheds.

[1]Svoboda, M., D. LeComte, M. Hayes, R. Heim, K. Gleason, J. Angel, B. Rippey, R. Tinker, M. Palecki, D. Stooksbury, D. Miskus, and S. Stephens (2002). The Drought Monitor. Bulletin of the American Meteorological Society 83(8):1181-1190

[2]National Drought Mitigation Center, National Integrated Drought Information System, and National Centers for Environmental Information. 2020. Gridded Annual US Drought Monitor (USDM) Maps. https://www.drought.gov/drought/data-gallery/gridded-annual-us-drought-monitor-usdm-maps

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
National Integrated Drought Information System (NIDIS) historical records[2]	Percent of weeks in extreme or exceptional drought for the period 2000-2018	5km grid	Weekly

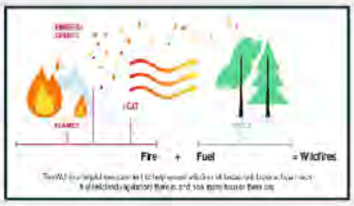
THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Percent of weeks	Historical Extreme Conditions	1.1

805 WILDLAND URBAN INTERFACE

HIGH INDICATOR VALUE
Higher values indicate greater wildfire risk

LOW INDICATOR VALUE
Lower values indicate lesser wildfire risk



THIS INDICATOR MEASURES THE PERCENT OF AN INSTALLATION IN THE WILDLAND URBAN INTERFACE

BACKGROUND

- Wildland Urban interface (WUI) is the percent of installation classified as wildland-urban interface or intermix (Martinuzzi et al. 2015).
- The WUI interface and intermix categories are areas where housing is adjacent to or intermixed with wildland vegetation (forests, shrublands) and fires originating in wildland vegetation areas can readily cross into housing areas (and vice-versa). Although non-housing development may also occur adjacent to or intermixed with wildland vegetation, such development is far more likely to concentrate to form developed areas separated from wildland vegetation.
- The WUI was mapped for CONUS by the USDA (Radeloff et al. 2017, Martinuzzi et al. 2015). The same methodology was used to develop this data for AK and HI.
- Intermix is defined as lands where houses at wildland vegetation intermingle and are characterized by ≥ 6.18 houses per km2 and ≥ 50 percent cover of wildland vegetation (Martinuzzi et al. 2015).
- Interface is defined as a developed area (such as a housing development) immediately adjacent to areas of heavy vegetation and are characterized as (Martinuzzi et al. 2015):
    - Areas with ≥6.18 houses per km2 and <50 percent cover of vegetation located ≤2.4 km of an area ≥5 km² in size that is ≥75 percent vegetated. 2.4 km represents the approximate distance than burning embers can be carried by the wind in the vicinity of a large wildfire.
- THIS IS A STATIC INDICATOR.

CALCULATION

- **CONUS**: Intersect USDA WUI map with installation boundary polygons and determine percent area classified as interface or intermix.
- **AK, HI**: The following steps were used to calculate the percent of installation in the WUI:
    - Using Census block data (number of houses, census block area) compute housing density.
    - Using NLCD dataset, Identify areas of natural vegetation (forests (coniferous, deciduous, mixed), shrub, grasslands, wetlands), and generate a shapefile that identifies areas of native vegetation.
    - Intersect Census housing density datalayer with vegetation data layer to determine the percent of each Census block area that is in natural vegetation.
    - Assign polygons to WUI classes based on the definitions provided by Martinuzzi et al. (2015).
    - The Wildland Urban interface Percent Area is then calculated as the percentage of an installation's footprint that is categorized as either intermix or interface.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS: USDA Wildland Urban Interface Map[1] (https://www.fs.usda.gov/rds/archive/catalog/RDS-2015-0012-2)	Percent of each installation in which housing and large stands of vegetation are in close proximity interface, intermix), allowing fire to easily cross between them[2,3]	**CONUS**: census block (coarsest resolution input)	**CONUS**: 2010
AK, HI: U.S. Census (www.census.gov): Population Data (2010). Multi-Resolution Land Characteristics Consortium (www.mlrc.gov): National Land Cover Database (NLCD), 2016 Alaska Product and 2011 and 2001 Hawaii, downloaded from https://www.mrlc.gov/data?f%5B0%5D=category%3Aland%20cover		**AK, HI**: census block (coarsest resolution input)	**AK**: 2020 + 2016 **HI**: 2010 + 2011 + 2001

[1] U.S. Department of Agriculture (USDA) (2015). The 2010 Wildland-Urban Interface of the Conterminous United States. http://www.nrs.fs.fed.us/pubs/48642

[2] Martinuzzi, Sebastián; Stewart, Susan I.; Helmers, David P.; Mockrin, Miranda H.; Hammer, Roger B.; Radeloff, Volker C. 2015. The 2010 wildland-urban interface of the conterminous United States. Research Map NRS-8. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 124 p. [includes pull-out map]. https://www.fs.fed.us/nrs/pubs/rmap/rmap_nrs8.pdf

[3] Radeloff, Volker C.; Helmers, David P.; Kramer, H. Anu; Mockrin, Miranda H.; Alexandre, Patricia M.; Bar Massada, Avi; Butsic, Van; Hawbaker, Todd J.; Martinuzzi, Sebastián; Syphard, Alexandra D.; Stewart, Susan I. 2017. The 1990-2010 wildland-urban interface of the conterminous United States - geospatial data. 2nd Edition. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2015-0012-2

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Percent of area	Historical Extreme Conditions	1.3

806 HURRICANE WIND > 50 KNOTS

USACE CLIMATE PREPAREDNESS AND RESILIENCE

HIGH INDICATOR VALUE
Higher values indicate that damaging hurricane winds occur more frequently

LOW INDICATOR VALUE
Lower values indicate that damaging hurricane winds are infrequent or absent

THIS INDICATOR MEASURES THE FREQUENCY WITH WHICH AN INSTALLATION HAS BEEN HIT BY DAMAGING HURRICANE WINDS (WIND SPEEDS >50 KNOTS)

BACKGROUND

- Hurricane Wind > 50 knots is the maximum frequency with which any portion of an installation's HUC8 watershed was impacted by hurricane winds greater than 50 knots. Damaging winds are not limited to hurricane events. However, wind damage from other causes is not included in this indicator.
- THIS IS A STATIC INDICATOR.

CALCULATION

- The following processing steps were used to create this indicator:
  - For each storm in the Extended HURDAT dataset for which there is wind data (1988-2018, 298 events, 30 years inclusive), identify the region falling within of the 50 knot windfield along the hurricane track.
  - For each grid cell, count the number of times it falls within the 50 knot windfield of hurricanes in the period of record.
  - For each HUC8, determine the maximum number of times any portion of the hydrologic unit fell within the 50 knot windfield during the period of record. Divide by 30 to get the annual probability of falling within the 50 knot windfield of a hurricane.
  - Installation is assigned the HUC8 value.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS, AK, HI: Extended HURDAT Best Track Dataset[1] for 1988-2018. (http://rammb.cira.colostate.edu/research/tropical_cyclones/tc_extended_best_track_dataset/index.asp) based on the National Hurricane Data Center's HURDAT dataset	Frequency with which an installation or its immediate watershed have been subject to high winds during a hurricane	Tabular data, decimal degrees with resolution of 0.1 degree (~11 km)	Daily

[1]Demuth, J., M. DeMaria, and J.A. Knaff, 2006: Improvement of advanced microwave sounder unit tropical cyclone intensity and size estimation algorithms. J. Appl. Meteor., 45, 1573-1581.

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Count/Year	Historical Extreme Conditions	1.4

807 HURRICANE MAXIMUM ANNUAL PRECIPITATION

LOW INDICATOR VALUE
Lower values indicate that precipitation volumes from hurricanes are lower and less likely to result in flood damage

HIGH INDICATOR VALUE
Higher values indicate that precipitation volumes from hurricanes are greater, with greater potential for flood damage

THIS INDICATOR MEASURES THE AVERAGE ANNUAL AMOUNT OF RAINFALL THAT OCCURS AS A RESULT OF HURRICANES

BACKGROUND

- Hurricane Maximum Average Precipitation is the maximum average annual precipitation from hurricane events experienced in any portion of an installation's HUC8 watershed across all storms.
- THIS IS A STATIC INDICATOR.

CALCULATION

- The following steps were used to calculate this indicator:
  - Storm total precipitation along each defined storm track within the defined 200 km buffer was obtained from the Multi-Source Weighted-Ensemble Precipitation (MSWEP) database. This precipitation was then averaged across all storm events crossing a given location for the period 1979-2016 to yield a gridded dataset of average annual precipitation from tropical cyclones. These totals are converted to inches.
  - Each HUC8 watershed is assigned the largest precipitation value for any grid cell falling in that watershed.
  - Each installation receives the value for the HUC8 watershed in which it is located. If the boundary crosses more than one watershed, the maximum value across HUC8 watersheds is assigned to the installation.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
CONUS, AK, HI: International Tropical Cyclone Best Track Dataset (IBTrACS, https://www.ncdc.noaa.gov/ibtracs/)[1]. This is a static indicator based on data from the period 1970-2017. The precipitation data comes from the Multi-Source Weighted-Ensemble Precipitation (MSWEP) dataset[2].	Average annual precipitation due to hurricanes	Tabular data gridded on a 0.25 degree grid	Daily

[1] Knapp, K. R., M. C. Kruk, D. H. Levinson, H. J. Diamond, and C. J. Neumann, 2010: The International Best Track Archive for Climate Stewardship (IBTrACS): Unifying tropical cyclone best track data. Bulletin of the American Meteor. Society, 91, 363-376. doi:10.1175/2009BAMS2755.1

[2] Beck, H. E., van Dijk, A. I. J. M., Levizzani, V., Schellekens, J., Miralles, D. G., Martens, B., and de Roo, A.: MSWEP: 3-hourly 0.25° global gridded precipitation (1979–2015) by merging gauge, satellite, and reanalysis data, Hydrol. Earth Syst. Sci., 21, 589–615, https://doi.org/10.5194/hess-21-589-2017, 2017.

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Impact Component	Importance Weight (Can vary from 1 to 2)
Inches	Historical Extreme Conditions	1.5

808 ICE JAM OCCURRENCE

HIGH INDICATOR VALUE
Higher values indicate that ice jams have occurred historically

LOW INDICATOR VALUE
Lower values indicate that ice jams are not known to have occurred historically

THIS INDICATOR MEASURES WHETHER AN ICE JAM IS KNOWN TO HAVE OCCURRED WITHIN THE VICINITY OF AN INSTALLATION

BACKGROUND

- Ice Jam Occurrence is a presence-absence indicator identifying places in the U.S. where ice jams have occurred in an installation's HUC8 watershed(s).
- Because the recording of ice jams requires an observer, and likely an impact to infrastructure to be worthy of recording, the data are likely inhomogeneous and spatially-incomplete. Consequently, this is used only as a presence-absence indicator.
- THIS IS A STATIC INDICATOR.

CALCULATION

- Ice Jam occurrence data are saved as a point geospatial data layer.
- Use GIS to intersect Ice Jam Occurrence point data with HUC8 polygons to determine occurrence (polygons with at least one ice jam in the database).
- For each installation, identify as vulnerable if any HUC8 watershed the installation boundary crosses is identified as have had an ice jam occurrence.

DATA SOURCES

Data Source	Description	Spatial Resolution	Temporal Resolution
USACE Cold Regions Research and Engineering Lab Ice Jams Database[1] (https://icejam.sec.usace.army.mil/ords/f?p=101:7)	Whether or not an ice jam is recorded to have ever occurred on rivers within the same watershed as the installation	Tabular data, variable resolution: Latitude and longitude values for ice jam events are of variable accuracy, based on descriptions in references sources, nearby USGS gaging stations, or city of occurrence and are subject to the accuracy of GPS measurements, interpolation from topographic or and other maps, and age of records	Daily

[1]Weyrick, P.B., K.D. White, S.F. Daly, M.J. Bullock and J.J. Gagnon. 2007. CRREL's Ice Jam Database and Website. CGU HS Committee on River Ice Processes and the Environment. 14th Workshop on the Hydraulics of Ice Covered Rivers. Quebec City, June 19 - 22, 2007

THIS INDICATOR WAS USED TO ASSESS EXPOSURE

Units	Hazard Category	Importance Weight (Can vary from 1 to 2)
Occurrence (presence, absence)	Historical Extreme Conditions	1.2

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APPENDIX C: CLIMATE PREPAREDNESS AND RESILIENCE MEASURES

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C.1 Introduction

Appendix C provides information on resilience measures for addressing projected climate change hazards on installations with respect to heat, drought, wildfire, energy demand, land degradation, riverine flooding, and coastal flooding.

This appendix also contains four tables that describe resilience measures in brief, including initial and operations and maintenance costs where available. The tables are categorized as follows:

- Management measures, which are defined as planning, regulatory, information gathering, and behavioral activities that enhance or guide resilience (such as updating installation design standards or zoning requirements).
- Temporary measures, which are designed to address short-term needs and are not intended to be permanent (such as sand bagging).
- Structural measures, which are permanent or long-lived measures that reduce the likelihood of an impact occurring (such as a levee that reduces the risk of flood waters from entering the land side of the levee, thereby reducing the frequency of floodplain flooding).
- Nonstructural measures, which are permanent or long-lived measures that mitigate the impacts of exposure to a hazard (such as dry flood-proofing or elevating a structure) but do not reduce the probability of an impact (e.g., the frequency of flooding is not changed, but the amount of damages is reduced).

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C.2 Heat Hazard

The most important strategy for addressing heat hazards at installations is to follow current installation design standards so that heat uptake in the built environment is reduced. Typical resilience measures are listed below (EPA 2008, 2012).

- Cool roofs: Light colored or reflective materials that reduce heat absorption (see Table C.1 for costs).
- Green roofs ($10–$20 per sq. ft to install, $0.75–$1.50 per square foot annual maintenance cost per EPA (2008).
- Cool pavement: asphalt or concrete pavement with high albedo materials mixed in or pavement treated to increase reflectivity (see Table C.2 for costs).
- Increasing tree canopy cover and vegetation to reduce heat exposure (shading buildings, roads, walkways and other urban surfaces). Tree maintenance costs are approximately $15–$65 annually per tree (EPA 2008).
- Adjusting pavement composition to be more resistant to heat damage as part of ongoing maintenance activities.

Figure C.1: Soldiers learning to repair airfield pavement (https://www.army.mil/article/164389/course_lays_foundation_for_airfield_pavement_management)

Other strategies include:

- Reducing heat retention by buildings by increasing building insulation and selection of materials to reduce heat absorption/reflection.
- Incorporating passive cooling in building design.
- Increasing distance between buildings to improve air circulation and therefore nighttime heat dissipation.
- Shaded parking structures (with or without rooftop solar generating capacity).
- Shaded parks, outdoor recreation areas, and seating areas adjacent to buildings.
- Shaded structures in outdoor training areas.
- Improving emergency response to heat-related illness.
- Establishing or enhancing heat preparedness plans, including designating areas as emergency cooling centers.
- Behavioral changes: Improved heat education, increasing acclimatization times, shifting activities to cooler times of day or seasons.
- Afforestation and reforestation of disturbed areas.
- Shifting to more heat and drought-tolerant shade tree species.
- Improving shade in reservoir areas to reduce water temperatures and controlling land use and land cover around reservoirs to reduce nutrient inputs that contribute to harmful algal blooms.
- Increasing the size of ecosystem habitat patches (larger patches are cooler) and increasing connectivity by creating and maintaining corridors.
- Improving energy efficiency of buildings and infrastructure to reduce demand and occurrence of brown-outs and black-outs during heat waves.
- Updating power grid (“smart grid”) to improve load balance.
- Diversifying power sources and have sufficient power generation capacity on base to limit dependence on off-base infrastructure.

