Report on Effects of a Changing Climate to the Department of Defense

January 2019

Office of the Under Secretary of Defense
for Acquisition and Sustainment

As required by Section 335 of the National Defense Authorization Act for Fiscal Year 2018 (Public Law 115-91).

The estimated cost of this report or study for the Department of Defense is approximately $329,000 in Fiscal Years 2018 - 2019. This includes $58,000 in expenses and $271,000 in DoD labor.
Generated on 2018Dec18 RefID: 9-D30BE5A

January 2019

Elements of Request for Report

This report responds to section 335 of the National Defense Authorization Act for Fiscal Year 2018 (Public Law 115-91). Specifically, this report provides an assessment of the significant vulnerabilities from climate-related events in order to identify high risks to mission effectiveness on installations and to operations. In developing this report, we discussed the approach with staff from the House and Senate Armed Services Committees, both majority and minority, on more than one occasion.

This report is organized into three primary sections:

I. Summary of Climate Effects and Resulting Vulnerabilities

II. DoD Efforts to Increase Installation Resiliency & Operational Viability

III. Conclusions

Background

The effects of a changing climate are a national security issue with potential impacts to Department of Defense (DoD or the Department) missions, operational plans, and installations. Our 2018 National Defense Strategy prioritizes long-term strategic competition with great power competitors by focusing the Department's efforts and resources to: 1) build a more lethal force, 2) strengthen alliances and attract new partners, and 3) reform the Department's processes.

To achieve these goals, DoD must be able to adapt current and future operations to address the impacts of a variety of threats and conditions, including those from weather and natural events. To that end, DoD factors in the effects of the environment into its mission planning and execution to build resilience.

For this report, the Office of the Secretary of Defense requested information and inputs from the Military Departments, Joint Staff, Geographic Combatant Commands, and other organizations.

Planning Handbook on Climate Change Installation Adaptation and Resilience – In January 2017, Naval Facilities Engineering Command released a handbook for use by planners in assessing climate impacts and evaluating adaptation options to consider in the existing Installation Development Plan (Master Plan) process. The Handbook contains an extensive set of worksheets to be used in documenting the results of planners' assessment and evaluation, including economic analyses of adaptation alternatives.

Updated United Facilities Criteria (UFCs) – In October 2017, DoD UFC 1-200-02, *High Performance and Sustainable Building Requirements,* was updated to ensure appropriate incorporation of climate-related impacts, amongst other updated/new areas. The UFC provides minimum requirements, and guidance for planning, designing, constructing, renovating, and maintaining high performance and sustainable buildings that will enhance DoD mission capability by reducing total ownership costs.

U.S. Army Corps of Engineers (USACE) Tools – Providing support to civilian and military infrastructure projects, USACE continues to develop assessment and adaptation tools useful in adapting to risks associated with potential changing weather patterns.

DoD Directive 4715.21 – In January 2016 the Department issued Department of Defense Directive 4715.21 *Climate Change Adaptation and Resilience*, assigning responsibilities to many levels and DoD components for incorporating climate considerations into planning for infrastructure and operations in order to assess and manage risks associated with the impacts of a changing climate.

I. Summary of Climate Effects and Vulnerabilities

INSTALLATIONS & INFRASTRUCTURE

Methodology for Installation Effects

The Office of the Secretary of Defense requested information from the Military Departments for climate-related events. To ensure connection to mission impacts, DoD focused on 79 mission assurance priority installations based on their operational role. The Office of the Secretary of Defense requested Military Departments analyze the climate-related events at these installations. The installations break down by organization as follows:

Air Force	35
Army	20
Navy	19
Defense Logistics Agency (DLA)	2
Defense Financing and Accounting Service (DFAS)	1
National Geospatial-Intelligence Agency (NGA)	1
Washington Headquarters Service (WHS)	1

The Military Departments noted the presence or not of current and potential vulnerabilities to each installation over the next 20 years, selecting from the events listed below. Note that the congressional request established the 20-year timeframe.

Climate-Related Events

- Recurrent Flooding
- Drought
- Desertification
- Wildfires
- Thawing Permafrost

Military Department input on the 79 installations is included in the Appendix, which is sorted by Military Service. In preparing input for the Appendix, the Military Services were free to select information sources they deemed relevant[1].

[1] Data sources used include: Screening Level Vulnerability Assessment Survey (SLVAS) responses included in the January 2018 *Climate-Related Risk to DoD Infrastructure Initial Vulnerability Assessment Survey (SLVAS) Report*; USGS Coastal Vulnerability Index (CVI); FEMA National Flood Hazard Layer; US Drought Monitor; USDA Global Desertification Vulnerability Map; USDA layer - 2010 Wildland Urban (continued) Interface (WUI) of the Conterminous US – Intermix and Interface classes; USGS Volcano Hazards Program; USGS Seismic Information

Summary Table of Current & Potential Effects to 79 Installations

The following tables provide a summary of current and future (20 years) vulnerabilities to military installations.

		Recurrent Flooding		*Drought*		*Desertification*		*Wildfires*		*Thawing Permafrost*	
Service	# Installations	Current	Potential	Current	Potential	Current	Potential	Current	Potential	Current	Potential
Air Force	35	20	25	20	22	4	4	32	32	-	-
Army	20	14	16	4	4	2	2	4	4	1	1
Navy	19	16	16	18	18	-	-	-	7	-	-
DLA	2	2	2	-	2	-	-	-	-	-	-
DFAS	1	-	-	-	1	-	-	-	-	-	-
NGA	1	1	1	1	1	-	-	-	-	-	-
WHS	1	-	-	-	-	-	-	-	-	-	-
Totals	79	53	60	43	48	6	6	36	43	1	1

A review of the chart above indicates that recurrent flooding, drought, and wildfires are the primary concerns at the 79 installations included in the analysis.

