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**INSTALLATION RESILIENCE TO WEATHER
EXTREMES AND CLIMATE CHANGE:
LEARNING FROM RECENT SURPRISES**

by

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April 18, 2024

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ABSTRACT

This report catalogs recent extreme weather and climate-driven disruptions at U.S. military installations, including hurricanes, fires, flooding, and winter storms, to provide a preliminary framework for understanding these events in the context of Department of Defense (DoD) climate policy. Specifically, this study surveys a dozen recent climate-driven events and the associated impacts at installations across the globe. We catalog each event in terms of what happened, how it affected DoD missions, and the scope of recovery efforts that were required. The vignettes in this report illustrate the challenges facing military installations related to weather extremes and climate change. This report emphasizes the importance of developing *adaptive capacity*—the capacity to adapt to challenges ahead when the exact challenge to be handled cannot be specified completely in advance—as a primary means to combat climate-driven surprise.

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List of Acronyms and Abbreviations

AFB	Air Force Base
AIRLANT	Commander, Naval Air Forces Atlantic
BLM	Bureau of Land Management
BLMFS	Bureau of Land Management Fire Service
Camp Pendleton	Marine Corps Base Camp Pendleton
CVW	Carrier Air Wing
DoD	Department of Defense
FEMA	Federal Emergency Management
Fort Hood	U.S. Army Base Fort Hood
Fort Liberty	U.S. Army Garrison Fort Liberty
Fort Wainwright	U.S. Army Garrison Fort Wainwright
GHG	Greenhouse Gases
Keesler AFB	Keesler Air Force Base
NAS	Naval Air Station
NAS Key West	Naval Air Station Key West
NAS Norfolk	Naval Air Station Norfolk
NAS Point Mugu	Naval Air Station Point Mugu
NAS Sigonella	Naval Air Station Sigonella
NAVAIR WD	Naval Air Warfare Center Weapons Division
NBVC	Naval Base Ventura County

NPS	Naval Postgraduate School
Offutt AFB	Offutt Air Force Base
PPD-21	Presidential Policy Directive
Reagan Test Site	U.S. Army Garrison-Ronald Reagan Ballistic Missile Defense Test Site
ROI	Return on Investment
SCIF	Sensitive Compartments Information Facility
SUPSALV	Supervisor of Salvage and Diving
TBD	To Be Determined
Tyndall AFB	Tyndall Air Force Base
U.S.	United States
USAF	United States Air Force
USARAK	United States Army Alaska
USJFCOM	United States Joint Forces Command
USS	United States Ship

Executive Summary

A systematic investigation of extreme weather events in this report reveals a pattern that suggests climate change may already be impinging on U.S. military installations. Extreme weather events are causing costly problems, both in terms of disrupted operations and damage. The direct costs associated with these incidents range from millions to potentially billions of dollars. The apparent increase in the frequency and intensity of these events suggests that future costs could be even higher.

By examining twelve case studies of extreme weather and climate-driven events across global military installations, this report demonstrates several key points for the challenges facing military installations related to weather extremes and climate change, both now and in the future.

Concern for military operations and readiness is often focused on military infrastructure, but the consequences of these events often depend on infrastructure outside the fence line. These events illustrate dependencies of military installations on surrounding civilian infrastructure, including gas, power, water, and transportation routes. These dependencies are often revealed during or after an incident as hidden vulnerabilities in our military infrastructure that reside in the civilian world.

Because climate-driven disasters occur both inside and outside the fence line, there may be limits for installation commanders on the possible safeguards and controls against these vulnerabilities. However, there may also be opportunities to increase resilience to climate-related hazard events through community-wide or regional climate resilience efforts.

The vignettes in this report demonstrate differing levels of advanced warning that complicate preparedness and response activities for installation personnel. The amount of advanced warning can vary, and in some cases operators might have little-to-no time to prepare. These events can last from days to weeks, and perhaps more importantly, the recovery from these types of events can persist from weeks to years.

It is tempting to think that better forecasting will prevent the catastrophic consequences of these events, but the future is not going to be like the past. Forecasts will be imperfect, and warnings are likely to be incomplete or unavailable. Hazards with traditionally

seasonal activity (e.g., increased hurricane activity during the late summer) can perhaps be anticipated; however, changes in climate are now creating higher risk during times outside of normal periods. This complicates the ability to anticipate potential events and clouds the signals associated with early warning. Installation emergency response plans will always be limited, and installations must learn how to prepare for surprise events.

These disruptive events exacerbate existing tensions related to the allocation of limited resources on installations. Climate-driven disasters have not only strained the U.S. military's resources but have also triggered a diversion of funding away from critical areas such as equipment modernization, personnel training, and technological advancements geared toward enhancing national defense capabilities. At the same time, immediate needs for preventive maintenance or repairs in aging infrastructure are often sidelined for investments in operational readiness, exacerbating the potential for disruptive events. As these climate-related events become more frequent and severe, the strain on military funding has the potential to jeopardize our ability to maintain readiness for potential conflicts or security threats.

The ability to respond to climate-driven events depends on what we can do, not what we have. Having resources is not enough if we are unable to put them into action when the time comes. It also challenges the way we think about how we invest our limited resources.

We should be investing in our adaptive capacity—the capacity to adapt to challenges ahead, when the exact challenge to be handled cannot be specified completely in advance. This capacity needs to be practiced to be effective.

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1 Introduction

The United States (U.S.) has experienced multiple extreme weather and climate-driven events over the last four decades. Since 1980, the U.S. has sustained 338 billion-dollar weather and climate disasters—a total of 33 disasters in the 1980s, 57 disasters in the 1990s, 67 disasters in the 2000s, 131 disasters in the 2010s, and 85 disasters from 2020-2023 (NOAA National Centers for Environmental Information (NCEI) 2024). To put these numbers in perspective, in the three years from 2021-2023, the total number of disasters (63) is greater than the entire 1990s decade (57 disasters).

Figure 1 highlights the increased number of disasters and their associated costs in the U.S. since 2005. Moreover, most of the identified disasters have occurred in the last five years, since 2018. The frequency and magnitude of extreme weather events are expected to increase in the future (Mirza 2003).

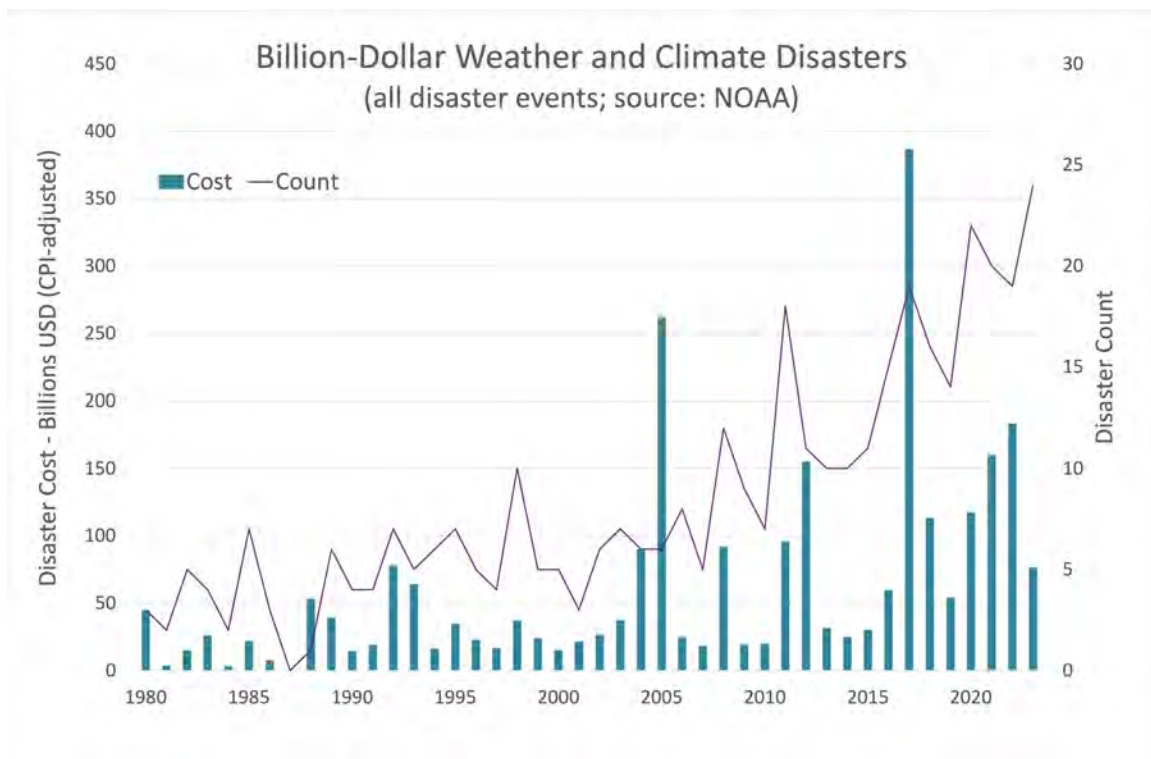


Figure 1. United States Billion-Dollar Disaster Costs 1980-2023. This figure emphasizes the escalating number of disasters that have impacted DoD installations and assets over the past two decades. Data accessed from: <https://www.ncei.noaa.gov/access/billions/>

The Department of Defense (DoD) depends on secure, safe, and functional military installations to carry out their stated missions, promote national security, and deter war by power projection. Climate change is altering the DoD's ability to carry out these duties and goals by disrupting operations (Stubblefield 2017) and canceling or delaying training and exercises that prepare the services to carry out mission-critical activities (VanDervort 2020). Additionally, climate change is forcing service members to operate and live in "theater" or facilities used in war environments (U.S. Department of Defense 2018) and highlighting critical military infrastructure vulnerabilities to climate-driven events (Fuente 2019).

Over the last decade, the DoD has experienced a variety of disruptive, climate-driven events ranging from installation-wide warnings and evacuations (VanDervort 2020) to installations remaining frozen in time for a decade post-climate-driven perturbation (Aguayo and Brennan 2021). This report aims to catalog some of the most prominent climate disruptions at U.S. military installations, with an eye toward providing a preliminary framework for understanding these events in the context of DoD climate policy.

1.1 DoD Climate Policy

The extensive record of reports, directives, and strategic initiatives within the DoD highlights the persistent recognition of climate change as a substantive risk to military operations and national security. Since at least the 1990s, the consensus has been that climate change poses a risk to the DoD's operations, strategies, readiness, personnel, and assets (Dahl 2013). The U.S. Navy War College report published in 1990 titled "Global Climate Change Implications for the United States Navy" outlines that because of sea level rise and thermal heating of the oceans and atmosphere, climate change poses significant effects on military facilities (Kelley 1990).

In 2009, the Chief of Naval Operations created the United States Task Force on Climate Change to address the implications of climate change for national security and naval operations. Since 2009, there have been over 100 documents, articles, directives, and reports on the impacts of climate change and security for the DoD. Executive Order 14008 ("Tackling the Climate Crisis at Home and Abroad") and Executive Order 14057 ("Catalyzing Clean Energy Industry and Jobs Through Federal Sustainability") require that all federal agencies develop climate adaptation plans and submit annual progress reports. In 2022, the U.S.

Army, Navy, and Air Force released climate change strategy documents to address current targets and goals associated with climate change adaptation and mitigation. Additionally, in 2022, the DoD released its climate adaptation progress report, which detailed current DoD actions to bolster climate adaptation and resilience (Department of Defense 2022a).