Finally, the planner should evaluate the long-term suitability of the installation to its missions under projected future conditions.

Table C.1: Cool roof types and costs (EPA 2008, Chapter 4, Table 2)

Roof Type	Reflectance	Emittance	Cost ($/sq. ft)
Built up roof with white gravel	0.30–0.50	0.80–0.90	$1.20–$2.15
Built up roof with gravel and cementitious coating	0.50–0.70	0.80–0.90	$1.20–$2.15
Built up roof with smooth surface with white roof coating	0.75–0.85	0.80–0.90	$1.20–$2.15
Single-ply membrane (white PVC)	0.70–0.78	0.80–0.90	$1.00–$2.05
Single-ply membrane (color with cool pigments)	0.40–0.60	0.80–0.90	$1.00–$2.05
Modified Bitumen (white coating over mineral surface)	0.60–0.75	0.80–0.90	$1.50–$1.95
Metal roof (white painted)	0.60–0.70	0.80–0.90	$1.80–$3.75
Metal roof (color with cool pigments)	0.40–0.70	0.80–0.90	$1.80–$3.75
Asphalt shingle (white or light gray)	0.25–0.27	0.80–0.90	$0.60–$2.10
Asphalt shingle (medium grey or brown with cool pigments)	0.25–0.27	0.80–0.90	$0.60–$2.10
Liquid applied coating (smooth white)	0.70–0.85	0.80–0.90	$0.60–$0.80
Liquid applied coating (smooth off-white)	0.40–0.60	0.80–0.90	$0.60–$0.80
Liquid applied coating (rough white)	0.50–0.60	0.80–0.90	$0.60–$0.80
Concrete tile (white)	0.70	0.80–0.90	$1.00–$6.00
Concrete tile (color with cool pigments)	0.40–0.50	0.80–0.90	$1.00–$6.00
Clay tile (white)	0.70	0.80–0.90	$3.00–$5.00
Clay tile (terra cotta)	0.40	0.80–0.90	$3.00–$5.00
Clay tile (color with cool pigments)	0.40–0.60	0.80–0.90	$3.00–$5.00
Wood shake (bare)	0.40–0.55	0.80–0.90	$0.50–$2.00

Table C.2: Cool pavement types and costs (EPA 2012)

Basic Pavement Types	Example Cool Approaches	Approximate Installed Cost $/sq. foot	Estimated Service Life, Years
New Construction			
Asphalt (conventional)	Hot mix asphalt with light aggregate, if locally available	$0.01–$1.50	7–20
Concrete (conventional)	Portland cement, plain-jointed	$0.30–$4.50	15–35
Non-vegetated permeable pavement	Porous asphalt	$2.00–$2.50	7–10
	Pervious concrete	$5.00–$6.25	15–20
	Paving blocks	$5.00–$10.00	>20
Vegetated permeable pavement	Grass/gravel pavers	$1.50–$5.75	>10
Maintenance			
Surface applications	Chip seals with light aggregate, if locally available	$0.10–$0.15	2–8
	Microsurfacing	$0.35–$0.65	7–10
	Ultra-thin whitetopping	$1.50–$6.50	10–15

C.3 Drought Hazard

Drought is a hazard in its own right and contributes to other hazards (such as wildfire, land degradation, and heat). Drought is a concern because it reduces available surface water affecting municipal and industrial water supplies, including those used for energy generation. Drought hazard is important to track directly (in addition to its contribution to other hazards) because of the need to evaluate the fit between current drought resilience and future resilience needs. This is especially important with respect to water supply.

Drought contributes to stream flow reductions and reduced water levels in reservoirs, both of which concentrate pollutants and increase the likelihood of harmful algal blooms. Drought also reduces soil moisture, resulting in vegetation die back and loss, which leaves the ground surface open to erosion and the vegetation susceptible to wildfire. Bare ground and clear skies also exacerbate heat stress.

Most localities are adapted to a routine level of drought, having sufficient water supplies and other plans to address anticipated duration and magnitude of drought-induced water-supply shortfalls typical of that location's climate. However, increasing frequency and severity of droughts should be considered where appropriate. The most important strategy for addressing drought hazards at an installation is to ensure adequate water supply given the missions and demographics by:

- Increasing availability of supply:
    - Increase reservoir storage capacity
    - Stormwater collection/harvesting
    - Groundwater recharge
    - Rainwater capture
    - Wastewater recycling, which varies in treatment complexity by both source (Table C.3) and intended use (Table C.4)
    - Desalination of ocean water or brackish groundwater
- Reducing water use:
    - Develop and implement a water conservation plan, including seasonal water restrictions.
    - Meter all users.
    - Relocate/repurpose buildings and facilities that are heavy water users.
    - Increase water use efficiency and conduct routine water audits.
    - Upgrade old, leaky water supply infrastructure.
    - Reduce outdoor water use through replacing most lawn areas with xeriscaping, planting drought-tolerant shade and other species, and moving water-using activities to hangers and other locations where water can be captured, cleaned, and reused (outdoor water use is consumptive; indoor wastewater can be captured and reused).
    - Follow established military water policies (see Table C.5).

Table C.3: Water reuse terminology (Scholze 2011; Table 1)

Term	Definition
Blackwater	Water captured from toilets and urinals along with kitchen waste.
Direct Potable Reuse	The introduction of highly treated reclaimed water either directly into the potable water supply distribution system downstream of a water treatment plant or into the raw water supply immediately upstream of a water treatment plant.
Graywater*	Water captured from sinks, baths, showers, and residential laundries that can be treated and reused. It does not include water from kitchen sinks or dishwashers.
Indirect Potable Reuse	The planned incorporation of reclaimed water into a raw water supply, such as in potable water storage reservoirs or groundwater aquifer, resulting in mixing and assimilation, thus providing an environmental buffer.
Reclaimed Water	Municipal wastewater that has gone through various treatment processes to meet specific water quality criteria with the intent of being used in a beneficial manner such as irrigation. The term “recycled water” is often used synonymously with “reclaimed water.”
Wastewater	Used water discharged from homes, businesses, and industry.
* Some organizations do accept a definition of “graywater” that does include kitchen and dishwasher wastewater along with wastewater from soiled diaper washing. This graywater has higher levels of risk.	

Table C.4: Water reuse categories and typical applications (Scholze 2011; Table 3)

Irrigation	Industrial Recycling & Reuse	Groundwater Recharge	Recreational/ Environmental	Non-Potable Urban Uses
• Parks • School yards • Highway medians • Golf courses • Cemeteries • Parade grounds • Athletic fields • Building landscapes • Crops/vegetable gardens	• Cooling water • Boiler feed • Process water • Construction	• Groundwater recharge • Saltwater intrusion control • Subsidence control	• Lakes and ponds • Marsh enhancement • Streamflow augmentation • Fisheries	• Fire protection • Air conditioning • Toilet flushing • Water features

Table C.5: Office of the Secretary of Defense (OSD) and military department water policies (DoD 2019, Appendix A)

Department	Policy Code	Policy Title
Army	AD 2017-07	*Installation Energy and Water Security Policy*
Army	AD 2014-08	*Water Rights Policy for Army Installations in the U.S.*
Army	AD 2014-02	*Net Zero Installations Policy*
Army	AD 2014-10	*Advanced Metering of Utilities*
Army	AR 200-1	*Environmental Protection and Enhancement*
Army	AR 420-1	*Facilities Management*
Air Force	AFI 32-7062	*Comprehensive Planning*
Air Force	AFI 32-1061	*Providing Utilities to U.S. Air Force Installations*
Air Force	AFI 32-1067	*Water and Fuel Systems*
Air Force	AFI 90-1701	*Installation Energy and Water Management*
Navy	OPNA VINST 3502.08	*Mission Assurance*
Navy	SECNAV 4101.3A	*Department of the Navy Energy Program*
OSD	DoDD 3020.40	*Mission Assurance*
OSD	DoDD 4270.5	*Military Construction*
OSD	DoDI 41 70.11	*Installation Energy Management*
OSD	UFC 1-200-02	*High-Performing Sustainable Buildings Requirements*
OSD	UFC 3-210-10	*Low Impact Development*
Army	AD 2017-07	*Installation Energy and Water Security Policy*
Army	AD 2014-08	*Water Rights Policy for Army Installations in the U.S.*
Army	AD 2014-02	*Net Zero Installations Policy*
Army	AD 2014-10	*Advanced Metering of Utilities*
Army	AR 200-1	*Environmental Protection and Enhancement*
Army	AR 420-1	*Facilities Management*
Air Force	AFI 32-7062	*Comprehensive Planning*
Air Force	AFI 32-1061	*Providing Utilities to U.S. Air Force Installations*
Air Force	AFI 32-1067	*Water and Fuel Systems*
Air Force	AFI 90-1701	*Installation Energy and Water Management*
Navy	OPNA VINST 3502.08	*Mission Assurance*
Navy	SECNAV 4101.3A	*Department of the Navy Energy Program*
OSD	DoDD 3020.40	*Mission Assurance*
OSD	DoDD 4270.5	*Military Construction*
OSD	DoDI 41 70.11	*Installation Energy Management*
OSD	UFC 1-200-02	*High-Performing Sustainable Buildings Requirements*
OSD	UFC 3-210-10	*Low Impact Development*

A Wastewater Reuse Success Story

At Fort Carson, Colorado, the recycle system (Figure C.2) includes a water storage capacity of 10 million gallons and a treatment scheme that includes grit chamber, sand filters, oil skimmers, and aeration basins. Fort Carson estimates that its CVWF saves 150–200 million gallons per year in potable water (Headquarters, U.S. Army Corps of Engineers 2008).

Figure C.2: Central vehicle wash facility Fort Carson, Colorado (Scholze 2011, Figure 1)

C.4 Wildfire Hazard

Wildfire is a significant hazard for installations, whether starting off installation and crossing into an installation, or starting on the installation itself. Under the right dry and windy conditions, a wildfire may burn tens of thousands of acres in 24-hour period. A large, crowning fire may create its own weather system capable of spreading embers a mile or more downwind. If these embers fall on dry brush or on vulnerable structures, new fires may ignite. In addition to direct burn risk, wildfires also create significant air pollution hazards, posing health and visibility risks dozens to hundreds of miles downwind.

Key strategies for addressing wildfire hazards at an installation include:

- Vegetation management to reduce fuel loads:
    - Thinning
    - Prescribed burns (both intentional burns and managed wildfire)
    - Establish fuel breaks
- Installation design standards, which may require:
    - Ignition-resistant construction (see Colorado State Forest Service's *FireWise Construction Site Design and Building Materials* [Bueche and Foley, 2012] for some examples)
    - Noncombustible building materials
    - Updated windows
    - Appropriate land use and zoning requirements
    - Firescaping in the built environment (buffer zones, defensible space, fuel breaks, and species selection)
    - Adherence to building codes, such as those established under the Wildland-Urban Interface (WUI) Federal Risk Mitigation Executive Order 13728 (May 18, 2016, https://www.usfa.fema.gov/downloads/pdf/eo13728_guidelines.pdf) and the 2015 International Wildland-Urban Interface Code (IWUIC) Model Code (https://codes.iccsafe.org/content/IWUIC2015). Some common code requirements are shown in Figure C.3.
- Establish a Wildfire Hazard Mitigation Plan:
    - Plan for a fire that is entirely on base in addition to one that includes non-installation areas requiring coordination with local and regional emergency entities.
    - Conduct regular exercises of this plan.
    - Maintain and implement a risk communication plan.
    - Ensure this plan includes an evacuation plan that takes into account the potential for a fast-moving wildfire (e.g., the Camp Fire that burned through Paradise, California, in 2018 or the 2016 Ft. McMurray Fire in Alberta, Canada).
    - Plan for and educate people about post-wildfire flood and debris flow hazards, which could be significant from years to decades post-fire.

BUILDING CODE
Roof must be Class A, B, or C fire-resistant
Windows must be double-paned
Chimneys must have spark-arresters
Soffits and decks must be enclosed
Sprinklers are required in larger structures

FIRE CODE
Multiple accesses required for subdivisions or projects of certain size
Access roads must be of certain width and gradient
Emergency firefighting water supply required
Flammable materials (wood piles) must be located 30 feet or more from the principal structure
Proper addressing and signage required to guide wildfire and emergency service providers
Clearance of flammable vegetation (defensible space) required around structures

LAND USE CODE
Overlay map of high fire-hazard areas
Clearance of flammable vegetation (defensible space) required around structures
Site plans must use natural features (lakes) or artificial features (golf courses) as fire breaks
Wildfire breaks around perimeter of development must be provided for larger and more complex projects
Maximum development density reduced in high-hazard areas
Clustering of new development away from high wildfire risk areas required or encouraged
Maintenance requirements for defensible space

SUBDIVISION CODE
Clustering of new development away from high wildfire risk areas required or encouraged
Multiple accesses required for subdivisions or projects of certain size
Requirement that homeowners' association be responsible to fund and maintain defensible space

Figure C.3: Common WUI-related provisions (NFPA 2013, Page 15)

C.5 Energy Demand Hazard

Energy demand is affected by rising temperatures that increase both energy demand for cooling overall and peak energy demands on the hottest days; reduce transmission efficiency of above-ground lines during the hottest days; reduce cooling efficiency of power plant cooling water through increases in water temperature; reduce the energy demands for heating where minimum temperatures are rising; and could in some locations reduce water available for energy generation (hydropower, cooling water for thermoelectric generation).