Examples of Vulnerabilities to DoD Installations and Infrastructure

The sections below provide examples of impacts to the selected military installations. Each section below includes a brief general description of the vulnerability factor and possible impacts to military installations or infrastructure followed by examples.

Recurrent Flooding

Vulnerabilities to installations include coastal and riverine flooding. Coastal flooding may result from storm surge during severe weather events. Over time, gradual sea level changes magnify the impacts of storm surge, and may eventually result in permanent inundation of property. Increasing coverage of land from nuisance flooding during high tides, also called "sunny day" flooding, is already affecting many coastal communities.

Joint Base Langley-Eustis (JBLE-Langley AFB), Virginia, has experienced 14 inches in sea level rise since 1930 due to localized land subsidence and sea level rise. Flooding at JBLE-Langley, with a mean sea level elevation of three feet, has become more frequent and severe.

Navy Base Coronado experiences isolated and flash flooding during tropical storm events, particularly in El Niño years. Upland Special Areas are subject to flash floods. The main installation reports worsening sea level rise and storm surge impacts that include access limitations and other logistic related impairments.

Navy Region Mid-Atlantic and the greater Hampton Roads area is one of the most vulnerable to flooding military operational installation areas in the United States. Sea level rise, land subsidence, and changing ocean currents have resulted in more frequent nuisance flooding and increased vulnerability to coastal storms. As a result, and to better mitigate these issues, the Region has engaged in several initiatives and partnerships to address the associated challenges.

Drought

Drought can negatively impact U.S. military installations in various ways, particularly in the Southwest. For example, dry conditions from drought impact water supply in areas dependent on surface water. Additionally, droughts dry out vegetation, increasing wildfire potential/severity. Specific to military readiness, droughts can have broad implications for base infrastructure, impair testing activities, and along with increased temperature, can increase the number of black flag day prohibitions for testing and training. Drought can contribute to heat-related illnesses, including heat exhaustion and heat stroke, outlined by the U.S. Army Public Health Center. Energy consumption may increase to provide additional cooling for facilities.

Several DoD sites in the DC area (including Joint Base Anacostia Bolling, Joint Base Andrews, U.S. Naval Observatory/Naval Support Facility, and Washington Navy Yard) periodically experienced drought conditions –extreme in 2002 and severe from 2002 through 2018. In addition, Naval Air Station Key West experienced drought in 2015 and 2011, ranging from extreme to severe, respectively. These examples highlight that drought conditions may occur in places not typically perceived as drought regions.

Drought conditions have caused significant reduction in soil moisture at several Air Force bases resulting in deep or wide cracks in the soil, at times leading to ruptured utility lines and cracked road surfaces.

Desertification

Desertification poses a number of challenges related to training and maneuvers. Desertification results in reductions in vegetation cover leading to increases in the amount of runoff from precipitation events. Greater runoff contributes to:

- higher erosion rates
- increased stream sediment loads
- deposition of sediment in unwanted areas

This reduces the effectiveness of flood risk management infrastructure while increasing the potential for siltation of water supply reservoirs. Following rain, eroded soil may be less suitable for native vegetation, resulting in bare land or revegetation with non-native, weedy species. In cases where this results in the expansion of shrub-lands, this could affect the suitability of the landscape for military maneuvers and off-road use.

Army installations Camp Roberts in San Miguel, California, and White Sands Missile Range in New Mexico were identified as vulnerable to current and future desertification, which

accelerates erosion and increases soil fragility, possibly limiting future training and testing exercises. Air Force bases in western states, including Kirtland, Creech, Nellis, and Hill were also identified as vulnerable to current and future desertification.

Wildfires

Due to routine training and testing activities that are significant ignition sources, wildfires are a constant concern on many military installations. As a result, the DoD spends considerable resources on claims, asset loss, and suppression activities due to wildfire. While fire is a key ecological process with benefits for both sound land management and military capability development, other climatic factors including increased wind and drought can lead to an increased severity of wildfire activity. This could result in infrastructure and testing/training impacts.

In March 2018 two related wildfires broke out in Colorado during an infantry and helicopter training exercise for an upcoming deployment. Later determined to be due to live fire training, gusty winds and dry conditions allowed the fire to spread, reaching about 3,300 acres in size, destroying three homes, and causing the evacuation of 250 homes.

A wildfire in November 2017 burned 380 acres on Vandenberg Air Force Base in southern California. While no structures were burned, the fire prompted evacuation of some personnel. Firefighters from the U.S. Forest Service, Santa Barbara County, and other localities assisted the Vandenberg Fire Department in managing the fire. The Canyon Wildfire at Vandenberg in September 2016 burned over 10,000 acres and came very close to two Space Launch Complexes. A scheduled rocket launch had to be delayed. Several facilities on the south part of the base were operating on generators due to the loss of electrical power lines.

Thawing Permafrost

Permafrost presents risks for critical built infrastructure. Soil strength, ground subsidence, and stability are primarily affected by the phase change of ground ice to water at or near 0°C and when the soil thermal regime changes (by human activity, infrastructure emplacement, or systemic shifts related to weather). Such subsidence may be rapid and catastrophic (days), very slow and systematic (decades), or somewhere in between. Whether rapid or slow, thawing permafrost decreases the structural stability to foundations, buildings, and transportation infrastructure and requires costly mitigation responses that disrupt planning, operations, and budgets. In addition, thawing permafrost exposes coasts to increased erosion.