The need to fortify critical infrastructure against climate-related risks is further emphasized through directives like the Presidential Policy Directive (PPD-21) (The White House 2013). PPD-21 outlines the need for “a national unity of effort to strengthen and maintain secure, functioning, and resilient critical infrastructure.” This top-down directive to advance critical infrastructure security and resilience has been a driving proponent for all DoD branches of the United States military to develop plans, policies, and initiatives that are branch-specific over the past 10 years. Some of the most recent documents addressing critical infrastructure and climate resilience include The Department of Defense Climate Adaption Plans 2021, the Department of Defense Sustainability Plan 2022, and the Department of the Navy Climate Action 2030, among others.

1.2 Climate Impacts on the DoD

Climate change poses a multifaceted challenge to the DoD, impacting various missions, infrastructure, assets, and personnel. One significant area of concern is the alteration of mission parameters and requirements due to changing climate conditions. The unpredictability and increasing frequency of extreme weather events can disrupt planned military exercises and operations, affecting training schedules and readiness. Furthermore, the shifting climate can necessitate the reevaluation of strategic priorities and the development of new capabilities to address emerging challenges, such as the need for enhanced disaster response capabilities.

The impact on military operations is pronounced as climate change introduces a range of environmental stressors. Rising sea levels and increased frequency of extreme weather events can directly impede the functionality of military installations, particularly those located in coastal areas. Flooding, storm surges, and other climate-related events can damage critical infrastructure, hindering the ability to deploy forces and conduct operations. Additionally, logistical challenges may arise as changing climate conditions affect supply chain routes and the availability of resources, potentially limiting the effectiveness and efficiency of military operations.

Infrastructure and assets are also under threat as climate change intensifies. The vulnerability of military installations to sea-level rise, extreme heat, and other climate-related hazards requires significant investments in fortification and adaptation measures. The strain on infrastructure not only jeopardizes operational capabilities but also leads to increased maintenance costs and resource allocation. The potential for more frequent and severe natural disasters amplifies the risk of asset damage, ranging from military equipment and vehicles to communication systems, further impeding the DoD's operational capabilities.

Military personnel face additional challenges. The changing climate introduces new health risks and operational considerations for military personnel, particularly those deployed in diverse and challenging environments. Heat-related illnesses, changes in disease patterns, and the need for specialized training to operate in extreme weather conditions are all concerns that must be addressed to ensure the well-being and readiness of military personnel.

Climate change exerts indirect yet substantial impacts on military families, influencing their well-being and daily lives. Deployments and relocations to diverse geographic regions, often prone to different climate stressors, expose families to varying environmental challenges. Increased frequency and severity of extreme weather events in these areas can heighten stress and anxiety among family members, impacting mental health and stability. Furthermore, the strain on military infrastructure due to climate-related damages can disrupt the quality and accessibility of essential services such as healthcare and education, affecting the livelihoods and safety of military families. Addressing these challenges necessitates comprehensive support systems and resources tailored to the unique needs of military families facing the dynamic consequences of climate change.

Adapting to these climate-driven challenges requires a holistic and integrated approach from the DoD. This involves not only fortifying infrastructure and assets but also incorporating climate considerations into strategic planning, training regimens, and personnel management. The DoD's ability to navigate these challenges effectively will be crucial for maintaining operational readiness and national security in an era marked by the dynamic and evolving impacts of climate change. As the climate continues to change, proactive measures and strategic foresight will be imperative to ensure the resilience and effectiveness of the United States military across its various missions and responsibilities.

1.3 DoD Responses to Climate Impacts

Among the DoD's current efforts to mitigate the impact of climate change impacts, there is a concerted effort to reduce Greenhouse Gases (GHG) emissions by reducing petroleum use and adopting alternative fuels (Department of Defense 2011). Additionally, the DoD is focusing on sustainability efforts in energy, water, high-performance and sustainable buildings, and facility investment efficiency (Department of Defense 2022b), which can slow down the long-term impacts of climate change. However, these efforts do not address the urgency and frequency of annual climate-driven, near-term implications on military installations.

Over the period spanning 2017 to 2021, the DoD revealed that natural disasters and extreme weather events wrought havoc on U.S. military bases, accumulating damages exceeding \$13 billion (Sense 2023). This fiscal toll accentuates the acute vulnerability of the more than 1,700 military installations situated in coastal areas, where the confluence of rising sea levels and intensified severe weather events pose a heightened threat to these strategically crucial assets. The need for proactive measures to address the impacts of climate change on defense infrastructure has never been more apparent.

The adverse effects of flooding, drought, and wildfires on military bases closely parallel the challenges faced by civilian infrastructure (Klare 2019). In response to this shared vulnerability, the Pentagon has undertaken strategic initiatives to adopt mitigation measures to curtail future costs (The White House 2022). However, the enormity of the challenge is magnified by the DoD's management of a vast global real estate portfolio, estimated to be around \$1.2 trillion (Government Accountability Office 2020). This extensive network of military installations spans diverse climate regions, necessitating a comprehensive approach to confront various climate change challenges.

Adding another layer of complexity, many existing military installations were conceived and constructed prior to or without full recognition of the looming threats posed by climate change. This reality amplifies the intricacies of the situation, further intensifying the associated costs of adapting and fortifying these installations (Badicheck 2016). As the DoD grapples with the dual imperatives of protecting strategic assets and mitigating financial burdens, the need for a forward-looking, adaptive approach to climate resilience within military planning and infrastructure development becomes increasingly evident.

1.4 Goals of this Report

This study surveys a dozen recent climate-driven events and the associated impacts at U.S. military installations across the globe. We catalog each event in terms of what happened, how it affected DoD missions, and the scope of recovery efforts that were required.

This study is not intended to serve as an all-inclusive, deep-dive into each incident but as an accessible overview of the various U.S. military installations already grappling with challenges posed by climate-driven events.

The vignettes in this report highlight some of the significant risks and vulnerabilities for the DoD related to climate-driven events. We offer several key points for understanding and managing the challenges facing military installations, both now and in the future.

2 Military Installation Vignettes

This section provides twelve abridged case studies on U.S. military installations and commands that have experienced a disruptive climate-driven event over the past two decades. The military installations and commands in this study have been identified by either (1) a mission assurance installation list authored by each representative service and submitted to Congress (Department of Defense 2019b) or (2) the installation was impacted by a climate surprise not listed on the mission assurance list.

Table 1 below provides an overview of the installations considered in this study and the associated climate-driven disaster. Each installation vignette includes a description of the installation’s primary mission, the climate-driven event, event impacts, and case-specific details regarding recovery efforts.

Year	Installation	Event	Cost (U.S.\$)
2005	Keesler Air Force Base, MS	Hurricane Katrina	\$950 million
2010	Marine Corps Base Camp Pendleton, CA	Aliso Canyon Fire	\$0.3 - 3 million*
2013	U.S. Army Garrison Fort Wainwright, AK	Stuart Fire	\$5.5 million
2018	U.S. Army Garrison Fort Liberty, NC	Hurricane Florence	\$55 million
2018	Tyndall Air Force Base, FL	Hurricane Michael	\$5 billion
2018	Naval Base Ventura County, CA	Hill Fire and Woolsey Fire	Cost unknown
2019	Offutt Air Force Base, NE	Missouri River Flooding	\$1.1 billion
2021	U.S. Army Garrison Fort Hood, TX	Winter Storm Uri	\$30 million +
2021	Naval Air Station Sigonella, Italy	Flooding	\$1 - 2 million
2022	Naval Air Station Norfolk, VA	Thunderstorm Cell	\$2.5 million +
2022	Naval Air Station Key West, FL	Hurricane Ian	\$100 billion**
2022-	Flash Events	Extreme Weather	TBD

Table 1. Case Studies of DoD Installations and Related Climate-Driven Events. This table catalogs chronologically the case studies in this report with the name of the event and the associated cost, if known. *Camp Pendleton monetary estimate is based on prescribed burn cost per acre of \$100 to \$1,000 (Burke et al. 2020). **NAS Key West monetary estimate is based on the total damage cost to Florida from Hurricane Ian, not the cost to rebuild the installation; that estimate is unknown.

Figure 2 places these events highlight the increased number of disasters and their associated

costs in the U.S. since 2000. Moreover, most of the identified disasters have occurred in the last five years, since 2018. The frequency and magnitude of extreme weather events are expected to increase in the future (Mirza 2003). Thus leading to the increased cost of recovery from these climate-induced events.

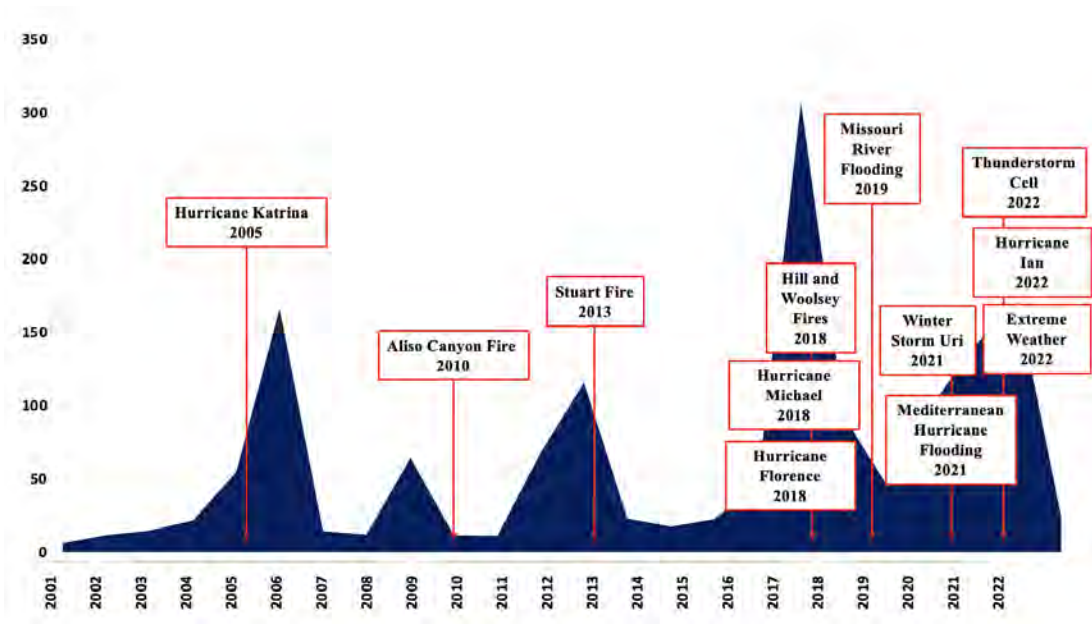


Figure 2. United States Billion-Dollar Disaster Costs 2000-2023. This figure emphasizes the escalating number of disasters that have impacted DoD installations and assets over the past two decades. Data accessed from: <https://www.ncei.noaa.gov/access/billions/>

2.1 Keesler Air Force Base, Mississippi (2005)

Primary Mission

Keesler Air Force Base (Keesler AFB) is located in Biloxi, a coastal city along the Gulf Coast of Mississippi. The primary mission of Keesler AFB is to “train, develop and deliver focused, driven warriors” (Keesler Air Force Base 2023). As such, Keesler AFB is a training and education base that harbors three main commands or units.