Installation energy security can be increased by:

- Installing additional capacity, including solar and wind, to reduce dependency on regional power grids that may become overloaded during extreme events, leading to brown-outs and black-outs
- Modernizing the grid to improve load sharing
- Using microgrids to increase resilience
- Diversifying the electrical supply (geothermal, hydropower, solar, wind, biomass and biofuel); installations where alternative energy sources are being implemented are shown in Figure C.4
- Working more closely with local and regional entities to ensure sufficient energy availability and security
- Taking advantage of diverse third-party financing mechanisms that the DoD permits for energy development (see Table C.6)
- Using metering to track and regulate usage
- Assessing and reducing potential water supply impacts to generation
- Reducing energy demand by installing more efficient lighting (e.g., LEDs), retrofitting buildings, following Leadership in Energy and Environmental Design (LEED) building design principles, using cool or green roofing to reduce building heat retention (see tables in the Heat Hazard section), taking advantage of passive solar for winter heating, and making use of shade structures wherever practical
- Conducting energy audits and acting on findings

Table C.6: Third-party financing definitions (table modified from DoD 2018; Tables E-1 and 5-1)

Funding Mechanism	Definition
Energy Savings Performance Contracts (ESPC)	An ESPC is a partnership between a federal agency and an energy service company (ESCO). The ESCO conducts a comprehensive energy audit for the federal facility and identifies improvements to save energy. In consultation with the federal agency, the ESCO designs and constructs a project that meets the agency's needs and arranges the necessary funding. The ESCO guarantees that the improvements will generate energy cost savings sufficient to pay for the project over the term of the contract. After the contract ends, all additional cost savings are accrued to the agency. Contract terms up to 25 years are allowed.
Utility Energy Service Contracts (UESC)	In a UESC, a utility arranges funding to cover the capital costs of the project, which are repaid over the contract term from cost savings generated by the energy efficiency measures. With this arrangement, agencies can implement energy improvements with no initial capital investment. The net cost to the federal agency is minimal, and the agency saves time and resources by using the one-stop shopping provided by the utility.
Utility Service Contracts (USCs)	Authority: 10 United States Code (U.S.C.) § 2410q A contract enabling the DoD to enter into agreements for the provision and operation of energy production facilities and the purchase of energy from such facilities.
Power Purchase Agreement (PPA)	Authority: 10 U.S.C. § 2922(a) An agreement enabling the DoD to enter into a contract for the purchase of electricity from sources of renewable energy.
Energy Enhanced Use Leases (EULs)	Authority: 10 U.S.C. § 2667 An EUL for the production of energy allows an installation to lease land to a lessee in return for cash or in-kind contributions. For renewable energy projects that use the authority, DoD requires that the Military Department demonstrate more than a mere passive activity. For production of procurement of facility energy to qualify as being consistent with the DoD energy performance goals and master plan (and consequently qualify for an energy certification), DoD must do one of the following: • Consumption by the DoD Component of some or all of the facility energy from the project • Structure the project to provide energy security for the installation by, for example, retaining the right to divert to the installation the energy produced by the project in times of emergency • Reinvestment in renewable facility energy or program conservation measures of a minimum of 50% of proceeds (including both in-kind and cash) from any lease

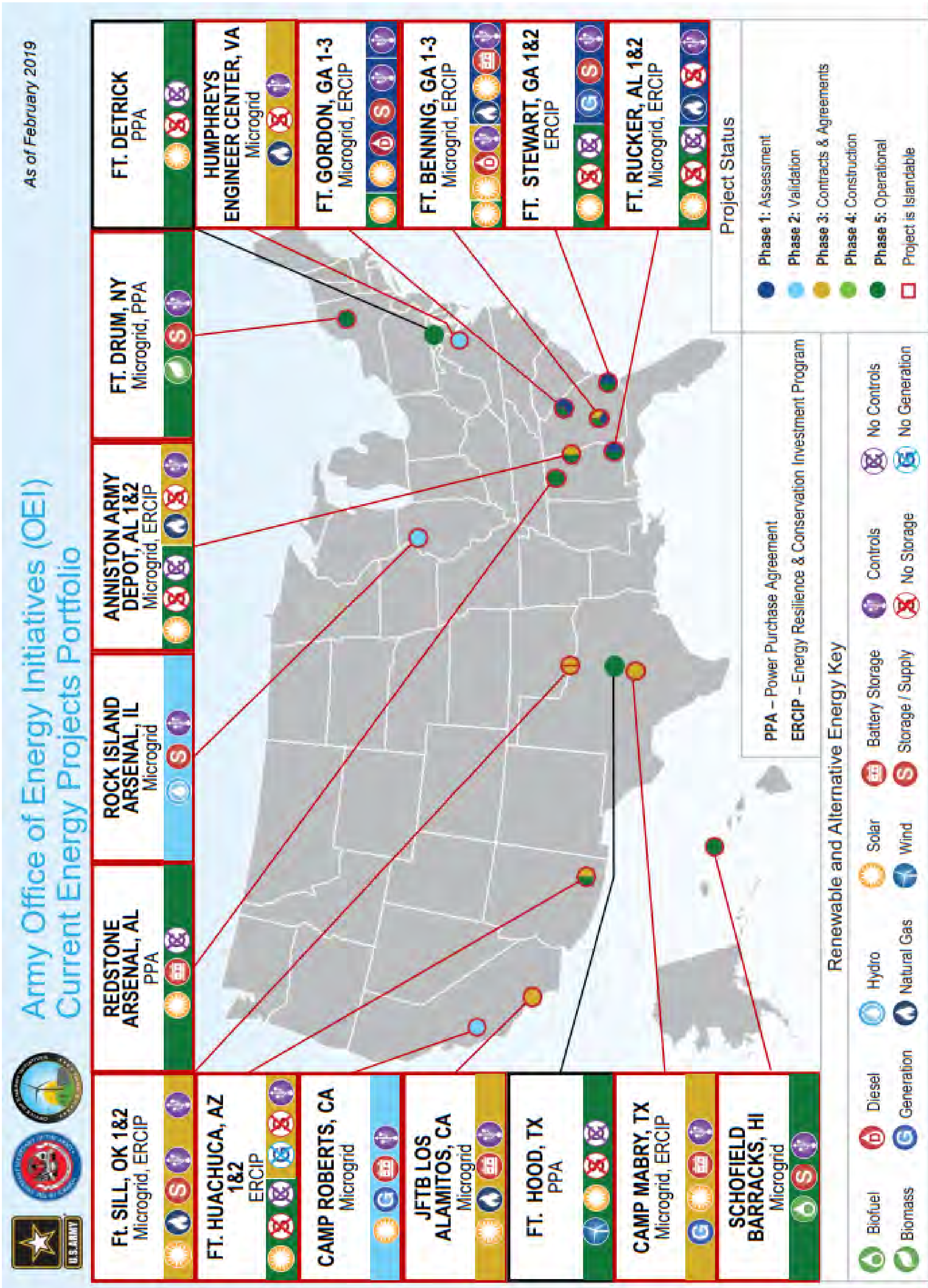

Figure C.4: Army Office of Energy Initiatives energy projects as of February 2019 (McGhee 2019, Slide 2)

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C.6 Land Degradation Hazard

Land degradation is the loss of soil from the land surface (erosion) through a variety climate-related and other processes. Erosion can undermine buildings, roads and other infrastructure; can rapidly carve gullies deep enough to inhibit overland travel; can cause head-cuts or degradation of river channels with redeposition of sediment downstream, affecting flood conveyance in the channel and impacting navigation; and can result in potentially dangerous blowing dust hazards.

Land degradation in the context of arid climates can result in permanent damage to the land (formerly termed "desertification"); in the context of tropical climates, land degradation can result in the loss of all organic soil layers. Post-wildfire soils in areas subject to high-intensity burning may lose all cohesion. Significant post-wildfire land degradation is common. In the Arctic, permafrost thaw results not only in land subsidence and hydrologic change but weakens the soil significantly, allowing for accelerated riverine and coastal erosion. In many cases, natural causes of land degradation are exacerbated by human land use patterns that increase or sustain disturbance and inhibit land recovery.

The primary federal agency responsible for issues relating to land degradation is the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). The NRCS maintains a list of National Conservation Practice Standards, which provide information on methods for reducing soil loss and other sources of land degradation. A database of conservation practices can be found here: https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/cp/ncps/?cid=nrcs143_026849.

Additional steps installation planners can take to reduce land degradation are as follows:

- Use construction sediment management best practices to reduce soil erosion in disturbed areas and to minimize introduction of sediment to waterways.
- Minimize activities that may result in ground disturbance in steeply sloping terrain where erosion potential is highest.
- Identify areas where soils are loosely consolidated or have low cohesion and minimize ground-disturbing activities in these areas.
- Rotate ground-disturbing activities among training ranges to minimize the amount and duration of disturbance, and to allow vegetation to recover.
- Use vegetative windbreaks to reduce the blowing dust hazard and minimize soil loss.
- Plant ground cover to reduce soil loss in heavily disturbed areas.
- In floodplains, control erosion by:
    - Controlling erosion of riverbanks (revegetation, hardening, riprap, and revetment).
    - Diverting flows (bendway weirs, j-hooks, spur dikes, and similar structures).
    - Creating hardened failure points for flood risk management infrastructure.

- Slowing flows (wetland restoration, floodway development, upstream flood infrastructure to reduce flood peaks).
- In coastal zones, minimize beach erosion through the following measures:
  - Reduce wave energy offshore (breakwaters, artificial reefs, barrier islands).
  - Reduce erosion (sea walls, dunes, beach nourishment, shoreline hardening, submerged aquatic vegetation).
  - Encourage and sustain coastal wetlands shoreline revegetation, and maritime forest and mangrove forest habitat restoration, where appropriate.
- In areas underlain by permafrost, avoid construction on permafrost areas where possible (Currey 2020). Otherwise, employ technologies to maintain near-constant thermal regimes for facilities, transportation, and utility infrastructure:
  - Keep the ground frozen through elevation of buildings, the use of air-convection embankments, passive cooling thermopiles (heat-syphoning stilts) and theromsyphons (that use air-ground temperature differences to pull heat from the ground in winter), and ground source heat pumps.
  - In shallow permafrost areas, remove permafrost and replace it with stable material, or pre-thawing and consolidating the material before construction (Currey 2020).
  - Use compacted gravel pads under building foundations and other infrastructure, and plan for settlement (Currey 2020).
  - Identify areas of the installation where thaw hazard is reduced (e.g., gravelly soils; soils without permafrost) and adjust development plans to concentrate infrastructure in these areas where possible.

Figure C.5: Coastal erosion, Alaska (https://media.defense.gov/2012/Jul/19/2000757972/-1/-1/0/120719-A-CE999-028.jpg)

C.7 Riverine Flooding Hazard

Riverine flood risk occurs when the volume of water in a stream exceeds the conveyance of the channel so that water overflows on the adjacent land. Flooding is typically a result of heavy rainfall, especially multi-day events where rain falls on saturated soils or saturates soils to the point that excessive runoff occurs. Flooding can also result from intense precipitation in a small area at a faster rate than the soil can absorb. Finally, flooding can result from snowmelt runoff in the spring; in larger river systems, snowmelt runoff might be the dominant cause of flooding. Floods resulting from human factors (e.g., dam and levee failure) are not addressed in this document.

The primary federal agency that regulates flood risk in the United States is the Federal Emergency Management Agency (FEMA), which maps areas susceptible to flooding under different-sized flow events through the National Flood Insurance Program (NFIP). While many areas of the U.S. have been mapped, other areas, particularly those with low populations, limited contributing drainage area, and non-participating communities in the NFIP, have not been mapped by FEMA.

Flood maps developed from hydrologic and hydraulic analyses of watersheds are essential for defining flood risk for floodplain areas where it is reasonable to expect an increased annual exceedance probability (AEP) flood risk to occur, and thus where it is prudent to plan development in a manner that mitigates against future flood risk. These maps also areas where reduced flood risk exist. It is important to note that FEMA flood maps do not delineate areas of flood and no flood risk. They simply represent delineations based on contemporary conditions for selected return rate floods.

The ACAT includes maps of the expected flooding based on the 1% AEP flood event, the 1% AEP plus 2 feet (e.g., increasing the AEP elevation by 2 feet vertically and the corresponding horizontal amount), and 1% AEP plus 3 feet. These inundation maps are based on FEMA's National Flood Hazard Layer (NFHL), where available, and a two-dimensional (2D) hydraulic analysis for smaller tributaries or where the NFHL was not available. The 2D analysis was performed using a 10 nm digital elevation map to produce a consistent approach across all studied military installations. The user is strongly cautioned that engineering decisions require more detailed and precise floodplain delineations than those provided in the tool. The shapefiles underlying these maps are also included in the Defense Installation Spatial Data Infrastructure (DISDI) portal at http://disdiportal.osd.mil/.

Below are steps that installations can take to reduce their exposure to flood risk, both now and in the future:

- Update floodplain maps to identify flood-prone areas.
- Update zoning to limit floodplain development.
- Reduce inflow to stream through flood detention and other low-impact development infrastructure such as:
    - Stormwater infrastructure: channels, detention basins, drainage improvements.
    - Permeable pavement and similar infrastructure to increase infiltration in built environments.
    - Wetland restoration, upstream flood infrastructure to reduce flood peaks.
- Control in-stream floodwater release by dams.
- Reduce floodplain flooding in critical areas through the use of floodwalls and levees.
- Implement expedient measures (e.g., sand bags, deployable floodwalls, temporary flood barriers).
- Dredge to increase channel conveyance.
- Bypass critical areas by relocating channels or constructing diversion channels to bypass.
- Take measures to reduce the risk of bank erosion:
    - Protect riverbanks (revegetation, hardening, riprap, and revetment).
    - Divert flows (bendway weirs, j-hooks, spur dikes, and similar structures).
- Identify and develop plans to adapt, repurpose, or relocate at-risk infrastructure.
    - Elevate buildings, utilities, and roads.
    - Increase culvert size.
    - Dry and wet flood-proofing of buildings.
    - Relocate buildings and activities.
    - Use floodable development and floatable development.
    - Install ring walls, ring levees.
- Develop and implement a hazard mitigation plan that includes:
    - Early warning system
    - Evacuation plan
    - Expedient measures (sand bags, deployable floodwalls)
    - Risk communication plan
    - Coordination with local and regional governmental entities
- Integrate nature-based solutions to slow and control floodwaters:
    - Preserve open space.
    - Preserve and establish wetlands.
    - Restore floodplains.
    - Establish and maintain riparian vegetation.
    - Lower or terrace the riverbank close to the river.

Figure C.6: Water-filled temporary barrier. The barrier shown in this figure is 2 ft high (FEMA 2014, Figure 8-4)

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C.8 Coastal Flooding Hazard

Coastal flood risk changes under a warming climate in several ways that exacerbates coastal storm risk in many areas:

- Global mean sea levels are rising. In some coastal areas, relative sea level is increasing at or above the global rate due to coastal subsidence or other causes, resulting in higher tidal and coastal storm elevations, and therefore more extensive inundation of low-lying coastal areas.
- In other areas (mostly north of 45°N due to the effects of post-glacial isostatic rebound, or due to seismic effects), the earth's crust is rising at a faster rate than sea levels, resulting in local relative sea level fall.
- In areas where depth-limited waves are important, increased sea levels can cause increased wave heights.
- Changing sea levels exacerbate coastal shoreline erosion, which can threaten facilities and infrastructure.
- Coastal and estuarine geomorphology can cause amplification of tidal and storm surge effects well inland.
- Seasonal, steric (temperature-related), circulation, and large-scale atmospheric cycles can also increase (or decrease) water levels.

Loss of coastal estuaries, mangrove and maritime forests, submerged aquatic vegetation, oyster beds, other ecological changes, and in polar regions, permafrost thaw and loss of sea ice also contribute to rapid rates of shoreline erosion that exacerbate the effects of changes in sea surface elevation and storm surge heights.

In addition to direct damage through flooding and wave erosion, sea level rise can damage freshwater ecosystems (converting to brackish or saline) and result in saltwater intrusion to aquifers. Local stormwater drainage systems in coastal areas may experience reduced performance and operational windows due to higher tidal and coastal storm surge elevations. Similarly, increased sea level change can exacerbate riverine flood risk in locations where tidal and storm surge cause backwater in rivers, reducing conveyance.