Permafrost underlays about 85 percent of Alaska; it is thickest north of the Brooks Range and gradually diminishes southward. Permafrost thaw is relevant to DoD training and testing needs. Thermokarst, which is a type of landscape that results from thawing permafrost, increases wetland areas and creates more challenging terrain. In Fort Greeley, Alaska, Army training ranges are built on, or are being planned in permafrost-dominated areas. Predicting where this phenomenon occurs and how permafrost might change is vital to maintaining training operations and assessing impending environmental management challenges.

OPERATIONS

A changing climate can impact DoD's operations through:

- Changes in the manner in which DoD maintains readiness and provides support.
- Changes to what DoD may be asked to support.

Vulnerabilities to Mission Execution and Operational/Posture Plans

The National Defense Strategy sets the strategic priorities for the Department and, in turn, the Combatant Commands (CCMD). The CCMD missions may be affected by timing and severity of climate events, which may affect mission in some cases.

> "When I look at climate change, it's in the category of sources of conflict around the world and things we'd have to respond to. So it can be great devastation requiring humanitarian assistance — disaster relief — which the U.S. military certainly conducts routinely."
> Chairman of the Joint Chiefs of Staff General Dunford, November 2018

Country Instability Issues: In the United States Africa Command (USAFRICOM) Area of Responsibility (AOR), rainy season flooding and drought/desertification are very important factors in mission execution on the continent. Flooding and earthquake-induced tsunamis in Indonesia contribute to instability in the Indo-Pacific Command (INDOPACOM).

Logistics and Mission Support Issues: Weather conditions over the Mediterranean Sea currently impact intelligence, surveillance, and reconnaissance (ISR), personnel recovery/casualty evacuation and logistics flights from Europe to the African continent; potentially increasing no-go flight days.

At Naval Base Guam, recurrent flooding limits capacity for a number of operations and activities including Navy Expeditionary Forces Command Pacific, submarine squadrons, telecommunications, and a number of other specific tasks supporting mission execution.

Additionally, recurrent flooding impacts operations and activities of contingency response groups at Andersen Air Force Base, as well as mobility response, communications, combat, and security forces squadrons.

Arctic Region Issues: Climate-related effects impact accessibility and activity in the Arctic. The Northern Sea Route generally opens for four weeks each year – usually the month of September – and has the potential for increased Arctic maritime traffic. The demand for Arctic-specific search and rescue (SAR) resources will grow as Arctic activity increases.

There is need for further military support to civil authorities to enable the peaceful opening of the Arctic as access increases. The role of United States Europe Command (USEUCOM) in the high north will expand with enhanced opportunities for cooperation with

allies and partners and growth in the number and frequency of live training exercises in the region.

In the Arctic, acquisition and supply chain requirements are considerably longer and are much costlier. DoD will continue to partner with Federal departments and agencies, state, local, and tribal agencies, other nations, and the private sector on services as appropriate.

Humanitarian Assistance/Disaster Relief

Geographic Combatant Commands regularly conduct humanitarian assistance and disaster relief initiatives to improve the resiliency of the partner nation to natural and manmade disasters.

DoD conducts foreign disaster relief at the request of the U.S. Agency for International Development (USAID) and the State Department. USAID's Office of U.S. Foreign Disaster Assistance is the lead federal agency for coordinating the U.S. Government foreign disaster relief response. DoD does not develop its force structure for foreign disaster relief missions, but supports USAID with available unique military capabilities and assets, such as transportation, logistics, engineering assessments, air traffic control, and water.

DoD focuses its humanitarian assistance program on building capacity of partner nations for health-related activities and activities that promote sustainable public health capacity-building, disaster preparedness, risk reduction, and relief response. Examples include: emergency management training; construction/renovation of emergency operations centers and disaster relief warehouses; assistance with planning for disaster response and recovery; and country baseline assessments for vulnerabilities to disasters, including vulnerabilities from weather and climate impacts. Global health engagement activities such as disease mitigation and prevention initiatives address the basic survival needs of the population, promote stability and capacity, and thus also climate resiliency.

Defense Support of Civil Authorities

Domestically, DoD provides disaster assistance at the request of the Federal Emergency Management Agency (FEMA) and other federal Departments and Agencies. DoD always operates in support of civil authorities and is not the lead federal agency for domestic disaster relief missions, unless so designated by the President. DoD will maintain command and control over Federal military forces and Governors of responding States will maintain command and control over State National Guard forces. FEMA's ten regions are responsible for writing All Hazard Plans (AHPs) that guide response efforts to disasters including floods and hurricanes. DoD works to support these AHPs as requested.

Testing and Training

The Department conducts training in realistic field environments to achieve and sustain proficiency in mission requirements. Similarly, the Department conducts testing in realistic field environments in anticipation of the military's use of weapons, equipment, munitions, systems, or their components. As such, access to the land, air, and sea space that replicate the operational

environment is critical to the readiness of the Force. Climate effects to the Department's training and testing are manifested in an increased number of suspended/delayed/cancelled outdoor training/testing events and increased operational health surveillance and health and safety risks to the Department's personnel. Specifically, installations in the Southeast and Southwest lose significant training and testing time due to extreme heat.

Climate effects lead to increased maintenance/repair requirements for training/testing lands and associated infrastructure and equipment (e.g., roads, targets, buildings). In addition to the loss of use of training and test ranges, these impacts result in increased land management requirements due to stressed threatened/endangered species and related ecosystems on and adjacent to DoD installations. Recent specific examples include:

- Wildfires in the western United States affecting Vandenberg AFB and operations at the Western Range and Point Mugu Sea Range.
- Hurricanes resulting in damage to infrastructure and delays in training, testing programs, and space launches at Tyndall Air Force Base, at the Atlantic Undersea Test and Evaluation Centers, and the Eastern Range.
- Permafrost thawing at Cold Region Test Center, Fort Greely, Alaska, impacting cold weather testing activities.
- Rising seawater wash-over and contamination of freshwater on atoll installations.