- The 81st Training Group is the largest in the world electronics training group; it offers over 160 courses to Air Force officers, officers of the sister branches of the U.S. military, and civilian employees (Keesler Air Force Base 2023).
- The 81st Medical Group is the largest medical group in the Air Force, and its primary mission is to "maintain medical readiness for worldwide contingencies (Keesler Air Force Base 2023).
- The 81st Mission Support Group supports the entire base, from “administrative, personnel, civil engineering, transportation, morale and welfare, recreational, communications, supply, base security, and contracting services to an estimated 75,000 people who use base facilities and resources” (Keesler Air Force Base 2023).

Keesler AFB is also home to other tenant commands, including the Second Air Force, 403RD Wing, and the 85th Engineering Installation Squadron (Keesler Air Force Base 2023). Keesler AFB is home to roughly 7,000 military and civilian personnel, 5,000 military dependents, and 2,700 contractors (Military Bases Website 2023).

The Event — 2005 Hurricane Katrina

On the afternoon of August 23rd, 2005, Tropical Storm Katrina formed near Long Island in the Bahamas. After reaching hurricane strength, it made landfall north of Miami, Florida on the evening of August 25th, 2005, causing significant rainfall, flooding, tornadoes, and injuries across Southern Florida (National Weather Service 2023c). Moving southwestward across the extreme southern tip of Florida, Katrina entered the Southeastern Gulf of Mexico and intensified to a Category 5 hurricane with sustained winds of approximately 175 MPH on August 28th, 2005 (National Weather Service 2023c). Before changing course and heading northward.

Early in the morning on August 29th, 2005, Hurricane Katrina made landfall as a large Category 4 hurricane along the Gulf Coast, with sustained winds of around 145 MPH in Southeast Louisiana (National Weather Service 2023c). Its path continued northward, impacting areas from near New Orleans, Louisiana, to near Mobile, Alabama, and causing devastating damage along the Gulf Coast. Considered one of the worst natural disasters in United States history, Hurricane Katrina left a lasting impact.

By Monday evening, August 29th, 2005, Katrina weakened to a tropical storm northwest of Meridian, Mississippi. It then proceeded to move northward across Far Eastern Mississippi overnight and into Tennessee by Tuesday morning. As a result of Hurricane Katrina's 20-30 foot storm surge and 105-140 mph sustained winds for 12 hours straight, 75 percent of the Keesler AFB ended up submerged underwater (WXXV-TV News 2015). Katrina defied all assumptions and beliefs about the nature and intensity of hurricanes on the Gulf Coast, with winds over 170 mph recorded (WXXV-TV News 2015). Finally, on August 31st, 2005, Katrina lost its tropical characteristics as it merged with a cold front over Northern Pennsylvania.

Hurricane Katrina's size and resulting storm surge caused significant flooding at Keesler AFB, leading to the evacuation of over 2,400 students and personnel in the aftermath of the climate-driven disaster. Katrina was the second most intense hurricane to hit the Gulf Coast and the second highest storm surge recorded according to the National Oceanic and Atmospheric Association; the first being Hurricane Camille, in 1969, with a 5-10 foot storm surge (National Weather Service 2023a). Although Hurricane Camille was a significantly stronger (Category 5) storm at landfall, Hurricane Katrina was a considerably larger storm which contributed to its storm surge and flooding (National Weather Service 2023a). Figure 3 shows the extensive flooding at Keesler AFB during Hurricane Katrina. This climate-driven disaster impacted personnel stationed at Keesler AFB. USAF students at Keesler AFB evacuated to Sheppard AFB aboard a C-17 Globemaster III from Altus Air Force Base, Oklahoma, on September 1, 2005. More than 2,400 students and non-essential personnel were evacuated from Keesler after Hurricane Katrina's devastation.



Figure 3. Flooding at Keesler AFB. In the wake of Hurricane Katrina, Keesler AFB experienced a 20-30 foot storm surge, resulting in 75 percent of the installation submerging underwater. Image accessed from: <https://www.af.mil/News/Article-Display/Article/133540/people-venture-outside-keesler-shelters/>

Event Impacts

The Entire Installation. Flood waters inundated most of the base, causing damage to about 95 percent of the base (Arana-Barradas 2005a). Lt. Col. Claudia Foss, 81st Training Wing Public Affairs officer, said, “Fortunately, there have been no reports of people killed or injured at Keesler” (Arana-Barradas 2005a). Additionally, Lt. Col. Foss commented in terms of the base’s visual appearance, it “compares to being in Iraq because of the destruction and debris scattered everywhere” (Arana-Barradas 2005a). The storm knocked down trees, stripped trees of their limbs, downed power lines, light poles bent over with nothing around them, and everywhere had a layer of mud, muck, and damaged buildings (Arana-Barradas

2005a).

The Runway. The runway was completely submerged underwater. Commander General Lord stated that the runway at Keeler AFB is 33 feet above sea level, and “they were picking up live, flopping fish two days later off the runway” (Arana-Barradas 2005b). Despite being inundated, the runway was semi-drained and operational one day post-Katrina (Arana-Barradas 2005b).

Housing. Housing was the hardest hit at Keesler AFB. Out of 1,820 homes on base, 1,067 were destroyed beyond repair by the flood waters (Arana-Barradas 2005b; Perry 2006). Rebuilding these essential family housing units is a significant undertaking; it is the largest military housing construction contract in history (Arana-Barradas 2005b).

Medical Center. Additionally, flood waters severely damaged Keesler Medical Center, along with 95 percent of the base’s infrastructure. Mold, debris, and the power system had to be remediated before any patients could be seen. Temporary tents were erected to provide acute emergency health care for those active-duty personnel on base. Dr. Rob Thaxton with the 81st Medical Group stated, “All we can do here is triage then, make sure they’re safe and send them on to the next hospital” (Arana-Barradas 2005b). Despite initial expectations to reopen within six months post-Katrina, it took a year before the medical center reopened on August 29, 2006 (Arana-Barradas 2005b; Perry 2006).

Commissary. Katrina completely flooded Keesler AFB exchange and commissary. The damage caused to the commissary at Keesler AFB is depicted in Figure 4. A temporary commissary was erected in the Keesler Community Center on September 29, 2005. The exchange and the commissary were rebuilt on a higher elevation and opened their doors to patrons in 2010, 5 years after Katrina hit (Cutrer 2010).

Overall, Hurricane Katrina resulted in damages totaling over 950 million dollars at Keesler AFB alone (Perry 2006).

Recovery Efforts

Following the storm, Keesler AFB’s mission initially changed from training and education to humanitarian and disaster assistance, according to Keesler’s Commander General



Figure 4. Shopping Center Damage from Hurricane Katrina. Hurricane Katrina caused extensive flooding at Keesler AFB, including the military support and shopping privilege center. As seen here, floodwaters submerged halfway up the support column in the clothing store. Image accessed from: <https://publicaffairs-sme.com/FamilyServingFamily/2021/09/03/flashbackfriday-the-keesler-exchanges-resiliency-after-hurricane-katrina/>

William Lord (Arana-Barradas 2005b). All training and education typically conducted at Keesler AFB were on hold until further notice.

Coined “Operation Dragon Comeback,” Keesler AFB leaders and airmen have remained operational over the last ten years despite the devastation caused by Hurricane Katrina. Moreover, the rebuilding at Keesler AFB has been important to local economic recovery. As of 2015, Harrison County Development Commission stated that Keesler AFB was one of the Mississippi Gulf Coast’s largest employers, with a total economic impact of 1.1 billion dollars a year and employing more than 11,300 military and civilian employees (International Economic Development Council 2015). Rebuilding this installation was critical to meet its intended mission—to train, develop, and deliver future warriors—and ensure the local community could survive and thrive.

Key Takeaways

Hurricane Katrina’s impact on Keesler AFB illustrates how climate change is already exerting pressure on U.S. military installations. The operational focus at Keesler AFB shifted from routine training and educational activities to urgent humanitarian and disaster relief efforts in the aftermath of the hurricane. Despite the implementation of accurate warnings and preparedness measures before the storm, the extent of its devastation for both military and civilian populations was a surprise to installation commanders and tenants. The ensuing challenges, encompassing the coordination of disaster response and humanitarian aid, compounded by the damage to the installation, strained available resources and hindered overall military operations and readiness. Such shift in mission objectives following catastrophic events exacerbates existing systemic pressures, amplifying the potential for maladaptive responses amidst heightened tensions.

2.2 Marine Corps Base Camp Pendleton, California (2010)

Primary Mission

Marine Corps Base Camp Pendleton (Camp Pendleton) is the Marine Corps’ largest West Coast expeditionary training facility encompassing more than 125,000 acres in Northern San Diego County in Southern California (The Official Website of Marine Corps Base Camp Pendleton 2023). Camp Pendleton’s primary mission is to “operate a training base that promotes the combat readiness of the operating forces and the mission of other tenant commands by providing training opportunities, facilities, services and support the needs of Marines, Sailors, and their families” (The Official Website of Marine Corps Base Camp Pendleton 2023). Camp Pendleton’s mission is to support “today’s fight and prepare for tomorrow’s future” (The Official Website of Marine Corps Base Camp Pendleton 2023).

Camp Pendleton is home to the I Marine Expeditionary Force, 1st Marine Division, 1st Marine Logistics Group, and many tenant units, including Marine Corps Installations-West, to name a few (The Official Website of Marine Corps Base Camp Pendleton 2023). This large installation also harbors multiple commands and units that utilize this installation’s coastal and mountain terrain to support a variety of missions, operations, and training (The Official Website of Marine Corps Base Camp Pendleton 2023). Camp Pendleton is home to roughly 46,000 military and civilian personnel, 38,000 military dependents, 24,000 Military

Reserve component (USMC, Navy, and Army), and approximately 77,000 retirees living within 50 miles of the installation (Military One Source 2023a).

The Event — 2010 Aliso Canyon Fire

On July 13, 2010, at 9:30 am, a fire was sparked by military exercises in Aliso Canyon near the installation center of Camp Pendleton (City News Service 2010). In just 8 hours, the flames rapidly spread and engulfed a vast area of 2,700 acres. Figure 5, the only image publicly available from this fire, shows the smoke plume engulfing the midday sky at Camp Pendleton. Various agencies, such as the U.S. Forest Service, joined forces to combat the fire and brought in additional support, including three helicopters from outside agencies. The severity of the situation led to the closure of at least one road to ensure public safety. By Wednesday, July 14, 2010, at 6 pm, the fire was 100 percent contained and holding at about 3,000 acres; no structures were damaged or injuries to report (City News Service 2010; Village News 2010).

Event Impacts

No injuries or structural damages were reported. Training grounds and operations were disrupted, training days were lost, and resources to extinguish this fire were deployed and mobilized. These activities all come at a cost for the U.S. military and often surpass the allotted spending from the regular operating budget for that given fiscal year.