The USACE North Atlantic Coast Comprehensive Study (USACE 2015, https://www.nad.usace.army.mil/CompStudy/) and the USACE South Atlantic Coast Study (https://www.sad.usace.army.mil/SACS/) are useful resources for information about coastal resilience measures. Measures for increasing resilience to coastal flooding are in many ways similar to measures to increase resilience to riverine flooding:

- Measures to reduce risk of coastal inundation include:
  - Sea walls (see Figure C.7)
  - Deployable floodwalls
  - Levees
  - Revetments
  - Bulkheads
  - Dikes
  - Ring walls
  - Breakwaters
  - Storm surge barriers
  - Barrier islands
  - Near shore berms
  - Beach nourishment and fill
  - Nearshore placement
  - Thin layer placement
  - Groins (Figure C.8)
  - Update zoning to limit coastal floodplain development.
- Identify and develop plans to adapt, repurpose, or relocate at-risk infrastructure.
  - Elevate buildings, utilities, roads.
  - Dry and wet flood-proofing of buildings.
  - Relocate buildings and activities (see Figure C.7).
  - Use floodable development and floatable development.
  - Install ring walls, ring levees.
- Develop and implement a hazard mitigation plan that includes:
  - Early warning system
  - Evacuation plan
  - Expedient measures (sand bags, deployable floodwalls)
  - Risk communication plan
  - Coordination with local and regional governmental entities
- Integrate nature-based solutions to reduce coastal erosion and wave damage through restoration of (Figure C.8):
  - Mangrove forests
  - Wetlands
  - Maritime forests
  - Living shorelines
  - Submerged aquatic vegetation (SAV)
  - Coral reefs and oyster reefs
  - Tidal flats

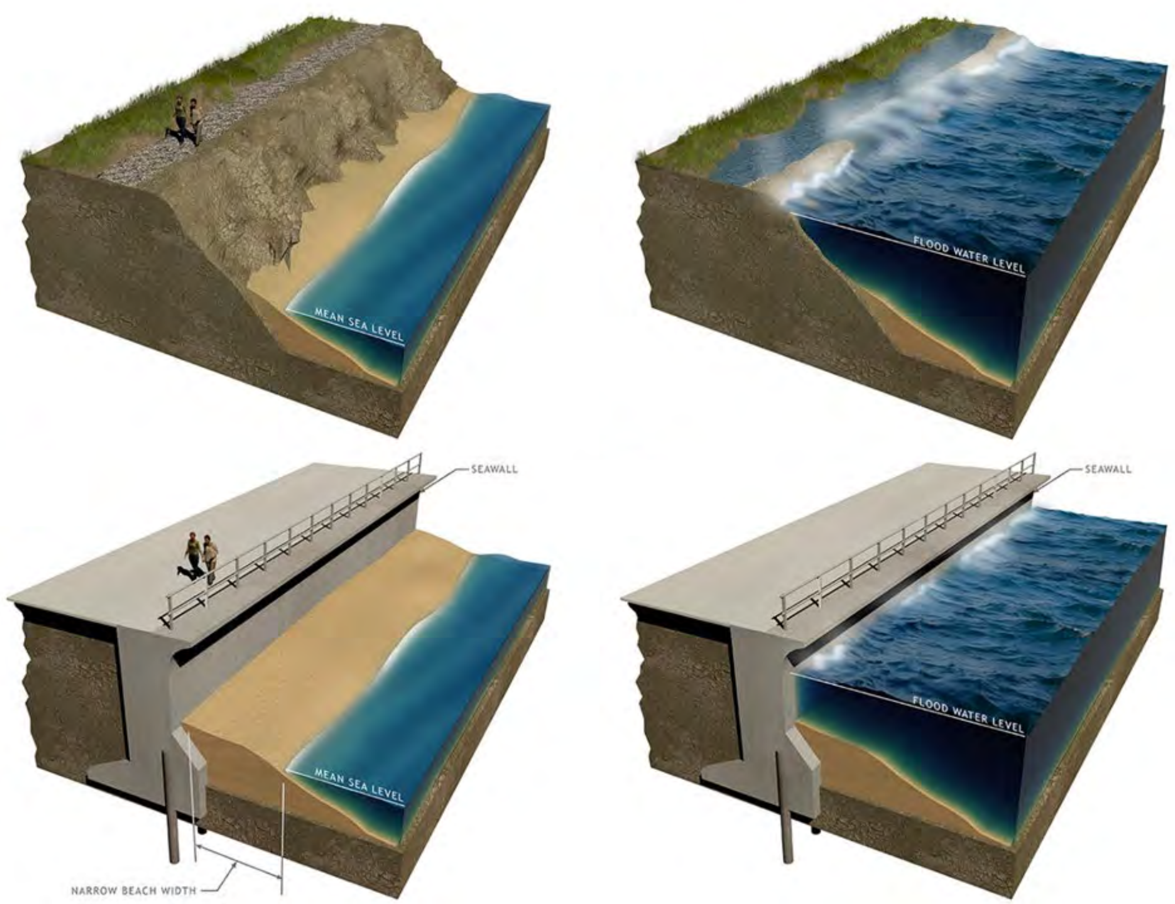


Figure C.7: Example of how a sea wall provides coastal resilience under tide-influenced flooding (left) and hurricane or extratropical storms (right) (after USACE 2015)

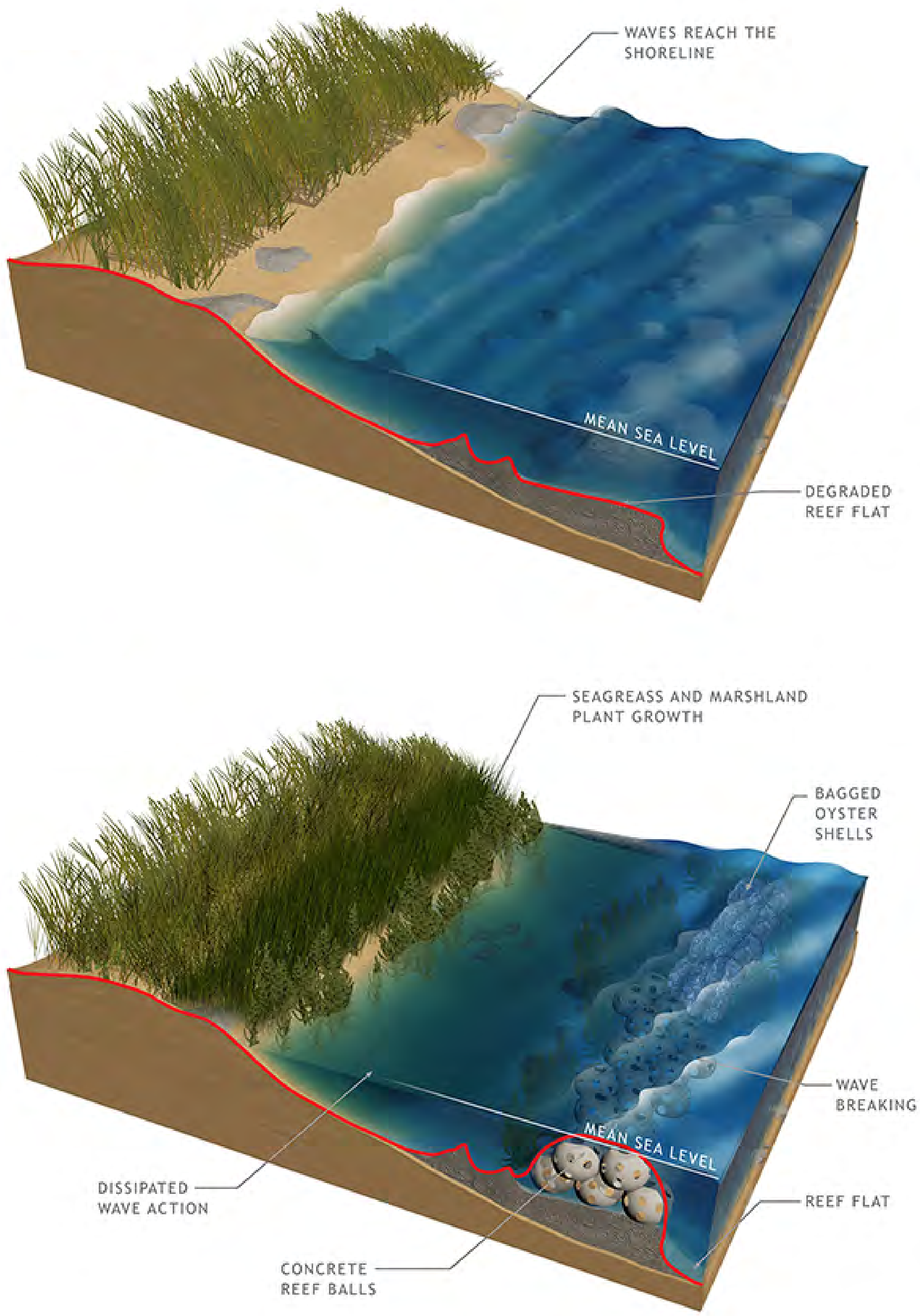


Figure C.8: Establishing artificial reefs (bottom) can reduce wave damage along the coastline, allowing for reestablishment of coastal and submerged aquatic vegetation, and reducing wave erosion (after USACE 2015)

C.9 Measures Tables

Table C.7: Management Resilience Measures

Management resilience measures are defined as planning, regulatory, information gathering, and behavioral activities that enhance or guide resilience. These measures help prepare for, absorb, recover from, and adapt to the exposure.

MEASURE[1]	DESCRIPTION	HAZARDS
Audits	Water and energy audits are inspections of infrastructure that evaluate water and energy use, look for waste (such as leaky pipes, lit spaces that do not need to be continuously lit) and identify steps needed to remediate the loss.	
Building Design: Energy Efficiency	Require improvements to the energy efficiency of buildings and infrastructure to reduce energy demand and, therefore, reduce the likelihood of brown-outs and black-outs during heat waves. These improvements could include passive heating and cooling, passive solar design, and increased building spacing (to facilitate nighttime heat dissipation).	
Design Standards: Wildfire	Incorporate information from the IWUIC Model Code (https://codes.iccsafe.org/content/IWUIC2015) or similar into the installation design standard to reduce infrastructure damage due to wildfire. Examples include requiring firebreaks/firescaping, ignition-resistant construction design, noncombustible building materials, and appropriate land use and zoning requirements.	
Diversification of Energy Supply	This is a strategy of having multiple energy supply types and sources contributing to an installation's energy portfolio. Disruptions in one supply source could be compensated for by bringing alternative resources online.	
Education: Drought	For installations where drought is a concern, drought education is essential for compliance with water use restrictions. Such education would focus on water uses issues, but also such drought-related issues as water quality, wildfire, and heat stress.	

MEASURE[1]	DESCRIPTION	HAZARDS
Education: Heat	Improve education around heat-related morbidity and mortality, including recognition of conditions under which outdoor activity should be reduced, identification of signs and symptoms of heat-related illness, and methods for treatment in the field. Additional considerations include increasing acclimatization times for new arrivals on installation during the warmer months and adjusting the timing of outdoor activities to coincide with cooler portions of the day.	Heat
Emergency Response: Cooling Centers	Designate locations to function as cooling centers during heat waves, as necessary, particularly in locations where air conditioning is not a common feature of buildings.	Heat
Energy metering	Metering allows for tracking of energy use by location, and provides essential information needed for energy planning and for the management of energy supplies.	Energy
Flood mapping	Use FEMA NFIP flood inundation maps to identify portions of an installation at risk from riverine flooding. Zone accordingly. If NIFP maps are not available for an installation, seek funding to have maps developed to guide engineering decisions.	Riverine Flooding
Hazard Mitigation Plan	All potential impacts should be addressed in a comprehensive installation hazard mitigation plan. This plan should be coordinated with federal, state, regional, and local government and emergency response entities. Comprehensive interagency practice of this plan should occur annually, and the plan adjusted based on the outcome of these activities and of actual implementation during critical hazard events. This plan should include a risk communication plan, evacuation plans, and an outreach component to make soldiers and civilian employees aware of the hazards and strategies for avoiding or mitigating them.	Heat, Land Degradation, Drought, Coastal Flooding, Riverine Flooding, Energy, Wildfire
Microgrids	Rather than supplying an installation with a single grid, which is vulnerable to disruption, the installation is powered by a series of inter-connected but isolatable microgrids, to increase resilience to energy disruption.	Energy
Minimize erosion	Use construction sediment management best practices to reduce soil erosion in all disturbed areas and to keep sediment out of waterways.	Land Degradation

Heat | *Wildfire* | *Land Degradation* | *Drought* | *Energy* | *Riverine Flooding* | *Coastal Flooding* | *NA Information not available*

MEASURE[1]	DESCRIPTION	HAZARDS
Minimize ground disturbance	Ground-disturbing activities should be minimized in areas where soils are loose and unconsolidated, and on steeply slope surfaces to reduce dust and erosion hazards; consider rotating activities to allow the land to recover.	Land Degradation
Permafrost hazard mapping	Map locations on the installation where permafrost hazard exists (where permafrost exists, mean annual ground temperatures are approaching 32°F, and the soil substrate is not gravelly), and adjust development plans to concentrate infrastructure outside these areas, where possible.	Land Degradation
Plan to relocate, repurpose, or adapt buildings	Identify and develop plans for adapting, repurposing, or relocating buildings at risk from flooding due to riverine and coastal inundation. Measures could include elevation of buildings, roads and utilities; dry and wet flood-proofing; relocation; floodable development; floatable development; and ring walls/levees.	Coastal Flooding, Riverine Flooding
Third-party financing for energy	The DoD permits installations to make use of a diverse array of third-party financing mechanisms to support energy development and independence on installations.	Energy
Update floodplain zoning	Zoning for areas in a floodplain should identify areas where development is infeasible and areas where resilience measures (such as flood-proofing and building elevation) area required.	Riverine Flooding
Water Conservation Plan	A water conservation plan sets out long-term goals for water supply management. In addition, such a plan identifies water supply thresholds below which increasingly stringent water restrictions would come into effect.	Drought
Water metering	Metering allows for tracking water use by location and provides essential information needed for water resources planning. All water uses should be metered.	Drought

1 An extensive list of management measures was compiled as part of the USACE North Atlantic Coast Comprehensive Study (2015) and the South Atlantic Coast Study (2020). These resilience measures are included here as appropriate.

Heat *Wildfire* *Land Degradation* *Drought* *Energy* *Riverine Flooding* *Coastal Flooding* *NA Information not available*

Table C.8: Temporary Resilience Measures and Estimated Costs

Temporary measures reduce the exposure to a hazard, but do not affect the likelihood of a hazard occurring. These measures help infrastructure absorb and recover from the exposure.

MEASURE[1]	HAZARDS	TOTAL ESTIMATED FIRST COST RANGE PER UNIT [2]	UNITS
Floodwalls Deployable, Floodwalls Temporary		$11,249–$27,731	Cost/ Linear Foot
Dry Flood-Proofing		$31,961–$67,677	Cost/ Asset (Structure)
Temporary Flood, Barriers, Temporary Wet Flood-Proofing		$8,603–$20,987	Cost/Asset

1 Extensive lists of resilience measures compiled as part of the USACE North Atlantic Coast Comprehensive Study (2015) and the South Atlantic Coast Study (SACS, 2020). Resilience measures presented here represent an aggregated list of the categories of measures and corresponding conceptual parametric unit cost estimates from the SACS, unless otherwise stated.

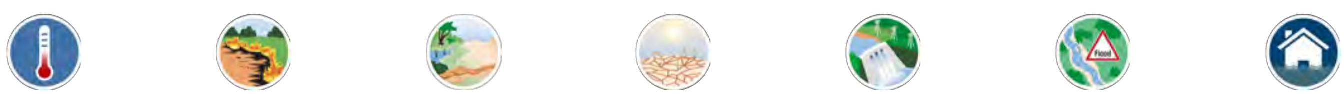
2 Regional factors, such as materials, labor, and fuel, could affect overall costs. The total construction cost estimates must take into account more localized costs of these factors as part of the development of project cost estimates. Please note that the ranges of costs provided considers the variation in regional differences across the USACE South Atlantic Division (SAD) Area of Responsibility (AOR).

Heat | *Wildfire* | *Land Degradation* | *Drought* | *Energy* | *Riverine Flooding* | *Coastal Flooding* | *NA Information not available*

Table C.9: Structural Resilience Measures and Estimated Costs

Structural measures reduce the likelihood of a hazard occurring. These measures help infrastructure absorb, recover, and adapt to the exposure.