Mitigation efforts for unplanned climate events necessitate contingency planning for training and test events and the minimization of planned range/facility use during historical adverse climate condition seasons of the year. Other climate and non-climate related facility maintenance and contingency of operations efforts are included in installation mitigation plans.

II. DoD Efforts to Increase Installation Resiliency & Operational Viability

INCREASE INSTALLATION RESILIENCY

The Department considers climate resilience in the installation planning and basing processes to include impacts on built and natural infrastructure. To ensure that DoD facilities better withstand flooding and severe weather events, DoD makes appropriate changes to installation master planning, design and construction standards.

To continue missions in the event of loss or damage to critical energy and water infrastructure, the Department uses the Mission Assurance process (DoD 3020.40, *Mission Assurance Strategy*) to plan and conduct mitigation and remediation actions to improve the resilience of critical assets and capabilities to reduce risk to critical missions. In May 2016, DoD updated Directive 4170.11 on *Installation Energy Management* and developed Installation Energy Plan guidance that included a focused goal of increased energy resilience and critical energy infrastructure requirements. In February 2017, the Army added water to this effort and released guidance to establish requirements for Army energy and water security to enhance resilience on Army installations.

The Department has published several issuances to ensure that the Military Services and Joint Staff integrate climate scenarios and long-term projections into planning, including DoDD 4715.21 (*Climate Change Adaptation and Resilience*) to establish roles and responsibilities and DoDI 4715.03 (*Natural Resources Conservation Program*) requiring consideration of climate impacts during development of Installation Natural Resources Management Plans (INRMPs).

Unified Facilities Criteria, or UFCs, provide planning, design, construction, sustainment, restoration, and modernization criteria, and apply to the Military Services, the Defense Agencies, and the DoD Field Activities. In June 2018, the UFC on *High Performance and Sustainable Building Requirements* was updated to include and strengthen climate considerations. The UFC 20-100-1, *Master Planning*, also includes language requiring Master Planners to consider changes in climatic conditions that may impact new and existing facilities and infrastructure. The UFC on *Landscape Architecture* is being updated to support installation water resilience. Additionally, UFC 3-400-02 directs installation planners to request engineering weather data (EWD) from Air Force's 14th Weather Squadron (WS) that focuses on climatic variables of temperature, humidity, precipitation, and winds. Recently the 14th WS moved from a 10 to 5 year update cycle to ensure climate impacts are captured.

DoD is also updating various built and natural infrastructure design standards to better adapt to climate impacts. The Coastal Assessment Regional Scenario Working Group released a report in April 2016 that provided a database with regionalized sea level scenarios for three future time horizons (2035, 2065, and 2100) for 1,774 DoD sites worldwide. The database also contains extreme water levels statistics (storm surge without waves and wave run up) for four types of annual chance events (1, 2, 5 and 20 percent) based on historical tide gauge data. This information can be used to establish base flood elevation and potential future flood inundation areas of concern for installations in coastal and tidal areas.

The Military Services and the Defense Logistics Agency approach installation resiliency through the integration of weather and climate considerations into existing plans and processes, using partnerships with other federal agencies, state governments, local governments, non-governmental organizations, and local communities to increase preparedness and resilience. Examples:

- Patrick Air Force Base imposes strict Florida Building Code hurricane requirements and finished floor elevations for all new construction based on flood plain and storm surge data. Base staff coordinates with state, county, and academic institutions to ensure these requirements are implemented.

- As mentioned earlier in this report, flooding at JBLE-Langley Air Force Base has become more frequent and severe. JBLE-Langley is using a flood visualization tool to understand flooding impacts across the base. By modeling different storm flooding elevations, they were able to determine where to install door dams, which require less time and less labor than sandbags. The base reduced the number of required sandbags by 70 percent. JBLE-Langley also requires that all new development is constructed at a minimum elevation of 10.5 feet above sea level with some projects planned for higher elevation due to high communication intensity and need for greater hardening. Additionally, the City of Hampton recently adopted a Resiliency and Adaptation Addendum to their original 2010

Joint Land Use Study. This addendum will help solidify a path forward for the City of Hampton and JBLE-Langley to identify and implement resilience strategies that support continued feasibility of base operations.

- Eglin and MacDill Air Force Bases in Florida partnered with local groups to address persistent coastal erosion around their installations. Oyster shells collected from local restaurants became the foundation for oyster reefs to create a living shoreline, bolstering natural protection of critical historic sites, stabilizing shoreline, protecting the riparian and intertidal environment, thereby creating habitat for aquatic/terrestrial species.

- Navy Region Southwest leadership have adopted decisive measures to evaluate climate impacts on shore infrastructure, and are pursuing a strategy to mitigate vulnerabilities through local agency collaboration, adaptive planning and implementation of innovative design techniques. This initiative will improve upon the Navy's scientific data, facilitate assessment of various sea level rise (SLR) scenario impacts, and help identify sustainable infrastructure strategies to offset stressors from flooding, beach erosion, and loss of wetlands and habitat.

- Navy Region Southwest facility planning efforts now incorporate adaptive planning measures from a variety of government agency sources, including NAVFAC's *Climate Change Installation Adaptation and Resilience Planning Handbook*. Regional planners are working with the National Oceanic and Atmospheric Administration and the Scripps Institute of Oceanography to study potential vulnerabilities at the Naval Amphibious Base. Sea level rise data for 2100 was used during the environmental planning and design phases of the Coastal Campus project. The design configuration of five buildings was modified to resist a moderate sea level rise event over their forecasted life cycle.