Additionally, the 2010 Fire exemplifies the additional land management problems that persist long after a wildfire is extinguished. An article published in 2020 by VanDervort titled *Sea level rise and Beyond: Is the U.S. military prepared for climate change?* postulates that although efforts by the Army through commissioning studies and funded resilience efforts, climate change impacts continue to grow more severe and more challenging to address (VanDervort 2020). In this study, the author specifically addresses how wildfires impact the military's ability to train and meet mission and operational requirements. In addition to training and assignments, wildfires pose ecological risks. For example, when a wildfire burns an area, bare land is left afterward; without vegetation and ground cover, the region becomes more susceptible to erosion and flooding. With Camp Pendleton occupying diverse landscapes from mountain ranges to coastal bluffs and beaches, decay and subsequent



Figure 5. Smoke from the 2010 Aliso Canyon Fire. The 2010 Aliso Canyon Fire broke out within the heart of the installation on July 13, 2010, sparked by military exercises. Image accessed from: <https://www.sandiegouniontribune.com/sdut-fire-on-camp-pendleton-could-grow-to-1000-acres-2010jul13-htmlstory.html>

land loss have become significant with the increased frequency and severity over the past few decades.

Recovery Efforts

Camp Pendleton's overall training and mission objectives require this installation to mitigate risks associated with wildfires. Wildfire management and natural resource stewardship responsibilities are carried out alongside mission assurance objectives at this installation. However, it is important to note that mission assurance is the top priority.

Minnich (1983) documented extremely high ignition rates and acreages burned at Camp Pendleton between 1972-1980, which equates to roughly 50 percent of the entire base burned during that time (Conard and Weise 1998). During this period, the primary source of ignition of wildfires at Camp Pendleton was military activities.

In 2010, the U.S. Conservation Biology Institute conducted a two-year project that focused on understanding the relationship between fires and natural resources at Camp Pendleton (Syphard 2010). Moreover, this research was used to establish the different variables associated with the current fire regime at Camp Pendleton and support in developing decision-making tools to meet future fire management objectives (Syphard 2010). The ongoing balance between stewardship responsibilities, live fire and ammunition training in support of missions and operations, and fire management at Camp Pendleton continues.

Additionally, between 2012 and 2015 alone, approximately 53,000 acres were lost to wildfires at Camp Pendleton (Syphard 2023). In the last two years, 2020-2022, numerous fires have erupted, most notably the Creek Fire in 2020, which prompted the evacuation of 7,000 people two days before Christmas (Syphard 2023). Figure 6 illustrates the intensity of the Creek Fire and the proximity to transportation routes.

To this day, over 200-300 fires at Camp Pendleton are extinguished each year by Camp Pendleton Fire Department (Department of Navy, Naval Facilities Engineering Command Southwest Division 2018). Prescribed burning is a fundamental part of fire management, although the exact time frame when prescribed burning started at Camp Pendleton is unknown. Every year since 2012, news reports have indicated when and for how long prescribed burning at Camp Pendleton would occur to ease the public's concern when flames and smoke plumes were visible.

Overall, the Aliso Canyon Fire exhausted resources and imposed damages between \$0.3-\$3 million dollars at Camp Pendleton (Burke et al. 2020).

Key Takeaways

The chronic threat of wildfire at Camp Pendleton means that at any point its operations and training missions can be interrupted. The 2010 Aliso Canyon fire exemplifies how climate



Figure 6. 2020 Creek Fire at Camp Pendleton. According to the Camp Pendleton base officials and the California Department of Forestry and Fire Protection, 7,000 residents were affected on the west side of the Fallbrook community and some Camp Pendleton locations on Christmas Eve because of the Creek Fire in 2020. Image accessed from: <https://www.cbsnews.com/news/southern-california-creek-fire-wildfire-burns-camp-pendleton-evacuation-orders-lifted-today-2020-12-24/>

change can make chronic threats more frequent and more acute on U.S. military installations. Despite implementing accurate warnings and preparedness measures before the fire event, the extent of fire damage can be unpredictable. The disruption caused by the fire affected training grounds and operations, resulting in the loss of training days. Significant resources were deployed and mobilized to extinguish the fire, but their utilization incurred costs for the U.S. military, often exceeding the budget from the regular operating expenses for that fiscal year. This incident emphasizes the challenges climate change poses on military readiness and the budgetary implications associated with adapting to and mitigating climate-driven surprises.

2.3 U.S. Army Garrison Fort Wainwright, Alaska (2013)

Primary Mission

U.S. Army Garrison Fort Wainwright (Fort Wainwright) is located in the city of Fairbanks, Alaska, in the North Star Borough. Fort Wainwright’s primary mission is to enable the readiness of U.S. Army forces in Alaska by “integrating resources and delivering installation services that enhance the quality of life for Arctic Warriors, families, civilians, and community” (U.S. Army Garrison Alaska 2023).

The North Star Borough of Fairbanks is home to roughly 96,000 people (United States Census Bureau: United State Government 2021) and is equivalent to a county in the lower 48 states. Fort Wainwright is home to approximately 10,000 military and civilian personnel, 6,500 military dependents, and 7,800 retirees and veterans (Military One Source 2023h).

Fort Wainwright is home to the United States Army Garrison and United States Army Alaska units, also known as the “Arctic Warriors” (U.S. Army Garrison Alaska 2023). This base also harbors multiple tenant commands, including the:

- 1st Stryker Brigade Combat Team,
- 25th Infantry Division, and
- 25th Aviation Regiment.

The primary mission of this installation is to train the Arctic Warriors to achieve proficiency in a wide range of military exercises, including combat and airborne missions. During winter, soldiers test their physical endurance and perform basic Arctic Warrior tasks in day and nighttime maneuver exercises (United States Department of Defense 2020). However, training at the installation over the past few decades has proven to be more cumbersome. Managing nearby encroachment from civilian development and using installation training grounds throughout the year has increased challenges and stressors at Fort Wainwright (United States Department of Defense 2020).

The Event — 2013 Stuart Fire

Extreme fire warnings are a typical accompaniment to fire season in Alaska, which typically runs from May to August each year. Fort Wainwright and the military operators in this

region adhere to the customary practice of maintaining vigilance during training exercises, particularly during fire season. However, on June 19, 2013, during U.S. Army artillery training, a fire erupted in the army training area at Fort Wainwright, resulting in plumes of smoke filling the sky, as illustrated in Figure 7 (Schwing 2013). By the beginning of July, more than 700 firefighters were battling the fire, which had doubled in size (Friedman 2013). The Stuart Creek 2 Fire burned over 87,000 acres over two months in west Fairbanks (Engman 2013). This fire was the largest wildfire in the United States in 2013 (Engman 2013).



Figure 7. Fort Wainwright Stuart Creek 2 Fire. The Stuart Creek 2 Fire began on June 19, 2013, and smoke plumes filled the skies for weeks and consumed over 87,000 acres. Image accessed from: https://www.newsminer.com/news/local_news/stuart-creek-fire-doubles-in-size-to-79-037-acres-evacuation-order-lifted/article_c80adcf6-e747-11e2-92b4-001a4bcf6878.htm

On October 22, 2013, Senator Lisa Murkowski communicated that two Defense Department investigations were underway into the cause and handling of this large and costly interior wildfire (Engman 2013). The two investigations from this incident focused on (1) the cause of the fire and (2) army training procedures during extreme fire warning conditions. The first investigation revealed that the U.S. Army was responsible for starting the Stuart Creek 2 Fire. Before training began, the Fort Wainwright Fire Department and the Bureau of Land Management (BLM) told the army that due to a Red Flag Warning (indicating the potential for extreme wildfire danger was high), it recommended that the army not perform artillery training (Gabbert 2013). Despite these warnings, the artillery training practice proceeded as scheduled. The fire's origin was attributed to a 155-millimeter high explosive artillery round, which was intended to burn out at an altitude of 1,000 meters but failed to do so (Engman 2013).

The second investigation revealed “systemic problems” with army training procedures. John Pennell, Chief of Media Relations for the U.S. Army Alaska, stated that “during an extreme fire warning, only the U.S. Army Alaska (USARAK) G3 [who serves as] Chief of Operations can approve a waiver for training to continue” (Schwing 2013). Still, in this case, it was delegated down to an installation range officer instead, who was stationed at Joint Base Elmendorf-Richardson near Anchorage, which is roughly 356 miles south of Fort Wainwright (Schwing 2013).

Event Impacts

The Stuart Creek 2 Fire burned nearly 87,000 acres, destroying training and operations grounds for Fort Wainwright and disrupting training in this area. The specifics of disruptions to operations and missions are not public knowledge. However, this wildfire significantly impacted the 2013 artillery training season. Moreover, this fire ended up being the costliest fire suppression effort in Alaska for the 2013 summer fire season – totaling more than \$5.5 million to fight (Doogan 2013).

Recovery Efforts

In the aftermath of the Stuart Creek 2 Fire, the U.S. Army changed its training procedures. The revised practices involve implementing stricter criteria for determining when training can be conducted and specifying authorized personnel who can approve training events

during severe weather conditions (KUAC 2014). Another change is to the artillery rounds used during these training events. The investigation report suggested that the U.S. Army is looking into using artillery rounds that are less likely to catch fire in the forest (KUAC 2014).



Figure 8. Prescribed Burning at Fort Wainwright. U.S. Army training at Fort Wainwright includes a collaborative effort with the Bureau of Land Management Fire Service to mitigate fire threats through prescribed burning efforts. Image accessed from: <https://akfireinfo.com/2020/05/05/about-60-of-prescribed-burning-to-reduce-the-threat-of-wildfire-on-interior-alaska-military-training-lands-complete/>

Moreover, senior leaders drafted a revised protocol for U.S. Army training at Fort Wainwright including a collaborative effort with the Bureau of Land Management Fire Service (BLMFS). In 2020, a news report detailed the emerging prescribed burning collaboration between the BLMFS and the U.S. Army Alaska in Alaska (BLM Alaska Fire Service 2020). Figure 8 illustrates a prescribed burn effort that Fort Wainwright and the BLMFS have undertaken since the Stuart Creek 2 Fire. An estimated 2,000-acre complex on Fort Wainwright was burned to diminish the threat of wildfires by burning enough perimeter area so that if a wildfire ignited, it would not be able to burn outside of the training area (BLM Alaska Fire Service 2020). This is one example of how the U.S. Army has changed its procedures since the 2013 Stuart Creek 2 Fire.

The risk of wildfire has remained prevalent in this region of Alaska. From 2017 to 2021, on average, there were 234.4 fires in the Fairbanks region in Alaska (North Star Borough and City of Fairbanks) each year (see Table 2 and Table 3; Alaska State Fire Marshall 2017, 2018, 2019, 2020, 2021). Out of those 140 fires, over a five-year average, about 56% were non-structural fires (Alaska State Fire Marshall 2017, 2018, 2019, 2020, 2021). After the 2013 Stuart Creek 2 Fire, wildfires remain a threat to training and missions for the U.S. Army.

Year	Total Fires	Structural Fires	Other Fires
2017	107	55	52
2018	100	47	53
2019	83	31	52
2020	111	42	69
2021	115	55	60

Table 2. Fire Incidents in North Star Borough, Alaska 2017-2021. Source: Alaska State Fire Marshall; Alaska State Fire Marshall; Alaska State Fire Marshall; Alaska State Fire Marshall; Alaska State Fire Marshall.

Year	Total Fires	Structural Fires	Other Fires
2017	104	43	61
2018	120	52	68
2019	148	57	91
2020	133	64	69
2021	151	70	81

Table 3. Fire Incidents in the City of Fairbanks, Alaska 2017-2021. Source: Alaska State Fire Marshall; Alaska State Fire Marshall; Alaska State Fire Marshall; Alaska State Fire Marshall; Alaska State Fire Marshall.