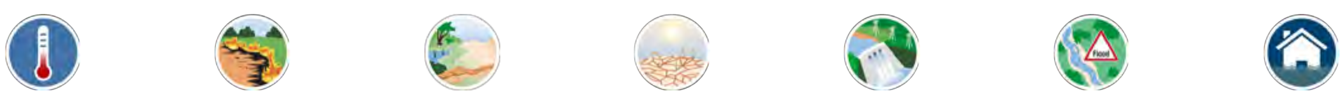
MEASURE[1]	DESCRIPTION	HAZARDS	TOTAL ESTIMATED FIRST COST RANGE PER UNIT [2]	UNITS
Air-convecting embankment (ACE)	An embankment consisting of large loose rocks placed to foster air movement within the embankment, helping to extract heat from the ground and keep it colder (permafrost areas).		NA	NA
Barrier Island Restoration	Construction of a barrier island to shield a coastal area from wave damage.		$243,126–$1,104,307	Cost/Acre
Beach Fill (initial)	Initial construction or reconstruction of a beach to reduce future erosion by increasing the amount of beach area separating the active shoreline from infrastructure and developed areas.		$1,620–$7,060	Cost/Linear Foot
Beach Fill (renourishment)	The periodic addition of sediment to a beach to replace that lost through erosion in order to sustain beach function.		$1,041–$3,985	Cost/Linear Foot
Bendway Weir	A low level, submerged rock dike angled up stream designed to deflect stream flow away from a river bank.		NA	NA
Breakwaters	A breakwater is a barrier built out into a body of water to protect a coast or harbor from the force of waves.		$5,533–$22,653	Cost/Linear Foot



Heat *Wildfire* *Land Degradation* *Drought* *Energy* *Riverine Flooding* *Coastal Flooding*

NA Information not available

MEASURE[1]	DESCRIPTION	HAZARDS	TOTAL ESTIMATED FIRST COST RANGE PER UNIT [2]	UNITS
Bulkhead	A wall that prevents erosion of the shoreline due to wave action.		$16,431–$23,354	Cost/Linear Foot
Channel Relocation	Channel relocation is the dredging of a new channel through a floodplain to divert stream flow away from vulnerable infrastructure.		NA	NA
Discharge Gates	Systems that reduce the impact of sea level rise and tides on gravity draining. Requires storage capacity upstream from gates. Smaller storm surge barriers used to reduce risk to areas with coastal inlets.		NA	NA
Stormwater Drainage Improvements	Stormwater drainage systems are the means by which stormwater is transported from one area (typically urban) to another area (typically a river system, ocean, wetland, or retention pond). Increasing capacity and slowing flows are key improvements for such systems.		NA	NA
Dune Enhancement (Initial)	Dunes provide a barrier to coastal erosion and, if continuous along the coastline, a barrier to coastal inundation.		$812–$2961	Cost/Linear Foot
Flood Barriers, Temporary Flood	Flood barriers are barriers that can be raised when there is a flood risk, but lowered to permit access when flood risk is absent.		$5,500	Feet



Heat *Wildfire* *Land Degradation* *Drought* *Energy* *Riverine Flooding* *Coastal Flooding* *NA Information not available*

MEASURE[1]	DESCRIPTION	HAZARDS	TOTAL ESTIMATED FIRST COST RANGE PER UNIT [2]	UNITS
Floodwalls[3]	An engineered barrier, usually of concrete, masonry, or both, designed to hold back floodwaters.	Coastal Flooding, Riverine Flooding	$510,350–$833,572	Cost/Linear Foot
Groins	A barrier built perpendicular to a shoreline for the purpose of trapping sand moving in longshore currents. This retains the beach at the groin location, which shields coastal development from wave damage.	Land Degradation, Coastal Flooding	$961,643–$4,521,486	$/Groin Unit
Vanes/Barbs/J-hooks	Low profile structures of stone or other material angled upstream, designed to reduce bank erosion by deflecting the river current away from the bankline.	Land Degradation, Riverine Flooding	NA	NA
Levees & Dikes	Compacted earthen structures designed to hold back floodwaters.	Coastal Flooding, Riverine Flooding	$4,032–$6,586	Cost/Linear Foot
Living Shoreline (Artificial Reefs)	A living shoreline is a protected, stabilized coastal edge made of natural materials such as plants, sand, or rock. Living shorelines grow over time and provide wildlife habitat.	Land Degradation, Coastal Flooding	$83,272–$106,566	Cost/Linear Foot
Living Shoreline/Riparian Vegetation Establishment-(Vegetation Only)	Creation of a living shoreline only through the addition of vegetation that stabilizes the substrate and reduces wave impact in low wave energy environments.	Land Degradation, Coastal Flooding	$19–$1,383	Cost/Linear Foot

Heat *Wildfire* *Land Degradation* *Drought* *Energy* *Riverine Flooding* *Coastal Flooding* *NA Information not available*

MEASURE[1]	DESCRIPTION	HAZARDS	TOTAL ESTIMATED FIRST COST RANGE PER UNIT [2]	UNITS
Living Shoreline-(Edging)	Hardening of the toe slope of an existing or vegetated slope to reduce erosion.		$1,400	Cost/Linear Foot
Living Shoreline-(Sills)	Rocks, cement, or other material placed parallel to existing or vegetated shoreline for the purposes of reducing wave energy and preventing erosion.		$10,011–$13,772	Cost/Linear Foot
Locks & Gates	Locks are structures used to temporarily impound water to for the purpose of raising and lowering boats and other watercraft between stretches of water that are at different elevations. Flood gates are adjustable gates used to control water flow.		$4,311,360,000–$6,956,056,000	Cost/Each
Mangrove Restoration	Mangroves are a woody plant that grown along the shoreline in the southeastern U.S. They serve to stabilize the shoreline and reduce wave impact.		$1,859–$3,160	Cost/Acre
Maritime Forest Restoration	A maritime forest is a coastal wooded habitat found on higher ground than dune areas within range of salt spray. They are typically associated with shoreline estuaries along barrier islands. They may serve to attenuate and/or dissipate waves and reduce shoreline erosion.		$2,619–$8,781	Cost/Acre

Heat *Wildfire* *Land Degradation* *Drought* *Energy* *Riverine Flooding* *Coastal Flooding* *NA Information not available*

MEASURE[1]	DESCRIPTION	HAZARDS	TOTAL ESTIMATED FIRST COST RANGE PER UNIT [2]	UNITS
Native Material and Rootwad Revetments	Provides toe support for bank revegetation techniques and collects sediment and debris that will enhance bank structure over time. Moves the location of high velocity flows away from the bankline.		NA	NA
Oyster Reefs	Oyster reefs are a form of living shoreline treatment used to reduce wave energy, mitigate wave damage, and erosion in lower energy environments.		$19–$300	Cost/Linear Foot
Prevent/delay thawing (Permafrost)	Any of a series of measures, such as installing passive convection structures (thermopiles, thermosyphons), ground source heat pumps, and gravel barriers that serve to increase ground heat loss and therefore delay permafrost thaw, and therefore the weakening of soils that accelerates loss due to riverine and coastal processes.		NA	NA
Revetment	Revetments are sloping concrete or masonry structures placed on banks or cliffs in such a way as to absorb the energy of incoming water and therefore reduce erosion.		$4,335–$14,113	Cost/Linear Foot
Riprap	Rock of various sizes uses to army banklines and shoreless to absorb the energy of incoming water, and therefore reduce erosion.		$4,800	Feet


Heat


Wildfire


Land Degradation


Drought


Energy


Riverine Flooding


Coastal Flooding

NA
Information not available

MEASURE[1]	DESCRIPTION	HAZARDS	TOTAL ESTIMATED FIRST COST RANGE PER UNIT [2]	UNITS
Submerged Aquatic Vegetation (SAV) Restoration	Submerged provides extensive near shore habitat, while at the same time providing significant attenuation of wave energy in coastal environments.		$266,448–$864,248	Cost/Acre
Seawall	Seawalls are concrete or masonry structures placed on banks or cliffs in such a way as to absorb the energy of incoming water and therefore reduce erosion.		$8,370–$15,179	Cost/Linear Foot
Shade Structure	Any structure constructed that allows breaks from the glare of the sun like an open shed, shade cloths, or umbrella. May be temporary or permanent.		NA	NA
Floodways and Side Channels (perennial, high flow, oxbows)	An additional feature of a complex channel. During high flows, flow may spill or avulse to a second channel at a low point in the bankline. This is an intermediary step before uniform conveyance across the floodplain, but the side channel also serves to reduce erosive energy in the main channel by reducing main channel flow and flow depth. Side channels can reconnect abandoned floodplain areas.		NA	NA
Spur Dikes	Low profile structures of stone or other material angled upstream, designed to reduce bank erosion by deflecting the water motion away from the bankline.		$7,400	Feet

MEASURE[1]	DESCRIPTION	HAZARDS	TOTAL ESTIMATED FIRST COST RANGE PER UNIT [2]	UNITS
Stormwater capture and reuse[4]	Stormwater can be captured by a variety of channels, drains, and detention basins. Capturing this water prevents it from reach the stream network where it might increase flood flows and contribute to flood damage. This water can then added to the water supply system (with treatment) or injected into the local aquifer for long-term storage and later use.		$2,000–$440,819	Cost/Average stormwater capture (Acre-ft/year)
Surge Barrier/ Closure Dam	A surge barrier or closure dam is designed to prevent a storm surge or spring tide from flooding the area behind the barrier but is open most of the time to enable passage of ship traffic. A surge barrier or closure dam is typically part of a larger system of levees, floodwalls, and other coastal flood risk management structures.		$243,126– $1,104,307	Cost/Linear Foot
Terraces	In coastal and riverine settings, an area of lowered ground designed to accommodate flood waters; in steeply sloping terrain, a series of flat surfaces cut into the slope to slow runoff and reduce hillslope erosion.		NA	NA
Thin layer placement	Thin layer placement is the deposition of dredge material in thin, uniform layers over emergent vegetation or shallow bay bottoms. Benefits wave attenuation and/or dissipation, shoreline erosion, stabilization, and soil retention.		NA	NA

Heat *Wildfire* *Land Degradation* *Drought* *Energy* *Riverine Flooding* *Coastal Flooding* *NA Information not available*

MEASURE[1]	DESCRIPTION	HAZARDS	TOTAL ESTIMATED FIRST COST RANGE PER UNIT [2]	UNITS
Tidal Flats, Engineered	Like natural tidal flats, engineered flats are low-gradient, tidally-inundated coastal surfaces that allow waves to attenuate before reaching the shoreline, thereby reducing coastal erosion.		$2,069,116–$4,609,313	Cost/Each
Vegetative Windbreaks	Row of trees or other type of vegetation that provides shelter or protection from the wind. Reduces soil erosion.		NA	NA
Wetland Restoration[5]	Restoration of coastal or freshwater wetlands serves a number of functions beyond habitat creation: Wetlands also absorb floodwaters and attenuate erosion.		$112,473– $580,073	Cost/Acre

1 An extensive list of management measures was compiled as part of the USACE North Atlantic Coast Comprehensive Study (2015) and the South Atlantic Coast Study (SACS, 2020). Measures presented here represent an aggregated list of the categories of measures. Corresponding conceptual parametric unit cost estimates given as ranges are from SACS unless otherwise noted.
2 Regional factors, such as materials, labor, and fuel, could affect overall costs. The total construction cost estimates must take into account more localized costs of these factors as part of the development of project cost estimates. Please note that the ranges of costs provided considers the variation in regional differences across the USACE South Atlantic Division (SAD) Area of Responsibility (AOR).
3 The concept design identified for the floodwall category consists of a concrete structure. These structures might also require closure structures including stoplogs, miter gates, swing gates, or roller gates, which were not included in the development of the parametric unit cost estimate. A simple steel sheetpile I-wall may be more economical.
4 Stormwater capture and reuse costs are highly variable. Costs included here are from Appendix A of Southern California Water Coalition (2018) Stormwater Capture, 2018 Whitepaper Update, SCWC Stormwater Task Force, April 2018, projects since 2010, in 2017 $.
5 An annual average cost of $120 per foot was used in the SACS Tier 1 evaluation assuming a nominal wetland width (i.e., dimension perpendicular to the shoreline of 200 feet).

Heat | *Wildfire* | *Land Degradation* | *Drought* | *Energy* | *Riverine Flooding* | *Coastal Flooding* | *NA Information not available*

Table C.10: Nonstructural Resilience Measures and Estimated Costs

Nonstructural measures are measures that reduce the exposure to a hazard, but do not affect the likelihood of a hazard occurring. These measures help infrastructure absorb, recover, and adapt to the exposure.

MEASURE[1]	DESCRIPTION	HAZARDS	TOTAL ESTIMATED FIRST COST RANGE PER UNIT [2]	UNITS
Building Removal and Relocation	Removal or relocation of a building or other infrastructure puts it out of reach of floodwaters without altering the frequency of inundation events.		$349,000	Building
Building/Asset Elevation[3]	Elevating a building or other infrastructure puts it out of reach of floodwaters without altering the frequency of inundation events.		$93,488–$441-708	Cost/Asset
Coral Reefs	Coral reefs act to reduce or dissipate wave energy, and therefore contribute to reduction in coastal storm damage.		$5,973–$16,383	Cost/Linear Foot
Dune Enhancement (Renourishment)	Renourishment is the periodic addition of sediment to dunes to compensate for that lost due to erosion.		$711–$2,448	Cost/Linear Foot
Elevation (Utilities/Roads)[3]	Involves raising the infrastructure in place to achieve a reduction in the frequency of inundation during flood events. Elevation can use fill, foundation walls, piers, piles, posts, or columns as appropriate.		NA	NA

Heat *Wildfire* *Land Degradation* *Drought* *Energy* *Riverine Flooding* *Coastal Flooding* *NA Information not available*

MEASURE[1]	DESCRIPTION	HAZARDS	TOTAL ESTIMATED FIRST COST RANGE PER UNIT [2]	UNITS
Floatable Development	Structures that float on the surface of the water, or may be floated occasionally during a flood, reducing vulnerability to changing sea level, tides, and some storm surge or wave conditions.		NA	NA
Floodplain Restoration	A floodplain is the area bordering a river that naturally provides space for the retention of flood and rainwater. Restoring floodplains means either partially or fully restoring their functionality as a floodplain post-disturbance.		NA	NA
Reflective Roofing	Reflective or light-colored roofing may be installed as way to reduce heat gain in buildings, thereby reducing indoor temperatures and cooling energy demands.		NA	NA
Relocation (Utilities/Roads)	Involves moving the infrastructure to another location away from flood hazards. Dependable method of protection and provides the benefit of use of the evacuated area.		NA	NA
Relocation/Repurposing (Buildings/Facilities)	Moving facilities and buildings from impacted or exposed areas to areas aligned with mission criticality. Repurposing buildings and facilities to house activities with lower mission criticality. Dependable method of protection and provides the benefit of use of the evacuated area building/facility.		NA	NA
Revegetation of Slopes/Ground Covers	Revegetation of slopes is critical for reducing soil erosion; ground cover in all areas reduces rainsplash erosion, land surface heat gain, and evaporative losses.		NA	NA

Heat *Wildfire* *Land Degradation* *Drought* *Energy* *Riverine Flooding* *Coastal Flooding* *NA Information not available*

MEASURE[1]	DESCRIPTION	HAZARDS	TOTAL ESTIMATED FIRST COST RANGE PER UNIT [2]	UNITS
Ring Walls/Ring Levees (Facility)	A ring wall or ring levee is a wall or levee that encloses a facility, thereby preventing that facility from flood damage when adjacent portions of the floodplain are inundated.		$4,840,000	Facility
Ring Walls/Ring Levees (MultiFamily Housing)	A ring wall or ring levee is a wall or levee that encloses a housing, thereby preventing that housing from flood damage when adjacent portions of the floodplain are inundated.		$3,680,000	Building
Wet Flood-Proofing	Wet Flood-proofing includes permanent or contingent measures applied to a structure or its contents that prevent or provide resistance to damage from flooding while allowing floodwaters to enter the structure or area.		$8,450–$16,873	Cost/Asset (Structure)

1 An extensive list of management measures was compiled as part of the USACE North Atlantic Coast Comprehensive Study (2015) and the South Atlantic Coast Study (SACS, 2020). Measures presented here represent an aggregated list of the categories of measures. Corresponding conceptual parametric unit cost estimates given as ranges are from SACS.
2 Regional factors, such as materials, labor, and fuel, may affect overall costs. The total construction cost estimates must take into account more localized costs of these factors as part of the development of project cost estimates. Please note that the ranges of costs provided considers the variation in regional differences across the USACE South Atlantic Division (SAD) Area of Responsibility (AOR).
3 The range of costs to elevate structures and roadways can vary considerably. Costs are highly site-specific and vary widely.