- The greater Hampton Roads area is very vulnerable to flooding caused by rising sea levels and land subsidence. Navy Region Mid-Atlantic is working with several academic, local community, non-profit organizations, and state and federal agencies to increase understanding of current and future risks to inform discussions on possible adaptation strategies for communities and military bases. In addition, the cities of Norfolk and Virginia Beach are currently engaged in a Joint Land Use Study to identify specific conditions, including recurrent flooding, coastal storms, and erosion, outside of the military footprint that have the potential to impact Navy operations in the Hampton Roads area.

- Fort Hood, Texas, endured severe flash flooding in June 2016. A training exercise that involved a low river crossing resulted in the death of several soldiers. In response, the installation replaced the two most dangerous low water crossings with bridges, installed stream and depth gauges at critical locations on the west side to better monitor and predict flash flooding, and focused on clear signage and training.

- To address wildfire risk, Navy Region Southwest successfully worked with the California Department of Forestry and Fire Protection (CALFIRE) to promote joint training opportunities in an effort to protect key infrastructure and communities within San Diego County. Navy squadrons conduct semiannual joint training with CALFIRE to ensure interoperability and an immediate response capability in support of local authorities for

emergency events. At the installation level, natural resource managers work to evaluate the threat of wildfires to key resources and promote sustainable management practices, such as the development and implementation of fire management plans for major facilities and aligned special areas.

- DLA is upgrading its data center layout and mechanical equipment to ensure provision of the cooling needed for processors and servers to operate efficiently in warmer temperatures. All data centers will eventually migrate to a cloud server following the Data Center Optimization Initiative.

- Other DLA approaches to increase installation resilience involve relocation of assets from flood-prone areas to safer areas. For example, at two flood-prone sites, DLA installed backup power generators and other mechanical equipment like chillers on a higher elevation or mounted on concrete pads in accordance with building codes. Other mechanical rooms were located in building rooftops, which helps prevent flood water damage to equipment. In addition, other measures control rainwater flow, such as the use of retention swales to divert storm water, green roofs to absorb rainfall, and cisterns to store rainfall during downpours.

RESEARCH

Current Efforts

DoD's Strategic Environmental Research and Develop Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) invest in research focused on improving DoD understanding of environmental risks to installations and mission. SERDP and ESTCP investments support the development of the science, technologies, and methods needed to manage and enhance the resilience of DoD installation infrastructure with the goal of maximizing mission readiness. The following are a few examples of SERDP research efforts related to infrastructure and mission resiliency:

- In response to drought risk, SERDP initiated a study to understand and assess environmental vulnerabilities on installations in the desert southwest. This research seeks to detect and assess drought response of sensitive riparian forests to drought stress over recent decades and will be carried out within three DoD bases in the Southwest, with widely applicable results.

- In response to wildfire risk, SERDP developed a Fire Science Strategy in 2014 focused on the following: improved characterization, monitoring, modeling, and mapping of fuels to support enhanced smoke management and fire planning at DoD installations; enhanced smoke management using advanced monitoring and modeling approaches; and research to quantify, model, and monitor post-fire effects.

- SERDP and ESTCP investments seek to understand changes to the arctic terrestrial environment relevant to DoD infrastructure. Permafrost degradation can impact soil, vegetation, buildings, roads, and airfields. SERDP and ESTCP investments are leading to tools for making arctic infrastructure more "aware" of permafrost changes before

costly failures occur. An example is Lawrence Berkeley National Laboratory's fiber-optic geophysical sensing package capable of providing real-time information on subsurface conditions relevant to infrastructure performance and failure in Arctic environments.

At the Military Service level, the Air Force's 14th Weather Squadron provides authoritative data sets and tailored decision aids to the Combatant Commanders, or CCMDs. This same information is available to installation managers/planners. Additionally, the Air Force is pursuing more accurate North Slope Alaska shoreline erosion prediction models that take into account warming water near the shore, increasing air temperatures, longer periods when sea ice is gone, increasing spatial extent of open water, increasing wind speeds, storm surges, wave height, and thawing permafrost.

The U.S. Army Cold Regions Research and Engineering Laboratory maintains a Permafrost Tunnel Research Facility in Fox, Alaska, for several types of research, including studies to better understand permafrost terrains for engineering, military planning, and science. In addition, the Cold Regions Research and Engineering Laboratory, together with the Construction Engineering Research Laboratory and Geotechnical and Structures Laboratory, developed solutions for damage caused by thawing permafrost at Thule Air Base in Greenland. A new technology incorporating buried extruded foam insulation boards was used for about 18 percent of the runway during a repaving project in the summers of 2015 and 2016; the existing white paint on the remainder of the runway was deemed sufficiently protective. New mitigation techniques were proposed to stabilize critical buildings that had re-settled after previous modifications and remodeling projects.

The Office of Naval Research (ONR) Arctic and Global Prediction Program is motivated by the need to understand and predict the environment at a variety of time and space scales in geographical areas of interest to DoD such as the Arctic. ONR is actively working to extend the capability to skillfully predict environmental conditions and disruptive weather events to several weeks and months in advance. The ability to provide useful forecasts of the operational environment, such as the location of the sea ice edge, the characteristics and evolution of sea ice, and the wind and wave conditions at the surface will be critical to enable safe and efficient naval operations in the Arctic.

Future Efforts

DoD realizes the need to better understand rates of coastal erosion, natural and built flood protection infrastructure, and inland and littoral flood planning and mitigation. To address this, we are focusing on the following in current SERDP Statements of Need that communicate the types of research we are interested in pursuing:

- Continued work to apply, evaluate, and improve scenarios and other tools for projecting interactions of sea level rise, storm surge, precipitation/land-based flooding at U.S. Military Installations.
- Research and products that fuse climate science, design, and decision sciences methods in the context of current DoD/Service planning, operations, and management.

- Research on materials fragility and implications for infrastructure/building design.