In 2021, another fire started in a pocket of vegetation left untouched by the Stuart Creek 2 Fire in 2013 (BLM Alaska Fire Service 2020). This fire, called Stuart Creek Fire (308), ignited in an area surrounded by the 2013 Stuart Creek 2 Fire (BLM Alaska Fire Service 2020). This fire did not pose any immediate risks to the community or training areas at Fort Wainwright.

Arctic and Sub-Arctic regions are strategically critical for the U.S. because of new and emerging navigable waterways, melting sea ice, and rising tensions and competitions with Russia and China (Knickmeyer 2022). More importantly, the DoD also believes that “the Arctic is a potential vector for an attack on the U.S. homeland”; thus, U.S. military presence is needed (Knickmeyer 2022). However, a report published in 2022 detailed that officials from five out of the six U.S. bases in this region said they had not begun incorporating future climate risks into their installations’ planning (Department of Defense: Office of the Inspector General 2022). The publicly available report redacted the specific details about the risks associated with climate change for these Arctic and sub-Arctic regions. However, it is common knowledge that extreme heat in inland areas creates the perfect conditions for a wildfire to ignite, given the proper fuel and ignition source.

In total, the Stuart Creek 2 Fire resulted in resource depletion and inflicted damages amounting to \$5.5 million dollars at Fort Wainwright (Burke et al. 2020).

Key Takeaways

Similar to the wildfire risks faced by Camp Pendleton, the ongoing threat of wildfires at Fort Wainwright indicates the potential for disruptions to mission and operations at any given time. The 2013 Stuart Creek 2 Fire at Fort Wainwright serves as a stark example of how climate change can intensify persistent hazards on U.S. military installations. The aftermath of this fire saw 87,000 acres scorched, training grounds destroyed, operations halted, and substantial resources mobilized and depleted during the two-month-long, 700-firefighter battle against the blaze. This incident exemplifies the complexities climate change introduces to military readiness and emphasizes the financial challenges associated with adapting to and mitigating unforeseen adversities arising from climate-related impacts.

2.4 Fort Liberty, North Carolina (2018)

Primary Mission

U.S. Army Garrison Fort Liberty (Fort Liberty)—previously named Fort Bragg (Garamone 2023)—is located in Fayetteville, North Carolina. Fort Liberty’s primary mission is to “equip, train, deploy and sustain full spectrum forces supporting combatant commanders that fosters a community of excellence where soldiers, families, and civilians can

thrive” (U.S. Army Fort Bragg 2023b). Fort Liberty is home to the U.S. Army Forces Command headquarters and consists of roughly 75,000 active army soldiers, U.S. Army Reserve, and Army National Guard soldiers (U.S. Army Fort Bragg 2023b). This installation specializes in Airborne and Special Operations Forces, and its primary goal is to maintain America’s Contingency Corps (U.S. Army Fort Bragg 2023a).

Additionally, this base harbors other commands, including:

- XVIII Airborne Corps,
- U.S. Army Special Operations Command,
- U.S. Army Reserve Command,
- 82nd Airborne Division, and
- 108th Air Defense Artillery Brigade.

Moreover, Fort Liberty is well known throughout the army as the training ground for housing the:

1. U.S. Army Special Operations,
2. Airborne Corps, and
3. the U.S. Army Golden Knights Parachute team (Military Bases.com Website 2023; U.S. Army Fort Bragg 2023c).

Fort Liberty is home to roughly 260,000 people, including 75,000 military and civilian personnel, 63,000 military dependents, 3,600 contractors, and a permanent locality for about 98,000 army retirees and family members in the surrounding community (U.S. Army Fort Bragg 2023a; Bledsoe 2023).

The Event — 2018 Hurricane Florence

Hurricane Florence, which originated off the coast of Africa on August 30, 2018, brought torrential rainfall and widespread flooding (National Oceanic and Atmospheric Administration 2023). The storm was characterized by sustained wind speeds of 38 mph and powerful gusts reaching up to 56 mph (National Oceanic and Atmospheric Administration 2023). In addition, the total rainfall from Hurricane Florence ranged between 17 to 20 inches (National Oceanic and Atmospheric Administration 2023). Over the next few weeks, Hurricane Florence grew stronger but weakened just before making landfall as a Category 1 hurricane



Figure 9. 2018 Hurricane Florence. Satellite image of Hurricane Florence advancing towards the United States East Coast on September 12, 2018. Image accessed from: <https://www.cbsnews.com/news/hurricane-florence-path-track-latest-weather-forecast-north-carolina-evacuation-2018-09-12-live-updates/>

at Wrightsville Beach, North Carolina, on the morning of September 14, 2018, (National Oceanic and Atmospheric Administration 2023). Florence made landfall roughly 120 miles southeast of Fort Liberty. Upon landfall, Hurricane Florence moved slowly inland and weakened (National Oceanic and Atmospheric Administration 2023). Figure 9 helps illustrate the magnitude and severity of Hurricane Florence by the sheer size of this severe weather event.

Fayetteville, home to Fort Liberty, is roughly 100 miles inland from the North Carolina coast and escaped the damaging storm surges and coastal flooding that other installations located near the coastline (Ortiz 2018). Fort Liberty spans 160,700 acres or 251 square miles and borders four counties (Department of Military and Veterans Affairs 2023).

Unlike other military installations in North Carolina, Fort Liberty was spared the damaging

wind speeds that Marine Corps Base Camp Lejeune experienced (Jacobs 2019). Nonetheless, despite its inland location, this installation was still impacted by perilous conditions to life and property due to the occurrence of heavy rainfall and flooding (Ortiz 2018). After the storm passed, secondary threats remained in the wake of Hurricane Florence, including flooding and damage to critical infrastructure (power and freshwater). Three days, Sunday to Tuesday (September 16 to September 19, 2018), the Fayetteville Police Department documented the height of the Cape Fear River, as seen in Figure 10, to show just how fast and high the water levels rose (Ortiz 2018).

Hurricane Florence was well-predicted, unlike previous storms that have impacted this installation, such as Hurricane Matthew two years earlier (Jacobs 2019). Throughout the weeks before Hurricane Florence made landfall, this installation readied soldiers and equipment capable of assisting in rescue operations and missions (King and Hayes 2018). Along the East Coast, this installation serves as a Federal Emergency Management (FEMA) hub during disaster events (King and Hayes 2018). FEMA had over 500 trailers lined up on the Simmons Army Airfield at Fort Liberty, waiting to disperse them where necessary after Florence (King and Hayes 2018).

Event Impacts

Fort Liberty suffered an estimated \$55 million dollars in damage from Hurricane Florence (Jacobs 2019). Florence damaged over 600 buildings at Fort Liberty, including office spaces, mission, and command buildings (Jacobs 2019). In addition to buildings supporting mission-critical activities, military housing at Fort Liberty was damaged; however, the number of homes impacted is not publicly available. Nevertheless, roughly 70 percent of active duty soldiers live off post (Jacobs 2019). As waters rose in the Little and Cape Fear Rivers, service members and their families living on post and still in their homes were evacuated to the Pine Forest High School (Friend 2018).

With widespread installation damage totaling \$55 million dollars in repair, rebuild, and recovery. However, no publicly available information detailing the extent of the damage caused by Hurricane Florence impacted Fort Liberty's missions, operations, and training requirements.

Regular operations and missions were likely disrupted in the wake of Hurricane Florence.

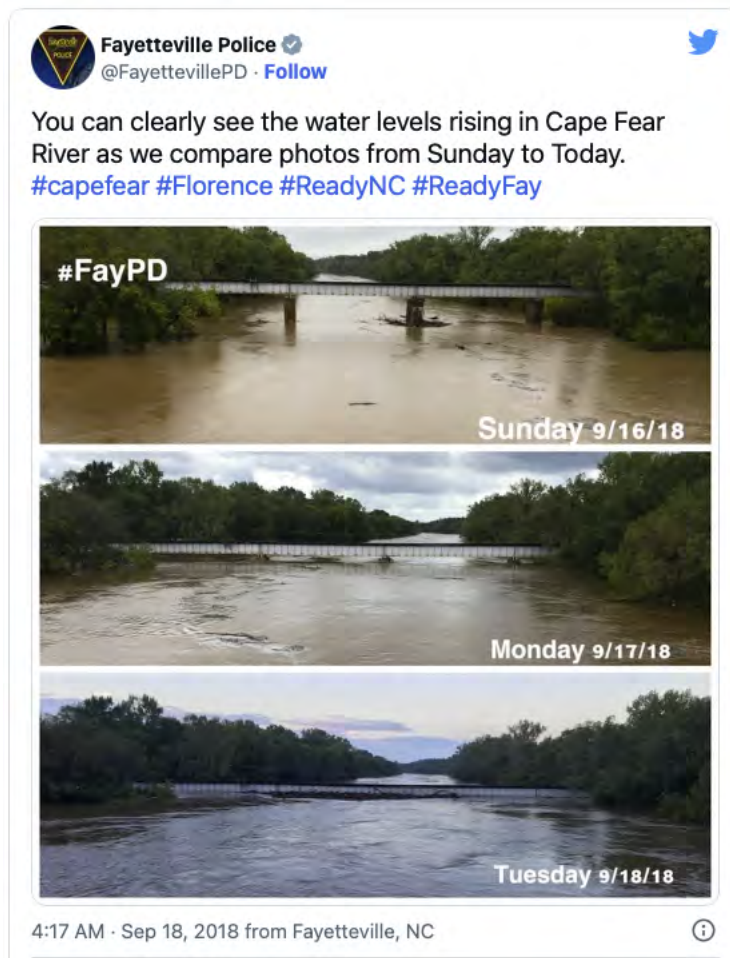


Figure 10. Cape Fear River Flooding from Hurricane Florence. This figure shows the water levels rising in the Cape Fear River in Fayetteville, NC, home to Fort Liberty. Image accessed from: <https://www.nbcnews.com/news/us-news/fears-major-flooding-fayetteville-n-c-florence-menaces-east-coast-n910626>

Hundreds of soldiers from Fort Liberty aided in Hurricane Florence’s rescue and recovery efforts, “even while watching their homes flooded and evacuated” (Friend 2018). Figure 11 shows soldiers loading and preparing for aid and relief missions on September 15, 2018, one day after Florence made landfall.



Figure 11. U.S. Army Prepping for Humanitarian Assistance after Hurricane Florence. On September 15, 2018, U.S. Army Soldiers assigned to various units at Fort Liberty prepared and loaded their Light Medium Tactical Vehicles to deliver supplies and aid to the areas affected by Hurricane Florence. Image accessed from: <https://www.dvidshub.net/image/4736598/hurricane-florence-fort-bragg-soldiers-mount-up-and-head-out-provide-aid>

Recovery Efforts

Recovery after Florence was not a quick process, and because of this, there was an increase in the amount of secondary damage from the storm. January 19, 2019, a news report covered a story about one active duty service member whose home at Fort Liberty had structural damage and mold issues before Hurricane Florence, signaling that maintenance and facility repairs were not being handled appropriately (ABC 11 Eyewitness News 2019). After Florence, the news reports state that this service member's roof caved in, causing increased health risks for her family, leading to the hospitalization of one of her family members (ABC 11 Eyewitness News 2019). Another new release from the Department of Defense on November 3, 2020, states that "work will be performed at Fort Liberty, North Carolina, with an estimated completion date of May 1, 2021" (U.S. Department of Defense 2020).