Heat *Wildfire* *Land Degradation* *Drought* *Energy* *Riverine Flooding* *Coastal Flooding* *NA Information not available*

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APPENDIX D: ACAT QUICK GUIDE

Army Climate Assessment Tool Quick Guide

The Army Climate Assessment Tool provides a nationwide, screening-level assessment of climate change exposure to Army mission, operations, and programs to inform master planning, natural resource planning, and infrastructure resilience planning. Indicators are used to develop exposure scores specific to each of the 148 locations within the contiguous United States, Alaska, and Hawaii included in the tool. The tool presents information for future climate conditions averaged at 2050 and 2085 for relatively higher and lower emissions scenarios (where higher scenarios are generally correlated with more severe climate impacts). For coastal flood extend, lower and higher sea levels are used in place of emissions scenarios. The Weighted Order Weighted Average (WOWA) method is used to aggregate individual exposure indicators and their associated data sets into the installation-scale exposure scores. The WOWA score combines indicators using a weighting technique to control how much an indicator with a small value can average out (or trade off) for an indicator with a large value, thereby affecting computed exposure.

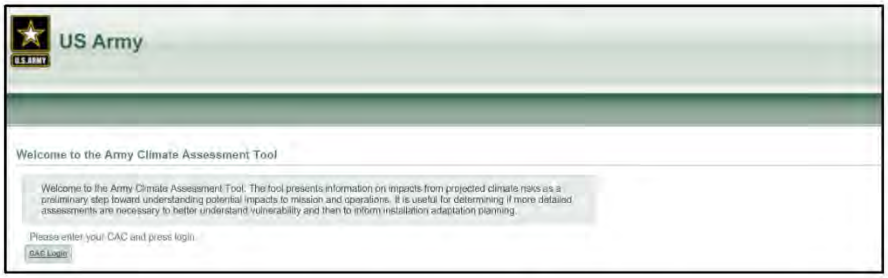
This Quick Guide provides instructions on how to review climate Impact Awareness information, the meaning of indicators used in the tool, and how to interpret the resulting exposure scores. This Guide also outlines how to perform custom settings should you desire to produce results tailored to your specific location or to better understand the sensitivity of the model assumptions. Follow the instructions below to (1) log in, (2) review background information, (3) view results, and (4) conduct a tailored assessment or explore sensitivity analysis with custom calculations.

All users, including those with a Read-only User role, can view the Impact Awareness information, indicator values, and National Standard View exposure assessments. Users with a standard User role can also run custom calculations. Users with an Army Command or Army Headquarters (HQ) role can share custom settings, change the National Standard View, or administer roles. These users will see an Admin tab between the Impact Awareness and Tool tabs.

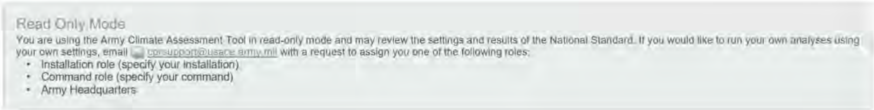
Login

STEP 1: Navigate to the Army Climate Assessment Tool system website located at: https://corpsmapr.usace.army.mil/cm_apex/f?p=116

STEP 2: Insert your CAC, and then click the **CAC Login** button.



After authenticating your credentials using the email certificate, the system will navigate to the Home page of the Army Climate Assessment Tool.



1

The tabs near the top of the screen are shown on every page in the tool; click a tab to navigate to the corresponding page:

- Home
- My Assessment
- I: Impact Awareness
- My Results
- II: National Standard View
- III: Follow-on Actions

STEP 3: Accessing the Army Climate Assessment Tool in read-only mode will allow you to view the National Standard results. If you would like to change settings or run custom calculations, request a standard User role from your local tool administrator. Users with a Read-only User role will not see the My Results tab and will only see the National Standard tab.

Review Background Information

Read the Climate Impact Awareness module

STEP 1: After logging into Army Climate Assessment Tool, click the **Impact Awareness** tab to access regional climate change information from the 4th National Climate Assessment produced by the U.S. Global Research Program in 2017 (Volume 1) and 2018 (Volume 2).

STEP 2: Under the *Select Your Region* section of the **Impact Awareness Home** tab, click your region on the map. Then click the *Go to next section: Regional Overview* button on the bottom of the page.

STEP 3: Review the content of the **Regional Overview** and click the *Background and Context* button to navigate to the next page. Continue to review each page of the **Impact Awareness** module. Hyperlinks bring you to the underlying resources. A list of additional references is provided on the **References** subtab.

Optional: Familiarize yourself with the WOWA scores

STEP 1: Click the **Home** tab, then click the **WOWA Score Overview** subtab.

STEP 1: Read through the description to better understand what a WOWA score means, how it is calculated, and how it is applied. This section also provides further explanation of ORness.

Optional: Familiarize yourself with impacts and indicators

STEP 1: Click the Home tab, then click the Installation Planning Background subtab.

STEP 2: Read through the table of impacts and their supporting indicators to better understand what indicators are used and how they are combined into impacts.

Optional: Familiarize yourself with impacts, indicators, and calculation settings

STEP 1: Click the **My Assessment** tab, then click the **Impacts** subtab. Review the list of impact components, each of which is set to a default value but can have its own priorities and risk factors.

STEP 2: Click the **Indicators** subtab and review the indicators used as the basis of the Army Climate Assessment Tool exposure assessments. The indicator values reflect climate, demographics, ecology, and other stressors that are combined into different impacts. A brief description of the indicator and the data sources making up the indicator value are listed on this page. If desired, scroll down to click the *Download This Table* link to download the information as a comma-separated (.csv) text file that summarizes the indicators. This function is possible on all pages of the Army Climate Assessment Tool that contain tables.

STEP 3: Click the **Importance Weights** subtab to review the group of indicators used to assess exposure for each impact and their default Importance Weight. Importance Weights incorporate information on how relevant each indicator is to an impact compared to the other indicators for that impact.

Optional: Familiarize yourself with the DISDI Atlas Pro link

This tool is linked to the **Defense Installations Spatial Data Infrastructure (DISDI) portal**. Users can access DISDI via a link under the **National Standard View** tab, **Installation Maps** subtab. This link will take the user to the **Climate Exposure Data** folder where they will be able to access ArcGIS shapefiles and PDFs of coastal flooding and riverine flooding data. This list of files can be filtered, and files can be downloaded by clicking on the filename link.

The shapefiles archived on DISDI are meant to be used for screening-level assessments at the 1:24,000 scale or coarser. They are not suitable for making engineering decisions: They indicate where additional assessment of exposure is advisable. For example, if a portion of the installation is shown as exposed to riverine flooding, a more detailed and finer-scale assessment of a proposed building site in that part of the installation would still be required as part of the planning process. The screening-level data indicates potential exposure risk only.

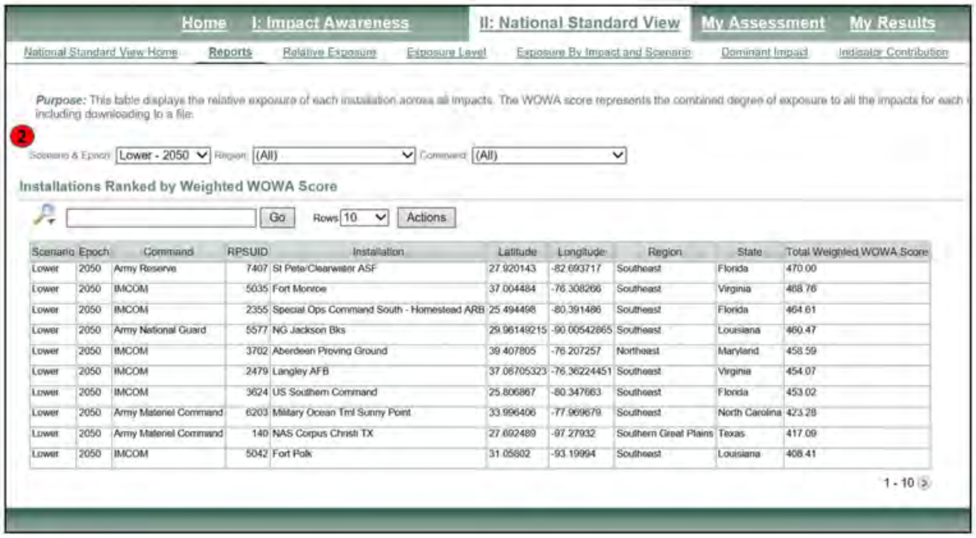
National Standard View: Reports

Purpose: These four standardized reports provide a quick assessment of the relative exposure of installations to the different climate change impacts. It allows the user to quickly generate a list of the most exposed installations. The Installation Climate Exposure Summary Reports provides an overview of the exposure of the selected single installation, including information on exposure sourced from the National Climate Assessment (key points from the Home page, Impact Awareness tab).

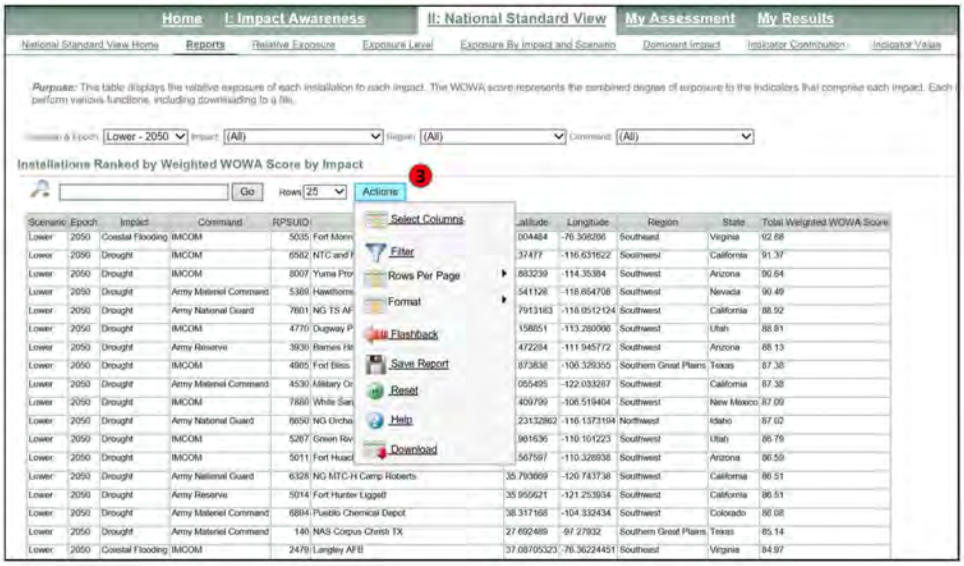
STEP 1: Click the **National Standard View** tab, then click on the **Reports** subtab. This section includes four Comparative Climate Exposure Reports: (1) Installations Ranked by Weighted WOWA Score Report, (2) Installations Ranked by Weighted WOWA Score by Impact Report, (3) First or Second Impact Comparison Report, and (4) Both First Impact Comparison WOWA Report, and one Installation Climate Exposure Summary Report: Installation Information Sheet .

STEP 2: Under the Comparative Climate Exposure Reports, click on a specific report link. This will open the report in the tool. From this view, the report can be filtered in multiple ways depending on the report type, including by scenario and epoch, impacts, region, and command .

3



STEP 3: Use the Actions button to manipulate the report table 3. This enables the user to perform various functions (Select Columns, Filter, Reformat), including downloading to a file.



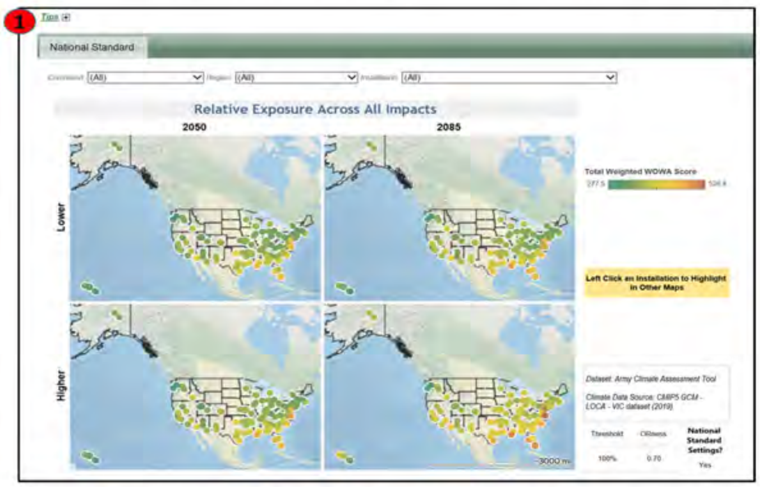
STEP 4: Under the Installation Summary Sheet, use the drop-down function to select an installation and click submit. This action will open a report summary in the tool. Click the Printable Report button to generate a PDF report of the information 4.

4

National Standard View: Relative Exposure

Purpose: This visualization shows the installations ranked by their aggregate exposure to all climate impacts in the Army Climate Assessment Tool, for 2050 and 2085, and for lower (slower warming) and higher (faster warming) scenarios. The purpose of this visualization is to compare among and across commands and regions.

STEP 1: Under the **National Standard View** tab, click the **Relative Exposure** subtab. Expand the *Tips* for more information on how to navigate this tab and all mapping tabs across the National Standard View 1.