ENSURE MISSION RESILIENCY

DoD is continuing to work with partner nations to understand and plan for future potential mission impacts. This is a global issue and a number of Ministries of Defense across the world are beginning to plan now for future impacts, as well. The Department has funded cost-effective climate related MIL-to-MIL engagements between the Combatant Commands and partner nations through the Defense Environmental International Cooperation (DEIC) program. DEIC projects have included:

- United States Africa Command (USAFRICOM) water security engagements in the Chad Basin and Tanzania,
- United States Europe Command (USEUCOM) water workshop in the Czech Republic, and
- United States Northern Command (USNORTHCOM) Arctic mission analysis with the Scandinavian countries.

Within the Geographic Combatant Commands, there is a standard review process that includes assessing manpower, operations, logistics, cyber, and resourcing operations through a resilience lens. This review also includes ensuring that risk assessment and mitigation, diversity, connectivity, reserves, and adequate redundancy are part of our major operations.

At United States Central Command, current and historic climate conditions are factored into theater campaign plans, including water scarcity which is a recurring issue in the region. Warning indicators are part of the deliberate planning process. United States Northern Command routinely includes severe weather-driven scenarios in training and exercise events and has developed planning tools to guide operational response efforts to these scenarios. United States Indo-Pacific Command (USINDOPACOM) focuses their training on readiness to respond to and be resilient to natural disasters, as well as sustainable resource management toward critical resources scarcity. This command has also established Pacific Augmentation Teams around its Area of Responsibility to identify quickly immediate needs that can be met with military assets.

United States Southern Command funded a National Preparedness Baseline Assessments to include a gap analysis as well as a five-year plan to build capability and capacity within the countries in the region. The collection of sub-regional data will provide a more nuanced depiction of each country's risks and vulnerabilities to disasters that may be influenced by climate as well as their readiness to respond to them. This command will also seek appropriate resources to fund assessments to determine the effects of its most serious and likely climate-related risks.

At USAFRICOM, climate impacts and drivers of instability and factional conflict are fully integrated into planning efforts. Planners must consider the impacts of drought and desertification as high potential instability areas and how these two hazards impact bases and

missions. USAFRICOM's capacity-building efforts are nested within its security cooperation programs and will adapt to a variety of trends and projections.

The Arctic Security Forces Roundtable is USEUCOM's engagement effort for nations that have security forces within the Arctic region. It is a forum in which senior military leaders from Arctic nations and other stakeholders confer and agree upon actions that can support stability and peaceful commercial activity in the region. Lessons learned from our Arctic allies and partners are used to enhance operational safety. In response to melting ice and newly accessible areas of the Arctic, USEUCOM sponsors the ARCTIC ZEPHYR series of table-top exercises focused on search and rescue operations in the Arctic.

III. Conclusions

This report represents a high-level assessment of the vulnerability of DoD installations to five climate/weather impacts: recurrent flooding, drought, desertification, wildfires, and thawing permafrost. From a resources perspective, DoD is incorporating climate resilience as a cross-cutting consideration for our planning and decision-making processes, and not as a separate program or specific set of actions.

Some impacts are closely related or intensify the effects of each other (e.g., drought, desertification, wildfire), whereas others are somewhat related (e.g., coastal flooding driven by changing sea level can impact river conveyance, compounding riverine flood levels for tidally-influenced rivers). Taken together, however, these impacts help describe the overall vulnerabilities to DoD installations from changing future conditions.

About two-thirds of the 79 installations addressed in this report are vulnerable to current or future recurrent flooding and more than one-half are vulnerable to current or future drought. About one-half are vulnerable to wildfires. It is important to note that areas subject to wildfire may then experience serious mudslides or erosion when rains follow fires. Impacts are dispersed around the country. Not surprisingly, impacts vary by region for coastal flooding, with greater impacts to the East coast and Hawaii than the West coast. Desertification vulnerabilities are limited to the sites on the list with arid soils; these are in California, New Mexico, and Nevada. Drought vulnerabilities are more widely dispersed across the country. Wildfire and recurrent flooding impacts are the most widely dispersed.

For the most part, if an installation was currently vulnerable to a specific factor, it will generally be deemed vulnerable to that same factor in the future. In a few instances, locations considered not currently vulnerable were deemed to be vulnerable in the future. Seven installations not currently vulnerable to impacts from recurrent flooding were estimated to be vulnerable in the future. Five sites not currently vulnerable to drought were deemed vulnerable in the future. Seven sites not currently vulnerable to wildfires were considered vulnerable in the future. A number of installations are subject to more than one vulnerability, most notably recurrent flooding, drought, and wildfires.

It is relevant to point out that "future" in this analysis means only 20 years in the future. Projected changes will likely be more pronounced at the mid-century mark; vulnerability

analyses to mid- and late-century would likely reveal an uptick in vulnerabilities (if adaptation strategies are not implemented.)

The Department considers resilience in the installation planning and basing processes to include impacts on built and natural infrastructure. This includes consideration of environmental vulnerabilities in installation master planning, management of natural resources, design and construction standards, utility systems/service, and emergency management operations.

Climate and environmental resilience efforts span all levels and lines of effort, and are not framed as a separate program. Additionally, resources for assessing and responding to climate impacts are provided within existing DoD missions, funds, and capabilities and subsumed under existing risk management processes. The Military Departments provide most of the resources for on-the-ground activities in the Geographic Combatant Commands.