The habitability of living quarters was a significant issue after Hurricane Florence. In addition to the damage to military family housing, Florence also damaged twelve barracks at Fort Liberty. These barracks are scheduled for demolition in 2023, and another five barracks are expected to be refurbished due to mold (ABC 11 Eyewitness News 2019). Additionally, U.S. Army leaders at Fort Liberty knew about the habitability issues in military housing and the barracks but failed to act until the complaints escalated to Congress (ABC 11 Eyewitness News 2019).

The Atlantic Ocean has a very active yearly hurricane season. Fort Liberty, since 1999, has experienced three major hurricanes and their associated impacts. One lesson learned since Hurricane Floyd in 1999, Hurricane Matthew in 2016, and Hurricane Florence in 2018 is that “inland and urban flooding demands more attention” (Davis 2021).

Fort Liberty was awarded rebuilding funds totaling \$65 million dollars from the Army Hurricane Relief Fund (Department of Defense 2019a). Hurricane Florence depleted resources and caused damages at Fort Liberty, which has military readiness implications (Jacobs 2019).

Key Takeaways

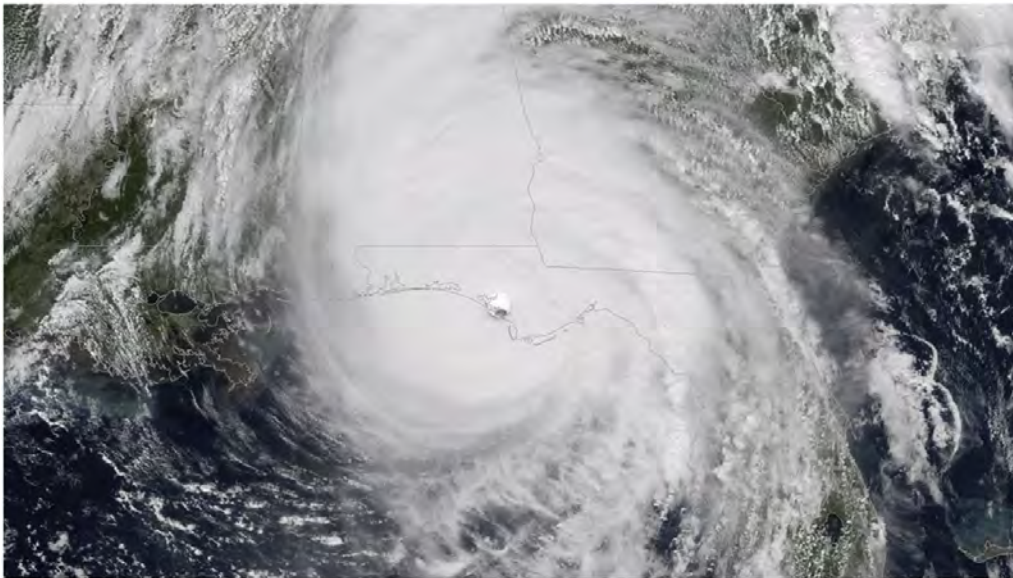
The persistent threat posed by increasingly potent and frequent hurricanes in the Atlantic region signifies the substantial impact of climate change on the prevalence and severity of such meteorological events. Despite the well-anticipated repercussions of Hurricane Florence, Fort Liberty incurred widespread damage to its installations. This emphasizes the pressure for enhanced adaptive capacities at U.S. military installations to contend with climate-induced disasters effectively. The compounded ramifications for these installations are exacerbated by aging infrastructure and the perpetual constraints of shrinking budgets. This incident illustrates the far-reaching consequences of an inland installation resulting from a hurricane, delineating the complex implications for military readiness, personnel, and sustained training requirements.

2.5 Tyndall Air Force Base, Florida (2018)

Primary Mission

Tyndall Air Force Base (Tyndall AFB) is located 12 miles east of Panama City, Florida. The installation's primary mission is to provide a combat-ready air dominance force (Tyndall Air Force Base 2023b). Tyndall AFB accomplishes this by training F-22A Raptor pilots and projecting unrivaled combat air power (Tyndall Air Force Base 2023b). This installation is home to roughly 5,000 military and civilian personnel, 5,500 military dependents, and 17,000 military retirees and their families living in the surrounding community (Military One Source 2023g).

Event — 2018 Hurricane Michael



NOAA's GOES-East captured this image of Hurricane Michael as it came ashore near Mexico Beach, Florida on Oct. 10, 2018. According to the National Hurricane Center, Michael intensified before landfall with maximum sustained winds of 160 mph, heavy rainfall, and deadly storm surge. (NOAA)

Figure 12. 2018 Hurricane Michael Satellite Image. This image of Hurricane Michael captures the precise moment on October 10, 2018, when this Category 5 hurricane made landfall. Image accessed from: <https://www.noaa.gov/media-release/hurricane-michael-upgraded-to-category-5-at-time-of-us-landfall>

Hurricane Michael, which originated over the Central and Western Caribbean Sea between October 1 to 2, 2018, brought with it massive amounts of rainfall and destructive winds (National Weather Service 2018). In the early morning hours of October 10, 2018, as 160 mph

winds started hammering everything in its path; the reality of Hurricane Michael's Category 5 strength would soon be realized throughout the Florida panhandle. Northwest Florida communities were prepared for a Category 2 hurricane, but that all changed in a few short hours (Tyndall Air Force Base 2022). Hurricane Michael escalated rapidly into a Category 5 hurricane and made landfall hitting the coastline and surrounding areas of Tyndall AFB, Mexico Beach, and Panama City (Tyndall Air Force Base 2019). As the storm advanced inland, the eye of the storm passed over Tyndall AFB. As the storm proceeded further inland, the assessment of Hurricane Michael's damage at this installation began. Hurricane Michael defied all beliefs and expectations about hurricanes in the Florida panhandle. Figure 12 depicts the eye of Hurricane Michael advancing inland through the Florida panhandle.

Event Impacts

Not one area across the 29,000-acre Tyndall AFB escaped the destructive impacts of this extreme weather event. Hundreds of buildings were damaged or destroyed, with about 484 scheduled for demolition (Tyndall Air Force Base 2019). This storm showed no favoritism; operating dormitories, family housing, support building (commissary, dental, medial), command and tenant command buildings, and aircraft hangers all sustained some damage. Most notably, out of 11 of Tyndall's AFB's operating dormitories, all but three were destroyed (Tyndall Air Force Base 2019).

Figure 13 illustrates the "Tent cities" erected to house commands, personnel, and disaster relief teams (U.S. Department of Defense 2018). Multiple commands operated out of one tent, an environment similar to wartime/deployed conditions. Moreover, some airmen were forced to live in tents until 2019 because of uninhabitable dormitories (U.S. Department of Defense 2018). Additionally, it took two weeks of around-the-clock efforts to erect this tent city and restore basic necessities (U.S. Department of Defense 2018).

However, building damage was not the only impact that Tyndall AFB faced. Seventeen out of the fifty-five F-22 Raptor stealth fighter jets remained on the installation because of the safety of short notice launch or planned maintenance rendering them unmovable [Note: 30 percent of total stealth fighter assets are stationed at Tyndall] (Lockheed Martin 2023a). Four jets sustained damage that required repairs along with other aircraft (Lockheed Martin 2023a). The damage to aircraft hangers and aircraft from Hurricane Michael is illustrated



Figure 13. “Tent Cities” at Tyndall AFB. “Tent Cities”, a typical operating environment during overseas or wartime conditions, is seen at Tyndall AFB after Hurricane Michael devastated this installation. Image accessed from: <https://www.defense.gov/Multimedia/Photos/igphoto/2002058179/>

in Figure 14.

Tyndall AFB is also an economic pillar of the community. Hurricane Michael prompted fear in the Florida panhandle that the Air Force might not rebuild. Tyndall AFB is responsible for one-third of the local economy and is a significant regional employer (The Washington Post 2018). Rebuilding this base is essential for the local and regional economy and national security. Lawmakers have assured that Tyndall AFB would rebuild despite the certainty of the future re-occurrence of another severe weather event.

Recovery Efforts

Hurricane Michael’s devastation at Tyndall AFB in 2018 was a surprise to military leaders at Tyndall AFB. The U.S. Air Force’s ability to promote force posture, air dominance, and



Hurricane Michael hit U.S.A.F Tyndall: Two F-16 & two F-22 can be spotted in a roofless hangar

Figure 14. Installation and Asset Damage at Tyndall AFB after Hurricane Michael. Hurricane Michael left roofless aircraft hangers and damaged aircraft necessary for mission assurance and training exercises. Image accessed from: <https://fighterjetsworld.com/latest-news/aircraft-crash/u-s-a-f-tyndall-air-force-base-took-a-direct-hit-from-hurricane-michael/8408/>

strategic advantage requires that this installation remain superior at controlling the skies and dictating the terms and conditions for flight globally. Hurricane Michael's impacts have obstructed mission readiness, operations, and training which have far-reaching implications for national security, global partnerships, and economic growth (Lockheed Martin 2023b).

Rebuilding this installation is expected to take 5-7 years (Tyndall Air Force Base 2023a). These efforts focus on meeting current capabilities and missions and sustaining mission assurance of future capabilities and capacities in an ever-changing operational environment (Tyndall Air Force Base 2023a). Overall, this storm is estimated to cost \$5 billion in addition to disrupting operations; repairs have been underway at the base since 2018 (NBC News 2022). A news report published on September 24, 2022, (NBC News 2022), states that the new trajectory of this installation, now being coined "the installation of the future," is expected to be fully finished by 2026, making rebuilding from Hurricane Michael an almost decade-long endeavor (NBC News 2022).

[Note: A month earlier, Hurricane Florence (September 14, 2018) hit the east coast, causing extensive damage to several Marine Corps Bases in North Carolina].

Key Takeaways

The case of Tyndall AFB illustrates the potential for widespread impact by extreme weather events on U.S. military installations. Hurricane Michael’s destructive force spared no sector, affecting operating dormitories, family housing, support buildings, command structures, assets, and aircraft hangars, resulting in widespread installation and asset damage. Tent cities, resembling wartime conditions, to accommodate personnel illustrate the severity of damage (approximately \$5 billion in cost) and the prolonged recovery process (projected to take 5-7 years). Because Tyndall AFB contributes one-third of the regional economy, the economic ramifications of the event highlight how disasters impact both installations and the surrounding communities.

2.6 Naval Base Ventura County, California (2018)

Primary Mission

Naval Base Ventura County (NBVC), comprised of the main base Port Hueneme and Naval Air Station Point Mugu (NAS Point Mugu), is located in Ventura County, California on the Oxnard plain, about 30 miles northwest of Los Angeles, California (Military One Source 2023e). Figure 15 provides an aerial view of the installation, west towards the Pacific Ocean. NBVC also includes the San Nicolas islands. NBVC’s primary mission is to “deliver proactive quality support to our tenants and enable their diverse missions through safe and secure base operations” (Military One Source 2023e).

Port Hueneme provides the Pacific Fleet with a premier mobilization site, including a deep water port, railhead, and airfield (Military One Source 2023e). Port Hueneme is also home to many major commands including:

- Naval Surface Warfare Center,
- Center for Seabee and Facilities Engineering,
- Engineering Duty Officers School, and
- the Naval Facilities Expeditionary Logistics Center.