STEP 2: Hover over an installation for a quick look at the Total Weighted WOWA Score for the installation. A pop-up box including this information will appear as you hover over different installations. Left click on an installation to

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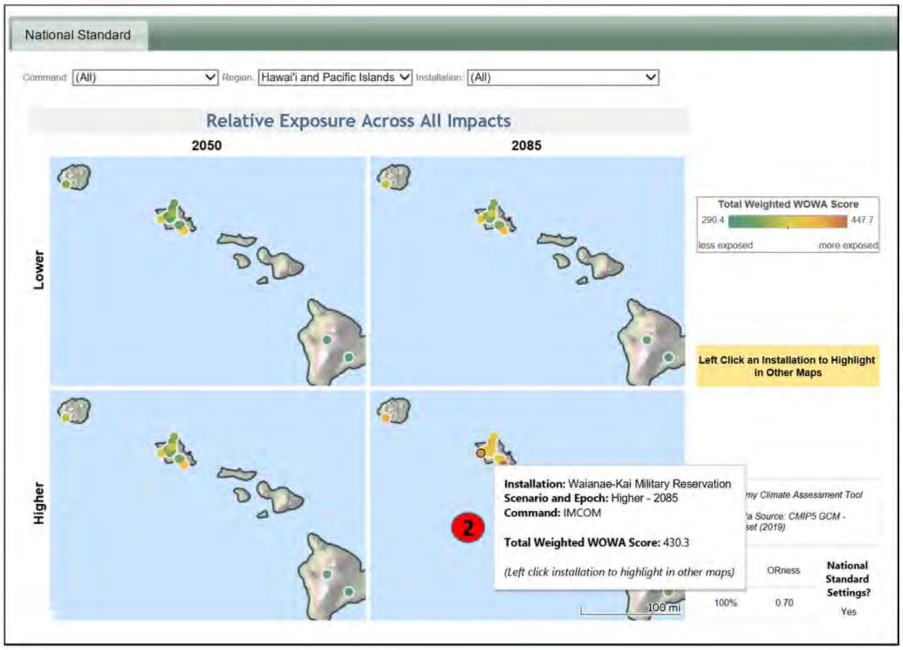
select it on all four maps, or use the drop-down menus to filter by command, region, and installation 2. This example shows the view when Hawaii and Pacific Islands is selected as the region and the user hovers over Waianae-Kai Military Reservation.



National Standard View: by Impact & Scenario

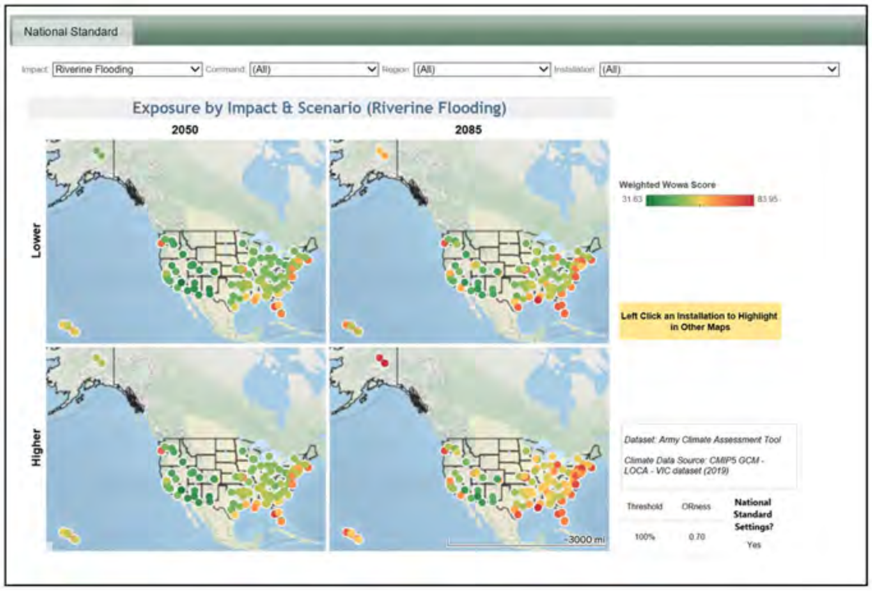
Purpose: This visualization helps the user understand installation exposure to individual impacts by epoch and scenario, and to filter this information by command and region.

STEP 1: Under the **National Standard View** tab, click the **Exposure by Impact and Scenario** subtab. Note: If you previously selected a command or installation, you should reset to All here.

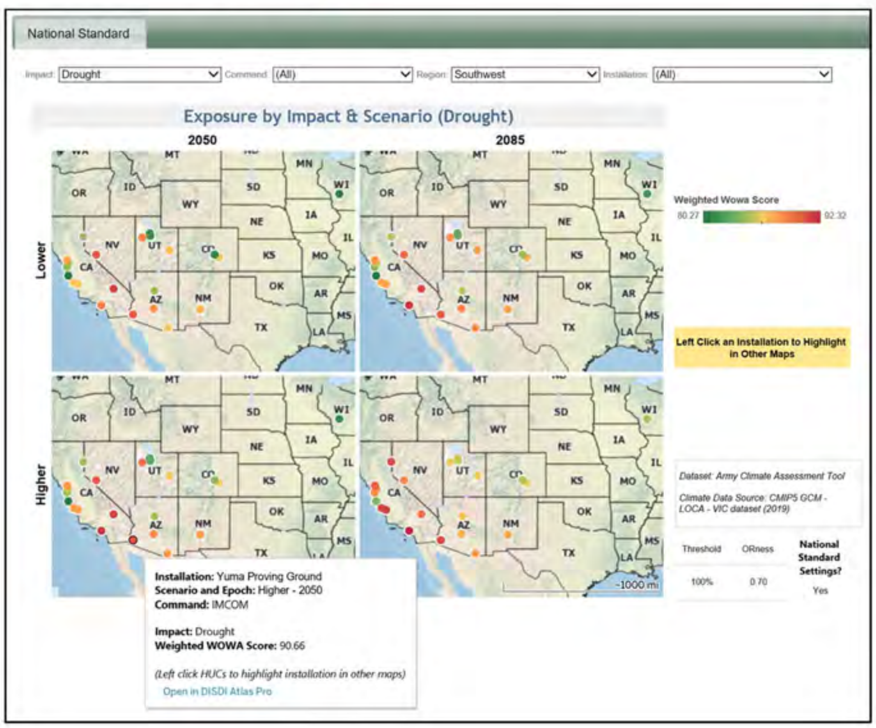
STEP 2: Select an Impact from the drop-down menu to review the relative exposure of the installations over time and with a higher or lower future scenario. Note, users may need to repeat drop-down selections if loading is slow.

STEP 3: Review the maps 1 to see the distribution of exposure scores across installations for a particular impact under the different scenarios and for the two epochs.

6



STEP 4: Select a region from the drop-down menu to see installations in that region. Hover over a particular installation to see the Weighted WOWA Score.



7

National Standard View: Dominant Impact

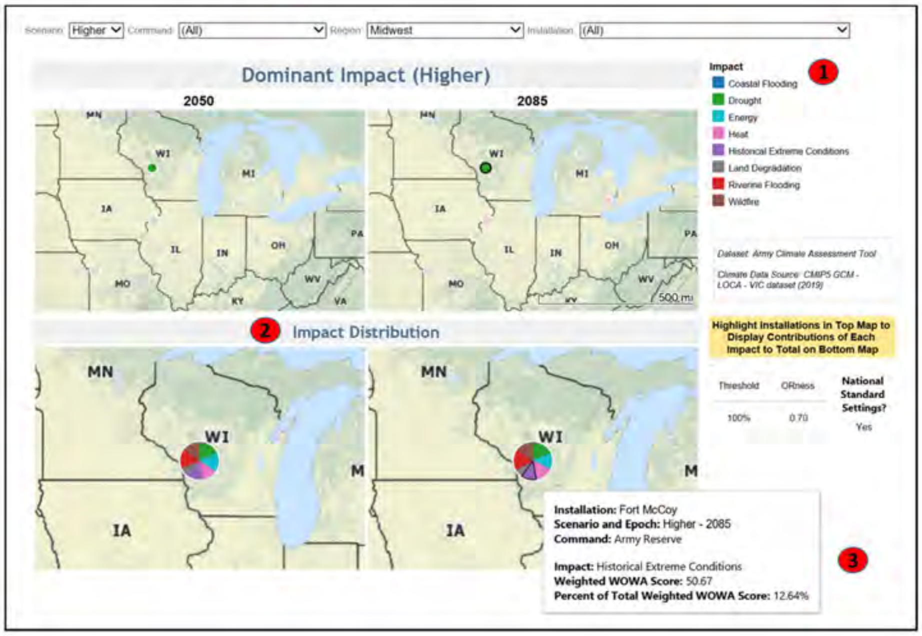
Purpose: The Dominant Impact visualization shows the user the largest projected impact to each installation.

STEP 1: After clicking the **National Standard View** tab, click the **Dominant Impact** subtab.

STEP 2: Use the drop-down menus to select the scenario of interest (higher/lower). The drop-down menus allow the user to filter by command, region, and installation. Use the color key on the right side of the maps to identify impacts 1.

STEP 3: Left click to select an installation of interest on the national map. This will generate regional maps for the two epochs (2050 and 2085) below the national maps for the selected installation 2.

STEP 4: Hover over the pie charts generated in the bottom maps to see the contribution of each impact on the total WOWA score for each epoch 3.



National Standard View: Indicator Contribution

Purpose: The Indicator Contribution visualization shows the contribution of a selected indicator to the exposure score for each installation for a selected impact component.

STEP 1: After clicking the **National Standard View** tab, click the **Indicator Contribution** subtab.

STEP 2: Use the drop-down menus to filter for scenario, impact, and indicator. A description of the indicator appears in a text box below the indicator title 1. A list of all available indicators in the selected impact are located on the

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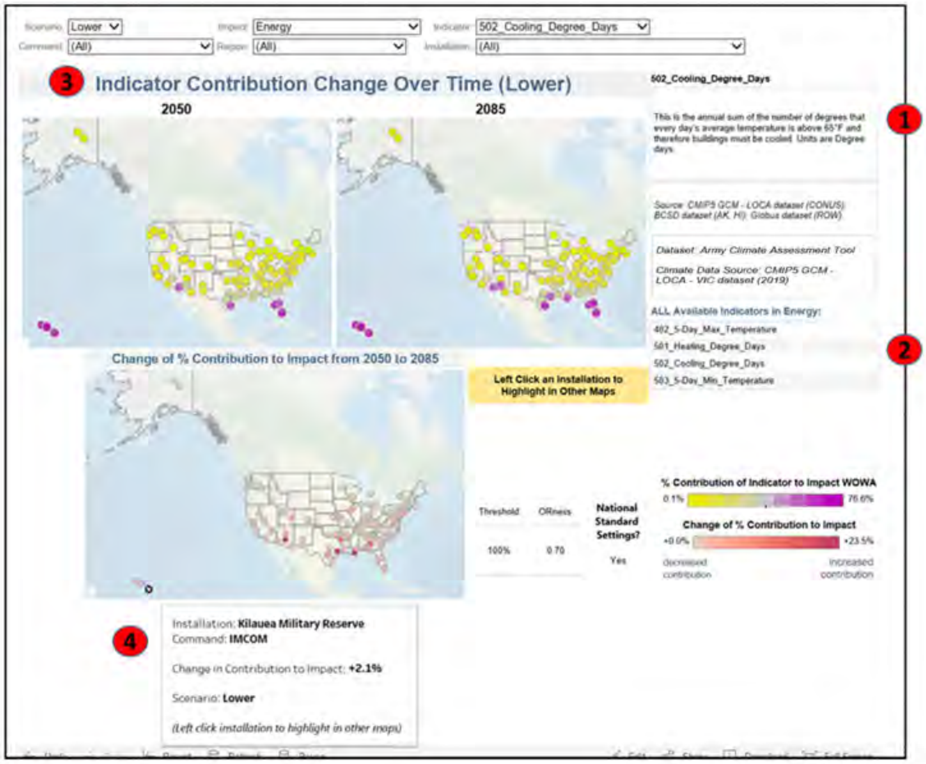
right for reference. If desired, use the command, region, or installation drop-down selections to filter to a specific location.

STEP 3: Use the "Indicator Contribution Change Over Time" maps to visualize how each indicator contributes to the overall WOWA score of the installation under each epoch.

STEP 4: View the "Change of % Contribution to Impact from 2050 to 2085" map to visualize how installation WOWA scores change over time due to changes in indicator contribution between the two epochs 2050 and 2085. Hover over any installation to see the percentage change in an indicator's contribution to an installation's WOWA score. Redder colors mean that the contribution of that indicator increases over time.



National Standard View: Indicator Value

Purpose: The Indicator Value visualization shows the contribution of a single selected indicator to the climate risk score for each installation for a given scenario at both future epochs, as well as the percent change between them.

STEP 1: After clicking the **National Standard View** tab, click the **Indicator Value** subtab.

STEP 2: Use the drop-down menus to select a scenario and an indicator. Drill down further to select command, region, an installation. Hover over the two upper maps (Indicator Value Over Time) to compare the Indicator Value at a given installation for the two epochs. Information to the right of the map includes a list of impacts that are associated with the Indicator selected.

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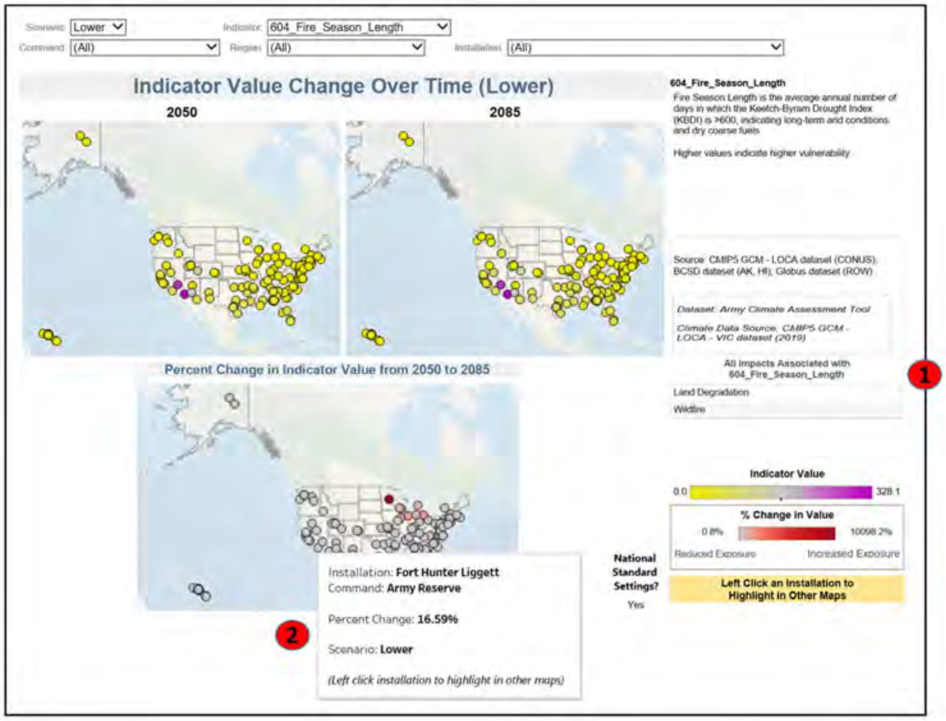
STEP 3: The map at the bottom shows the Percent Change in the indicator value from 2050 to 2085 at a given installation 1. This value helps to understand how a particular indicator drives exposure at an installation over time. Additional information about each indicator and the units for each indicator can be found in the fact sheets or in the Table at Home, Installation Planning Background.