Part IV. Appendix

APPENDIX - Report on Effects of a Changing Climate to the Department of Defense *January 2019*

ARMY			*Recurrent Flooding*		*Drought*		*Desertification*		*Wildfires*		*Thawing Permafrost*	
#	*Installation*	*State*	Current	Potential	Current	Potential	Current	Potential	Current	Potential	Current	Potential
1	Fort Greely	AK	No	No	No	No	No	No	No	No	Yes	Yes
2	Reagan Operations Center-Huntsville	AL	Yes	Yes	No	No	No	No	No	No	No	No
3	Pine Bluff Arsenal	AR	Yes	Yes	No	No	No	No	No	No	No	No
4	Camp Roberts	CA	No	Yes	Yes	Yes	Yes	Yes	No	No	No	No
5	Military Ocean Terminal Concord (MOTCO)	CA	Yes	Yes	Yes	Yes	No	No	No	No	No	No
6	U.S. Southern Command Headquarters-Miami	FL	Yes	Yes	No	No	No	No	Yes	Yes	No	No
7	Fort Gordon	GA	No	No	No	No	No	No	Yes	Yes	No	No
8	Fort Shafter	HI	Yes	Yes	No	No	No	No	No	No	No	No
9	Fort Detrick	MD	Yes	Yes	No	No	No	No	No	No	No	No
10	Fort Meade	MD	Yes	Yes	No	No	No	No	No	No	No	No
11	Lake City Army Ammunition Plant (AAP)	MO	Yes	Yes	No	No	No	No	No	No	No	No
12	Fort Bragg	NC	No	No	No	No	No	No	Yes	Yes	No	No
13	Military Ocean Terminal Sunny Point (MOTSU)	NC	Yes	Yes	No	No	No	No	No	No	No	No
14	White Sands Missile Range	NM	No	No	Yes	Yes	Yes	Yes	No	No	No	No
15	Watervliet Arsenal	NY	Yes	Yes	No	No	No	No	No	No	No	No
16	McAlester Army Ammunition Plant (AAP)	OK	Yes	Yes	No	No	No	No	No	No	No	No
17	Holston Army Ammunition Plant (AAP)	TN	No	Yes	No	No	No	No	No	No	No	No
18	Fort Hood	TX	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No
19	Fort Belvoir	VA	Yes	Yes	No	No	No	No	No	No	No	No
20	Radford Army Ammunition Plant (AAP)	VA	Yes	Yes	No	No	No	No	No	No	No	No

AIR FORCE			*Recurrent Flooding*		*Drought*		*Desertification*		*Wildfires*		*Thawing Permafrost*	
#	*Installation*	*State*	Current	Potential	Current	Potential	Current	Potential	Current	Potential	Current	Potential
21	Clear Air Force Station (AFS)	AK	No	No	No	No	No	No	Yes	Yes	No	No
22	Joint Base (JB) Elmendorf Richardson	AK	Yes	Yes	No	No	No	No	Yes	Yes	No	No
23	Maxwell Air Force Base (AFB) Gunter Annex	AL	No	Yes	No	No	No	No	No	No	NA	NA
24	Beale Air Force Base (AFB)	CA	Yes	Yes	Yes	Yes	No	No	Yes	Yes	NA	NA
25	Vandenberg Air Force Base (AFB)	CA	Yes	Yes	Yes	Yes	No	No	Yes	Yes	NA	NA
26	Buckley Air Force Base (AFB)	CO	No	Yes	No	No	No	No	Yes	Yes	NA	NA
27	Cheyenne Mountain Air Force Station (AFS)	CO	Yes	Yes	No	Yes	No	No	Yes	Yes	NA	NA
28	Greeley Air National Guard Station (ANGS)	CO	Yes	Yes	Yes	Yes	No	No	Yes	Yes	NA	NA
29	Peterson Air Force Base (AFB)	CO	No	No	No	Yes	No	No	Yes	Yes	NA	NA
30	Schriever Air Force Base (AFB)	CO	No	No	Yes	Yes	No	No	Yes	Yes	NA	NA
31	Cape Canaveral Air Force Station (AFS)	FL	Yes	Yes	No	No	No	No	Yes	Yes	NA	NA
32	Eglin Air Force Base (AFB)	FL	Yes	Yes	Yes	Yes	No	No	Yes	Yes	NA	NA
33	MacDill Air Force Base (AFB)	FL	Yes	Yes	No	No	No	No	Yes	Yes	NA	NA
34	Patrick Air Force Base (AFB)	FL	Yes	Yes	Yes	Yes	No	No	Yes	Yes	NA	NA
35	Warner Robins Air Force Base (AFB)	GA	Yes	Yes	No	No	No	No	Yes	Yes	NA	NA
36	Scott Air Force Base (AFB)	IL	Yes	Yes	No	No	No	No	Yes	Yes	NA	NA
37	Barksdale Air Force Base (AFB)	LA	No	Yes	No	No	No	No	Yes	Yes	NA	NA
38	McConnell Air Force Base (AFB)	KS	No	No	Yes	Yes	No	No	Yes	Yes	NA	NA
39	Cape Cod Air Force Station (AFS)	MA	No	No	Yes	Yes	No	No	Yes	Yes	NA	NA
40	Joint Base (JB) Andrews	MD	Yes	Yes	Yes	Yes	No	No	Yes	Yes	NA	NA
41	Selfridge Air National Guard Base (ANGB)	MI	No	Yes	No	No	No	No	Yes	Yes	NA	NA
42	Whiteman Air Force Base (AFB)	MO	No	No	Yes	Yes	No	No	Yes	Yes	NA	NA
43	Malmstrom Air Force Base (AFB)	MT	Yes	Yes	Yes	Yes	No	No	Yes	Yes	NA	NA
44	Cavalier Air Force Station (AFS)	ND	No	No	No	No	No	No	No	No	NA	NA
45	Minot Air Force Base (AFB)	ND	Yes	Yes	Yes	Yes	No	No	No	No	NA	NA
46	Offutt Air Force Base (AFB)	NE	No	No	Yes	Yes	No	No	No	No	NA	NA
47	Kirtland Air Force Base (AFB)	NM	No	No	Yes	Yes	Yes	Yes	Yes	Yes	NA	NA
48	Creech Air Force Base (AFB)	NV	No	No	No	No	Yes	Yes	Yes	Yes	NA	NA
49	Nellis Air Force Base (AFB)	NV	No	No	Yes	Yes	Yes	Yes	Yes[1]	Yes[1]	NA	NA

[1]Air Force Note: Answers only for installation sites within the main base. When associated ranges are included, answer is Yes.