Figure 15. An aerial view of Naval Base Ventura County. Image accessed from: <https://cnrsw.cnic.navy.mil/Installations/NAVBASE-Ventura-County/>

NAS Point Mugu is home to the Airborne Command Control and Logistics Wing, which supports four E-2C Hawkeye squadrons. Additionally, NAS Point Mugu is home to the:

- Fleet Logistics Support Squadron 55,
- Air Test and Evaluation Squadron Three Zero, and
- Naval Air Warfare Center Weapons Division (NAVAIR WD).

Home to roughly 10,000 military and civilian personnel, 5,000 military dependents, and 6,000 contractors (Military One Source 2023e).

The Event — 2018 Hill and Woolsey Fire

During November 2018, the entire state of California was under Red Flag conditions, with 60-70 mph winds stretching from border to border. In such dangerous conditions, two

wildfires sparked in Ventura and Los Angeles counties, requiring immediate resources to be deployed for containment. However, resources were already diverted to another ongoing crisis, leaving firefighting efforts stretched thin. Meanwhile, just 30 minutes later, another fire started to blaze, further exacerbating the situation.

(Note: resources were already deployed and exhausted from the mass shooting that occurred at Borderline Bar and Grill in Thousand Oaks, CA on November 7, 2018, at 11:20 pm, claiming the lives of 12 individuals and injuring 21 others (Ventura County Sheriff, Office of Emergency Services 2020). These fires broke out less than 24 hours after that incident occurred. Additionally, it is important to mention on a state level, California firefighters were also battling the Camp Fire (Commander, Naval Air Forces Atlantic 2019), which started on November 8, 2018, meaning that the fire that started in Ventura County had a limited amount of resources and available firefighters to assist).

Thursday, November 8, 2018

Thursday, November 8, 2018, the day after the mass shooting, the Hill Fire started in the afternoon, around 2 pm. Propelled by 30 mph winds in the Santa Rosa Valley, the Hill Fire quickly threatened lives and infrastructure and initiated evacuations in the surrounding areas (Ventura County Sheriff, Office of Emergency Services 2020). By Friday morning, the Hill Fire was raging, 3000 acres burned (Figure 16 illustrates) and was blazing along both sides of Highway 101 in Camarillo, just northeast of where NBVC sits. Figure 17 shows Master-at-Arms 2nd Class Courtney Altman communicating with base officials during the full mandatory evacuation order of NBVC. The threat of this fire advancing to the Pacific Ocean and consuming NBVC was a reality during this event (Wenzke 2018).

Thursday, November 8, 2018, about 30 minutes after the Hill Fire started, the Woolsey Fire started at about 2:30 pm in the Santa Susana Field Laboratory, south of Simi Valley (Ventura County Sheriff, Office of Emergency Services 2020). The fire erupted in a location that had potential threats to multiple jurisdictions, including Ventura County, Los Angeles County, and Los Angeles City (Ventura County Sheriff, Office of Emergency Services 2020). On Thursday, November 8, 2018, Ventura County Fire Protection District was fully immersed in battling the Hill Fire, which at that time, was perceived to be more of a threat (Ventura County Sheriff, Office of Emergency Services 2020). Initial efforts to contain the Woolsey



Figure 16. 2018 Hill Fire Encroaches on Surrounding Communities. Hill Fire in Ventura County encroaching Highway 101, endangering transportation and power resources. Image accessed from: <https://ktla.com/news/local-news/wildfire-burns-through-100-acres-in-ventura-county-as-residents-are-told-to-evacuate/>

fire were hampered by the resources diverted to the Hill Fire (Gabbert 2019).

Saturday, November 10, 2018

The fires had gained ground by Saturday, November 10, 2018, especially the Woolsey Fire (Gabbert 2019). The Woolsey fire had consumed 70,000 acres in less than two days (Ventura County Sheriff, Office of Emergency Services 2020). The Hill fire advanced into a burn scar area from the Spring Fire in 2013, quickly diminishing the fuel available to keep the fire raging (Ventura County Sheriff, Office of Emergency Services 2020). Firefighters were able to move rapidly toward containment after that. Re-population of some civilians who were evacuated from the fire threat areas after both fires were contained.



Figure 17. Evacuation of NBVC. Master-at-Arms 2nd Class Courtney Altman communicates with base personnel during the evacuation process of NBVC on November 10, 2018. Navy personnel assigned to NBVC work alongside CAL FIRE officials to aid in the Hill Fire and the Woolsey Fire firefighting efforts. Image accessed from: <https://www.dvidshub.net/image/4892245/nbvc-evacuates-families>

Tuesday, November 13, 2018

On November 13, 2018, the evacuation orders were lifted, and residence and non-essential personnel could return to NBVC (Adams 2018). By November 16, the Hill Fire was declared 100% contained, burning over 4,300 acres (Ventura County Sheriff, Office of Emergency Services 2020). On November 17, 2018, both the Hill and Woolsey Fires re-population of civilian evacuated areas was complete. Then, by November 23, 2018, the Woolsey fire was declared 100% contained, burning over 96,000 acres (Ventura County Sheriff, Office of Emergency Services 2020).

Event Impacts

All publicly accessible sources detailed that no extensive damage at NBVC from the Hill or Woolsey Fires. However, all three incidences (Borderline Bar and Grill and the Hill and Woolsey fires) impacted the surrounding communities. Furthermore, emergency resources and services were affected by the multiple incidences that required triaging of resources and emergency services.

Hill fire impacted the surrounding community by mandatory evacuations for areas in Ventura County, including the Camarillo Springs area and California State University Channel Islands (Jackson 2018). The Hill fire prompted mandatory evacuations for Point Mugu Naval Base (Wenzke 2018). Hill Fire investigation concluded that all other sources of ignition of this fire were pulled out except “human activity” (ABC 7 Staff 2018). Additionally, the Hill fire burned over 4,000 acres (ABC 7 Staff 2018).

The Woolsey fire erupted in one of the most populated areas in the nation and in an area well protected by emergency services and resources (County of Los Angeles 2019). However, this incident proved to take the community and emergency responders by surprise.

The Woolsey Fire impacted the community by forcing evacuations of over 250,000, including the entire city of Malibu (Daniels 2018). According to a report drafted by the Department of Toxic Substances Control, executive summary states that the Woolsey Fire burned approximately 96,949 acres in Ventura and Los Angeles Counties (Department of Toxic Substances Control 2020). Moreover, the report detailed that the fire destroyed or damaged almost 2,000 structures (400 homes and 1600 other structures) in the surrounding communities (Department of Toxic Substances Control 2020; Los Angeles Region Community Recovery Organization 2023). The investigation into the Woolsey fire concluded that a power company’s electrical equipment was at fault for igniting vegetation (Jackson 2018).

The Hill and Woolsey fires impacted NBVC operations and missions by mandatory evacuations for all personnel, civilians, non-essential personnel, and their families from November 9 - 13 (Wenzke 2018). Nevertheless, all three incidences have an implied impact on service members, their families, and their communities. Service members live in the surrounding communities of installations. Service member spouses work in the community. Service

members' children frequent local schools in the area. Events like the Hill and Woolsey fire disrupt the lives, monetary security, and education of military service members, their spouses, and children.

Additionally, statewide, firefighting resources were stretched thin, with three significant fires burning within California (Daniels 2018). Realizing that resources were inadequate for the scale and severity of these fires, state authorities asked for additional resources from neighboring states (Daniels 2018).

Recovery Efforts

Since 2018, Ventura and Los Angeles counties have come together to review the strengths and challenges all three incidents had on emergency response services, resources, and communities.

Operational and incident management assessments revealed that challenges from these three incidents included:

1. Diminished communication because of power and internet outages,
2. Ongoing difficulty with communication platforms, including satellite and radio devices,
3. Mandatory evacuations of areas, limited access for the utility companies to access and repair infrastructure, and
4. The weight of all three significant and emotional events impacted staff stress and fatigue levels (Ventura County Sheriff, Office of Emergency Services 2020).

Recommendations from these challenges include:

1. Increased training for city and county emergency operators,
2. Ensuring that all staff is knowledgeable about operating satellite phones and county-wide inter-operable radio systems radios, and
3. Ensuring that incident stress management resources are available to all emergency personnel (Ventura County Sheriff, Office of Emergency Services 2020).

The economic cost of a mandatory evacuation of NBVC is unknown. However, any large-scale evacuation has a monetary cost associated with it.

Key Takeaways

The case study on NBVC in California during the 2018 Hill and Woolsey Fires elucidates the multifaceted impact of environmental disasters on U.S. military installations. These wildfires impacted NBVC operations, leading to mandatory evacuations and disrupting missions. The recovery efforts and subsequent assessments revealed challenges such as communication breakdowns, limited access for utility companies, strained and limited resources to mobilize and deploy, and elevated stress levels among emergency personnel. Recommendations for increased training and stress management highlight the importance of resilience and adaptive capacity for military installations confronting the complexities of environmental disasters.

2.7 Offutt Air Force Base, Nebraska (2019)

Primary Mission

Offutt Air Force Base (Offutt AFB) is located south of Omaha, Nebraska. The mission of Offutt AFB is to “Provide dominant intelligence, surveillance and reconnaissance, electronic warfare, and nuclear command, control, and communications to national leadership and warfighters...Any time, Any place.” Offutt AFB is the largest wing-in Air Combat Command and the second largest in the Air Force (Military.com Website 2023). This installation is home to roughly 10,000 military and civilian personnel, 7,000 military dependents, and 26,000 military retirees living in the surrounding community (Military One Source 2023f).

Event — 2019 Missouri River Flooding

Over the course of 48 hours, from Friday, March 15 to Saturday evening, March 16, 2019, Offutt AFB mobilized 10,000 military and civilian personnel, along with 7,000 military dependents, to combat the impending flood. They worked tirelessly to deploy sandbags, construct flood barriers, and evacuate critical aircraft (Hasemyer 2019). However, the floodwaters advanced rapidly, reaching a height of 17 feet, and the efforts to safeguard the installation were eventually abandoned on the evening of Saturday, March 16, due to the severity of the flooding.

By Sunday, March 17 — 72 hours after the first warning that flooding was imminent — flood waters had reached strategic air, security, intelligence, reconnaissance, maintenance



Figure 18. 2019 Missouri River Flooding at Offutt AFB. Severe flooding at Offutt AFB caused extensive damage to 137 buildings and inundated over half of the aircraft runway. Image accessed from: <https://www.vox.com/2019/3/25/18280758/nebraska-flooding-air-force-offutt>

facilities, and headquarters (Losey 2019). A quick surveying of the installation rendered the shocking news - dozens of buildings were flooded, and the flightway (or runway) was rendered unusable (The Associated Press 2019). Figure 18 illustrates the extent of the flooding at Offutt AFB. Flood waters remained for weeks (Margery A. Beck and Burns 2019). But this devastating flood was even worse because the flood waters ran through the wastewater treatment facility - making this disaster much more hazardous (Losey 2020).

This 500-year Flood event was caused by record low temperatures and record high snowfall followed by a “bomb” cyclone or winter hurricane, causing temps to soar and high rainfall, which input a large amount of water into the Missouri River in a short period (Woody and Reuters 2019). These conditions caused the Missouri River to over-top levees at Offutt AFB.