National Standard View: Dominant Indicator

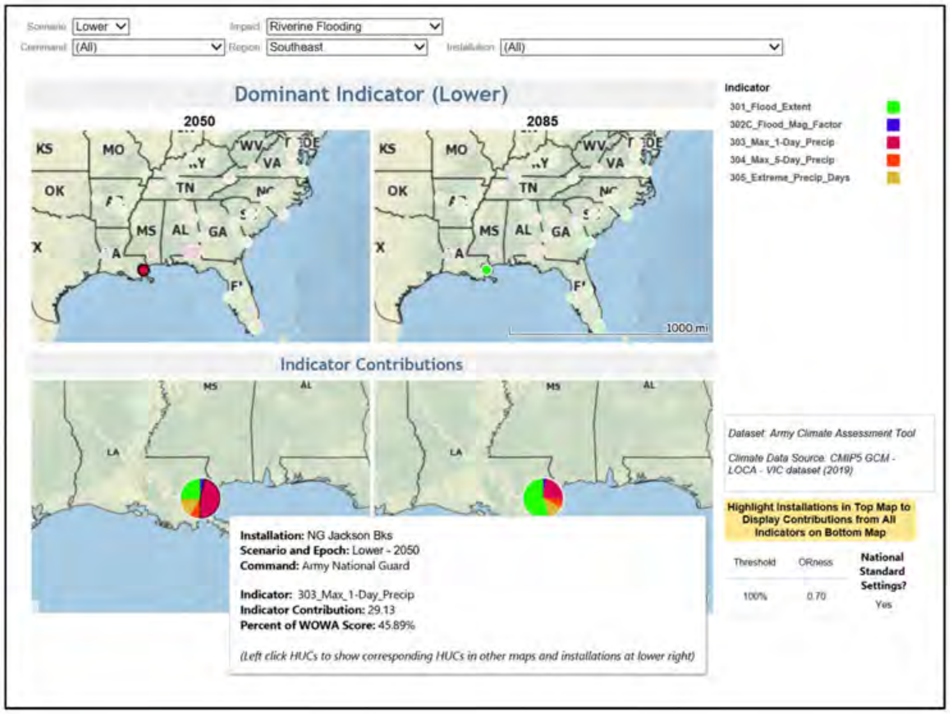
Purpose: ***The Dominant Indicator visualization allows the user to select an impact and identify the indicator that contributes the most to exposure for that impact at each installation.***

STEP 1: After clicking the **National Standard View** tab, click the **Dominant Indicator** subtab.

STEP 2: Use the drop-down menus to select a scenario and impact. Click an installation on the “Dominant Indicator” map to generate the “Indicator Contributions” maps below.

STEP 3: Hover over the pie charts by indicator to see the indicator contribution to the impact and the indicator percent contribution to the WOWA score 1.

10



National Standard View: Installation Details

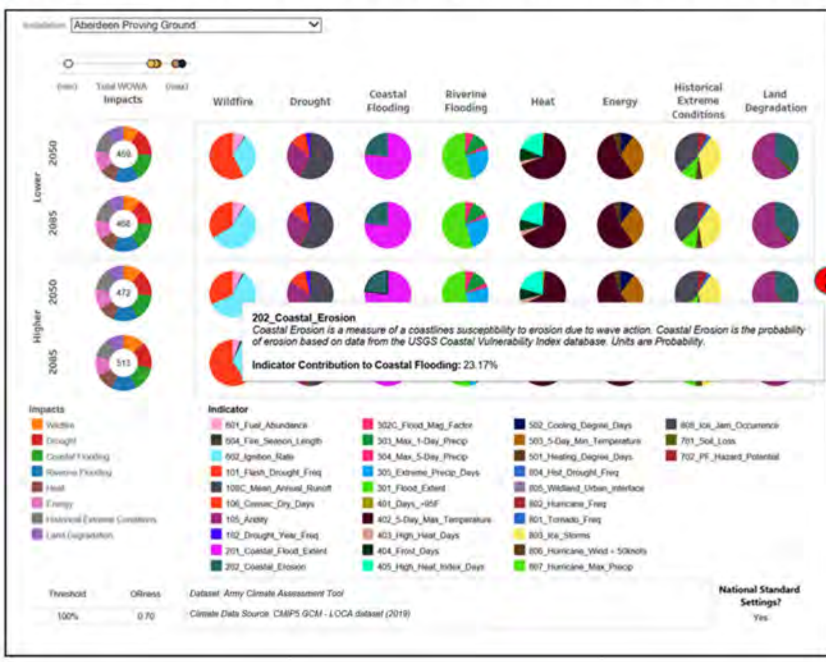
__Purpose:__ For the selected installation, this visualization provides a one-stop view of overall exposure to climate change.

STEP 1: After clicking the **National Standard View** tab, click the **Installation Details** subtab.

STEP 2: Use the drop-down menu to select an installation. Colors shown in each donut and pie chart are depicted in the legend below. In the first column (Impacts) the pairs of pie charts for lower and higher scenarios show how much each impact type is projected to contribute to installation exposure in 2050 and 2085, with the WOWA ranking in the center. A slider above the Impacts column shows how these WOWA rankings map to the minimum and maximum WOWA scores. For each impact, the pie charts in each column across the page show which indicators contribute the most to the installation's exposure to that impact.

STEP 3: The Weighted WOWA score of that impact under a given scenario and epoch is shown in the center of the donut.

STEP 4: Hover over the pie chart of the impact to view the percent contribution of the indicator to the impact.



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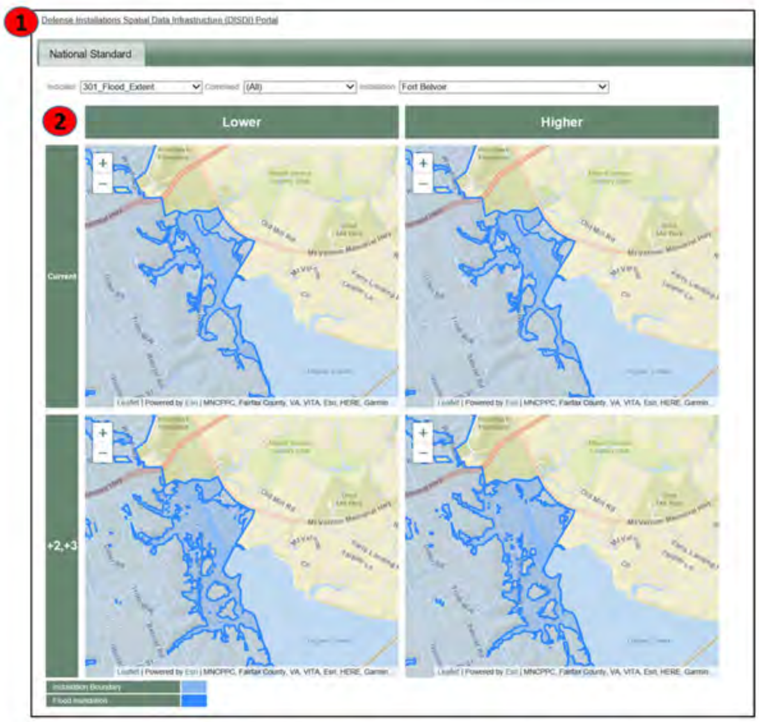
National Standard View: Installation Maps

***Purpose:* The Installation Maps visualization provides spatial data on the extent of coastal and riverine flooding under current and future 1% annual exceedance probability (AEP) events. These maps are intermediate products that were used to determine the coastal and riverine flood extent indicators and are intended to provide screening-level information on flood exposure for different portions of an installation.**

STEP 1: After clicking the **National Standard View** tab, click the **Installation Maps** subtab. A link to DISDI is available from this subtab.

STEP 2: Use the drop-down menu to select an indicator (301 Flood Extent or 201 Coastal Flood Extent) and an installation.

STEP 3: Use the "+" and "-" buttons on the maps to zoom in and out of the installation area. The installation boundary area is indicated by the translucent blue. Additional flooding under the different cases is indicated in a darker blue.



STEP 4: The maps under this tab are also available via the Climate Exposure Data page of the DISDI portal as ArcGIS shapefiles and as PDFs. Click the provided DISDI portal link to access these maps for your installation.

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DoD Service	RPSUID	Site Name	Impact	Indicator	Filename
Army Active	4980	Fort Belvoir	Coastal Flooding	201_Coastal_Flood_Extent	4980_Coastal_Inundation_Static_Map.pdf
Army Active	4980	Fort Belvoir	Coastal Flooding	201_Coastal_Flood_Extent	I_201_CoastalExtent_4980_2050L.zip
Army Active	4980	Fort Belvoir	Riverine Flooding	301_Flood_Extent	4980_flood_1per_plus3ft.zip
Army Active	4980	Fort Belvoir	Riverine Flooding	301_Flood_Extent	4980_1per.zip
Army Active	4980	Fort Belvoir	Riverine Flooding	301_Flood_Extent	4980_flood_1per_plus2ft.zip
Army Active	4980	Fort Belvoir	Riverine Flooding	301_Flood_Extent	4980_Inundation_Static_Map.pdf
Army Active	4980	Fort Belvoir	Coastal Flooding	201_Coastal_Flood_Extent	I_201_CoastalExtent_4980_2050H.zip
Army Active	4980	Fort Belvoir	Coastal Flooding	201_Coastal_Flood_Extent	I_201_CoastalExtent_4980_2085H.zip
Army Active	4980	Fort Belvoir	Coastal Flooding	201_Coastal_Flood_Extent	I_201_CoastalExtent_4980_2085L.zip
Army Active	4980	Fort Belvoir	Coastal Flooding	201_Coastal_Flood_Extent	I_201_CoastalExtent_4980_BaseNA.zip

National Standard View: Data

Purpose: This tab provides numerical results that complement the information within the visualizations.

STEP 1: After clicking the **National Standard View** tab, click the **Data** subtab.

STEP 2: Under the WOWA Aggregation Results, the WOWA score is presented by epoch-scenario for each impact for each installation.

STEP 3: The Drill-Down Analysis subtab allows the user to explore how each indicator contributes to impact exposure at each installation.

STEP 4: The Installation Report subtab provides a list of installations in the tool by command.

Manuals/Indicators

This section of the tool provides resources for users such as Indicator Fact Sheets and the tool's Quick Guide. Click the Indicator Fact Sheet icons to open them as a PDF.

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APPENDIX E: GLOSSARY

1% Annual Exceedance Probability (AEP)	The event that has a 1% chance of being exceeded in any year (i.e., any given year, the chance that a rainfall event or flood will be larger than the magnitude of the 1% AEP event is 1%).
Adaptation	Adjustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects.
Adaptive capacity	The potential of a system (1) to adjust to climate change (including climate variability and extremes) to moderate potential damages, (2) to take advantage of opportunities, and (3) cope with the consequences. With respect to installation infrastructure, it is the ease with which a structure, infrastructure, or other asset can be modified, moved, or repurposed to reduce harm from or improve performance in response to climate change hazards.
Built infrastructure	Capital improvements to land, such as buildings, structures, ground improvement structures, and utilities systems, as well as accessory equipment and furnishings that are engineered and built into a facility as an integral part of the final design that are required for operation, and are permanently affixed as part of the real property facility.

Climate	Climate in a narrow sense is usually defined as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organization (WMO). These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description of the climate system.
Climate change	Changes in average weather conditions that persist over multiple decades or longer. Climate change encompasses both increases and decreases in temperature, as well as shifts in precipitation, changing risk of certain types of severe weather events, and changes to other features of the climate system. Climate is “noisy,” meaning that there is a lot of variability around an average state, and some of these changes are cyclical (shifting back and forth between two or more states on a regular basis). Climate change differs from variability and cyclical change in that there is a trend with time.
Downscaling	Typical recent global model resolutions, at 15–30 miles (25–50 km) per gridbox, are unable to simulate all of the important fine-scale processes occurring at regional to local scales. Instead, downscaling methods are often used to correct systematic biases, or offsets relative to observations, in global projections and translate them into the higher-resolution information typically required for exposure assessments.

Ensemble	In modeling, refers to a process that incorporates the results of multiple models and model runs. The process of simplification inherent in making a model means that every model has biases. In general, model ensemble estimates of change are more robust than single model estimates of change because the ensembles effectively “average” across all the models, so the biases cancel out. This is an attribute of all models, not just climate models.
Epoch	A period of time. Climate is typically defined in 30-year epochs (called “climate normals”). In the ACAT Tool, two 30-year epochs are defined and labeled by their midpoint: 2035–2064 (2050) and 2070–2099 (2085). The historic (base) epoch is, for most indicators, the 55-year climate model historic period from 1950–2005.
Exposure	The nature and degree to which a system is exposed to significant climate variations or climate change.
Extreme weather	The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable. For simplicity, both extreme weather events and extreme climate events are referred to collectively as “climate extremes.”
Flood	The overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas that are not normally submerged. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods, and glacial lake outburst floods.

Greenhouse gas	Gases that absorb heat in the atmosphere near the Earth's surface, preventing it from escaping into space. If the atmospheric concentrations of these gases rise, the average temperature of the lower atmosphere will gradually increase, a phenomenon known as the greenhouse effect. Greenhouse gases include, for example, carbon dioxide, water vapor, and methane.
Measure	An action that can be taken, or something that can be constructed, to solve a planning problem.
Model uncertainty	Variability in climate model projections. Model uncertainty does NOT mean we are uncertain that climate change is happening. Model uncertainty means we are unsure of the magnitude and timing of the climate change threat.
Nonstructural	Nonstructural measures are permanent or contingent measures applied to a structure and/or its contents that prevent or provide resistance to damage from flooding.
Natural infrastructure	Natural features of the land and water environments created that evolve over time through the actions of physical, biological, geologic, and chemical processes operating in nature.

Nature-based features	Adaptation measures that rely on natural features or engineered nature-based features that may enhance resilience to climate change and include such features as dunes and beaches, vegetated features (e.g., salt marshes, wetlands, submerged aquatic vegetation), oyster and coral reefs, barrier islands, and maritime forests/shrub communities. Nature-based features are acted on by the same physical, biological, geologic, and chemical processes operating in nature, and as a result, they generally must be maintained in order to reliably provide the intended level of services.
Projection	A projection of the response of the climate system to emissions or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based upon simulations by climate models. Climate projections are distinguished from climate predictions in order to emphasize that climate projections depend upon the emission/concentration/radiative-forcing scenario used, which are based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial uncertainty.

Relative Concentration Pathways (RCPs)	Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases, aerosols, and other chemically active gases, as well as land use/land cover. The word "representative" signifies that each RCP provides only one of many possible scenarios that would lead to the specific radiative forcing characteristics. The term "pathway" emphasizes that not only the long-term concentration levels are of interest, but also the trajectory taken over time to reach that outcome. RCP 8.5 (the higher scenario, a more rapid change scenario) refers to a pathway that results in an increase of 8.5 Watts m-2 increase in heat accumulation around the world. The lower scenario (a less rapid change scenario) corresponds to a pathway that results in an increase of 4.5 Watts m-2 increase in heat accumulation around the world.
Resilience	The ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions.
Risk	In the DoD, risk is a potential future event or condition that might have a negative effect on achieving program objectives for cost, schedule, and performance. Risks are defined by (1) the probability (greater than 0, less than 1) of an undesired event or condition and (2) the consequences, impact, or severity of the undesired event, if it were to occur. Community risks are threats to life, health, safety, the environment, economic well-being, and other things of value. Risks are often evaluated in terms of how likely they are to occur (probability) and the damages that would result if they did happen (consequences).

Sensitivity	The degree to which exposure to climate change impacts or degrades an installation, its built infrastructure, and its natural/cultural resources or affects the performance or use of the installation, its built infrastructure, and its resources.
Scenario	Plausible and often simplified representation of future climate that takes into account a rate of change in atmospheric warming due to economic, technological, and other factors. In the ACAT Tool, the higher scenario refers to a more rapid change scenario than the lower scenario.
Vulnerability	The degree to which built infrastructure or other assets could be exposed to climate change, its sensitivity to this change, and its adaptive capacity.