AIR FORCE			***Recurrent Flooding***		***Drought***		***Desertification***		***Wildfires***		***Thawing Permafrost***	
#	***Installation***	***State***	Current	Potential	Current	Potential	Current	Potential	Current	Potential	Current	Potential
50	Wright Patterson Air Force Base (AFB)	OH	No	Yes	Yes	Yes	No	No	Yes	Yes	NA	NA
51	Tinker Air Force Base (AFB)	OK	Yes	Yes	Yes	Yes	No	No	Yes	Yes	NA	NA
52	Shaw Air Force Base (AFB)	SC	Yes	Yes	Yes	Yes	No	No	Yes	Yes	NA	NA
53	Joint Base (JB) San Antonio (aka JB Lackland / Sam Houston / Randolph)	TX	Yes	Yes	Yes	Yes	No	No	Yes	Yes	NA	NA
54	Hill Air Force Base (AFB)	UT	Yes	Yes	Yes	Yes	Yes	Yes	Yes[1]	Yes[1]	NA	NA
55	Joint Base (JB) Langley-Eustis	VA	Yes	Yes	No	No	No	No	Yes	Yes	NA	NA
56	F.E. Warren AFB	WY	Yes	Yes	No	No	No	No	Yes	Yes	NA	NA

[1]Air Force Note: Answers only for installation sites within the main base. When associated ranges are included, answer is Yes.

DEPARTMENT OF NAVY			***Recurrent Flooding***		***Drought***		***Desertification***		***Wildfires***		***Thawing Permafrost***	
#	***Installation***	***State***	Current	Potential	Current	Potential	Current	Potential	Current	Potential	Current	Potential
57	Naval Base (NB) Coronado	CA	Yes	Yes	Yes	Yes	No	No	No	No	No	No
58	Naval Base (NB) San Diego	CA	Yes	Yes	Yes	Yes	No	No	No	No	No	No
59	Joint Base (JB) Anacostia Bolling	DC	Yes	Yes	Yes	Yes	No	No	No	No	No	No
60	U.S. Naval Observatory / Naval Support Facility (NSF) Naval Observatory	DC	No	No	Yes	Yes	No	No	No	No	No	No
61	Washington Navy Yard	DC	Yes	Yes	Yes	Yes	No	No	No	No	No	No
62	Naval Air Station (NAS) Key West	FL	Yes	Yes	Yes	Yes	No	No	No	Yes	No	No
63	Naval Submarine Base (NSB) Kings Bay	GA	Yes	Yes	Yes	Yes	No	No	No	Yes	No	No
64	Joint Base (JB) Pearl Harbor Hickam	HI	Yes	Yes	Yes	Yes	No	No	No	Yes	No	No
65	Wahiawa Annex	HI	Yes	Yes	Yes	Yes	No	No	No	Yes	No	No
66	Naval Support Facility (NSF) Indian Head	MD	Yes	Yes	Yes	Yes	No	No	No	No	No	No
67	Naval Air Station (NAS) Oceana	VA	Yes	Yes	Yes	Yes	No	No	No	No	No	No
68	Naval Support Activity (NSA) Hampton Roads - Northwest / (former) Naval Security Group Activity (NSGA) Chesapeake	VA	Yes	Yes	Yes	Yes	No	No	No	No	No	No
69	Naval Station (NS) Norfolk	VA	Yes	Yes	Yes	Yes	No	No	No	No	No	No
70	Naval Support Activity (NSA) Hampton Roads	VA	Yes	Yes	Yes	Yes	No	No	No	No	No	No
71	Naval Magazine Indian Island	WA	Yes	Yes	Yes	Yes	No	No	No	Yes	No	No
72	Naval Base (NB) Kitsap Bangor (Naval Submarine Base (NSB) Bangor)	WA	No	No	Yes	Yes	No	No	No	Yes	No	No
73	U.S. Territory - Naval Base Guam	Guam	Yes	Yes	Yes	Yes	No	No	No	Yes	No	No
74	U.S. Territory - Andersen AFB	Guam	Yes	Yes	Yes	Yes	No	No	No	No	No	No

OTHER				*Recurrent Flooding*		*Drought*		*Desertification*		*Wildfires*		*Thawing Permafrost*	
#	*Installation*	*State*	*Service*	Current	Potential	Current	Potential	Current	Potential	Current	Potential	Current	Potential
75	Defense Finance and Accounting Service (DFAS) Indianapolis	IN	DFAS	No	No	No	Yes	No	No	No	No	No	No
76	Defense Finance & Accounting Service (DFAS) Columbus	OH	DLA	Yes	Yes	No	Yes	No	No	No	No	No	No
77	Defense Distribution Depot (DDD) Susquehanna	PA	DLA	Yes	Yes	No	Yes	No	No	No	No	No	No
78	National Ground Intelligence Center (NGIC) Charlottesville	VA	NGA	Yes[2]	Yes	Yes	Yes	No	No	No	No	No	No
79	Pentagon	VA	WHS	No	No	No	No	No	No	No	No	No	No

[2]Although the site did not experience flooding, flooding in the local area caused temporary loss of commercial water supply to the site.