Event Impacts

After the flooding receded, assessments of flood damage took several more weeks. Findings revealed 137 buildings were damaged, with about 60 damaged beyond repair (The Associated Press 2019). Additionally, one-third of commands and personnel were required to move offices due to flooded buildings (McCarthy 2020). Moreover, seventy-five percent (75 percent) of the SECRET areas at this installation were ruined, displacing over 3200 personnel (Chapman 2022). Figure 19 highlights the severity of damage to the 55th Security Forces Headquarters at Offutt AFB.



Shattered glass and other debris litters the entryway of the 55th Security Forces Squadron headquarters building six months after it was damaged in the March 2019 floods.

Figure 19. Flood Damage at the 55th Security Forces Squadron Headquarters. Six months after the 2019 Missouri River flooding inundated this installation with 17-foot-high floodwaters. Image accessed from: https://omaha.com/news/local/covid-related-shortages-could-send-tab-for-offutt-rebuilding-through-the-roof/article_9e91b108-5c71-11ec-ac36-c7baf2612ad4.html

Recovery Efforts

Military officials did not act in time to protect this installation from flooding despite the flood in 2011 (Danielson 2011) prompting a 2015 land use management plan and report highlighting the need to increase levee height (Hasemyer 2019). Offutt AFB is working with the Army Corps of Engineers, FEMA, and the community to re-evaluate the levee and rebuild at least 19 miles of the levee along the Missouri River to ensure that flooding of this magnitude does not impact this installation or the surrounding community in the future (Hasemyer 2019).

From 2018 to 2020, Offutt AFB experienced multiple disruptive events in two years. Reports state that Offutt AFB has remained mission-ready despite the trifecta of impacts - the replacement of their 80-year-old runway (Weber 2022), the 2019 Missouri River flood (The Associated Press 2019), and COVID-19 pandemic [US military as a whole (Nichter et al. 2021; Na et al. 2021), and Offutt and COVID-19 (Military.com Website 2020; McCarthney 2020) - which has disjointed daily activities and ultimately impacting mission readiness despite news reports stating otherwise. It has taken the installation/Air Force three years to regroup, including planning, designing, and financing, to advance towards the road to recovery (Garcia 2022).

On March 21, 2022, demolition finally began on buildings scheduled for replacement after the flooding in 2019, as illustrated in Figure 20 (Liewer 2022). From destruction to reconstruction, the silver lining after the disaster is rebuilding better (Garcia 2022). Moreover, Offutt AFB is consolidating its footprint with its future design during the rebuilding process. Offutt AFB will take a strategic step towards climate energy resilience and personnel efficiency by reducing its building footprint. The installation rebuild project is targeted to be completed in stages between the years 2024 - 2028 (Chapman 2022) and is costing the service roughly \$1.1 billion dollars (KETV Staff Report 2021).

Key Takeaways

Advanced warning by itself can be insufficient to avoid disaster. Despite suffering from a previous flood, knowledge of the impending incident, and significant efforts on the part of thousands of mobilized personnel, Offutt AFB was not able to protect itself from the magnitude of this flood, which over-topped levees and caused catastrophic damage. Despite



Figure 20. Demolition Started Three Years After the 2019 Flood. Sixty buildings were damaged beyond repair and will be demolished in phases. Image accessed from: https://omaha.com/news/local/offutt-offers-update-on-rebuilding-efforts-following-catastrophic-2019-flooding/article_ca633c86-a549-11ec-a01a-5b6e50743343.html

a meticulous and strategic approach to rebuilding, the recovery process is taking much longer than hoped or anticipated, at a cost to ongoing military readiness and mission assurance.

2.8 Fort Hood, Texas (2021)

Primary Mission

U.S. Army Base Fort Hood (Fort Hood) is halfway between Austin and Waco, Texas. The primary mission of Fort Hood is to provide integrated installation support services, including facilities, infrastructure, and programs to enable Fort Hood commanders to train and deploy their units as well as take care of their soldiers, families, civilians, and retirees (Military One Source 2023b). Home to roughly 45,000 active duty military, 10,000 civilian

personnel and contractors, 50,000 military dependents living on and off the post, and about 420,000 military retirees and their families living in the surrounding community (Military One Source 2023b). The installation is roughly 335 square miles and occupies parts of Bell and Coryell counties (Military One Source 2023b).

Event — 2021 Winter Storm Uri



Figure 21. Satellite Image of Winter Storm Uri. Winter Storm Uri caused widespread impacts across Canada, the U.S., and Northern Mexico from February 13 to 17 2021. Image accessed from: <https://www.neh.gov/news/neh-awards-humanities-texas-and-oklahoma-humanities-184352-assist-recovery-storm-damage>

Texans were caught by surprise when Winter Storm Uri hit in February 2021, bringing catastrophic power outages statewide and freezing conditions. The state experienced the worst cold spell and the largest snowfall in history, leading to burst pipes and a severe water shortage (Waller 2022). This severe winter storm was an unprecedented disaster and spotlights a gap in military preparedness (Cohen 2021). Figure 21 illustrates the magnitude of this severe winter storm spanning across multiple U.S. States.

Significant snow accumulation, freezing temperatures, and dangerous weather conditions left 70 percent of Texas lost power from February 15-18, 2021. However, Fort Hood was able to keep the lights on. The state of Texas imposed blackouts (III Corps and Fort Hood 2021) so as not to overload the entire power system. Winter storm Uri unleashed deadly cold, ice, and snow across several states, causing blackouts, loss of life, and disruption to daily life for civilians and the military. Only mission essential personnel are to report to Fort Hood on Wednesday, Feb. 17, 2021, (III Corps and Fort Hood 2021) due to winter weather, icy roads, and power outages continued in Central Texas. Figure 22 highlights the amount of snowfall across Texas.

On Tuesday, frigid weather, snow, and ice led to the delay or closure of non-essential operations at a minimum of 15 military installations. This weather phenomenon placed over 150 million Americans under various forms of winter weather alerts, as reported by the National Weather Service (Thayer 2021). Moreover, Texas experienced severe power failures, leaving over 4 million households and businesses without electricity (Thayer 2021).

Event Impacts

On Tuesday, numerous military installations spanning from Fort Drum in New York to Fort Hood in Texas shut down due to the widespread impacts of Winter Storm Uri (Thayer 2021). Uri severely impacted the military, causing damage to almost 700 facilities and more than 1,300 privatized military residences across four bases in Texas, Oklahoma, Kansas, and Louisiana (U.S. Congressmen Mike Johnson 2021). According to an Army official addressing House lawmakers, critical infrastructure has been fully repaired, and half of the storm-related repairs are complete (U.S. Congressmen Mike Johnson 2021). Aging facilities and systems failed first and suffered the most damage (U.S. Department of Defense 2021) because, over the past few decades, military infrastructure has felt the effects of high use and limited funding (U.S. Department of Defense 2021).

Numerous water lines across the military installation were broken from Winter Storm Uri, yet none of these issues affected military housing (Thayer 2021). Essential personnel that reported for duty throughout the storm spent a lot of time and worked turning off the power and water, cleaning up, and repairing what they could (Thayer 2021). Director of the base's public works at Fort Hood, Brian Dosa - stated that "snow and ice on our roads and parking

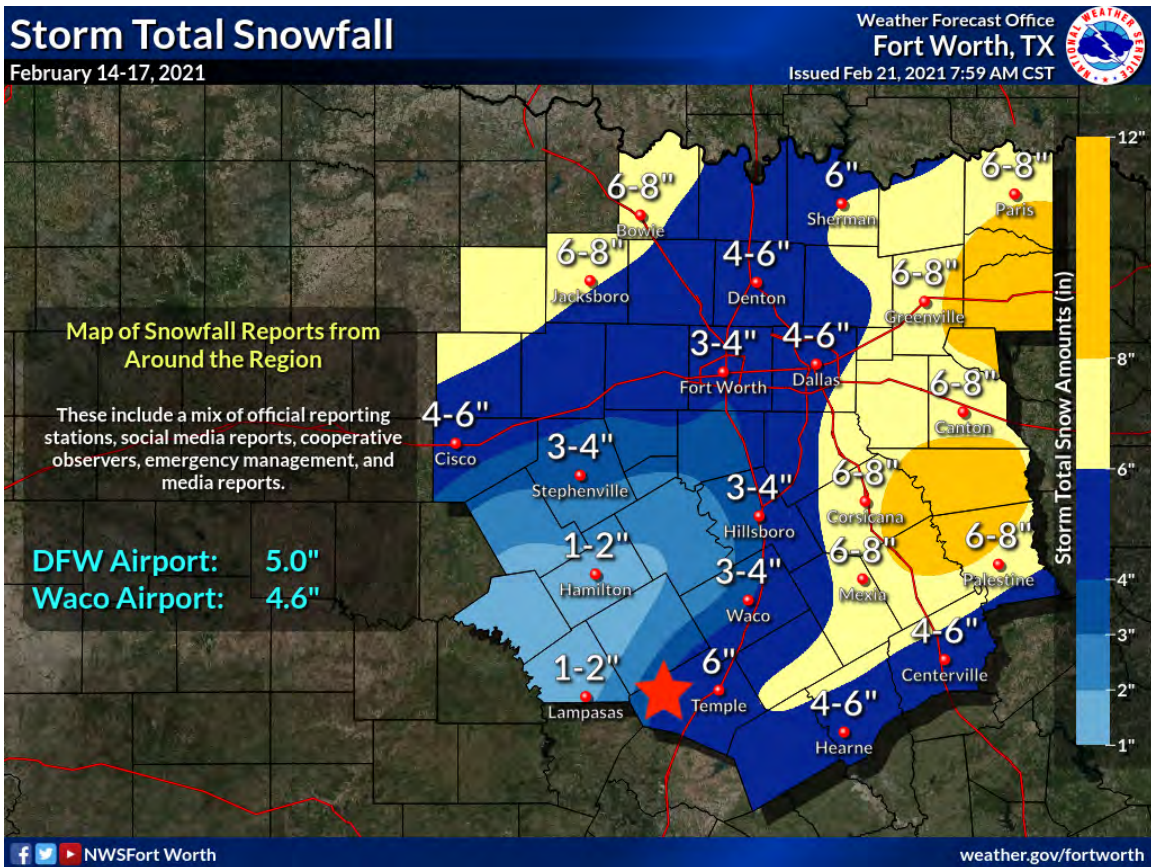


Figure 22. Snowfall Totals from Winter Storm Uri. Fort Hood, highlighted in this figure with a red star, was within the region of Texas that experienced over six inches of snowfall, freezing temperatures, and ice from Winter Storm Uri. Image accessed from: <https://www.weather.gov/fwd/Feb-2021-WinterEvent>

lots have also been an ongoing challenge, as we are not equipped for snow removal,” (Thayer 2021). Figure 23 depicts the situation at Fort Hood, including ice and snow on the roads and freezing temperatures. Storms are costly even without significant destruction. During the winter storm, the cost of electricity surged, resulting in a substantial increase in the electric bill for Fort Hood, Texas, amounting to around \$30 million for February, according to Gabram. This figure is nearly equivalent to the base’s energy expenditure in fiscal 2020, as highlighted by Republican Georgia Representative Austin Scott (Thorp 2021).

Dosa mentioned that despite the winter storm, Fort Hood’s main operations remained pow-



Figure 23. Base Housing at Fort Hood During Winter Storm Uri. Fort Hood recently privatized its utilities, including water, natural gas, and electricity. Because of this decision (and the ability of these privatized utility companies during Winter Storm Uri), Fort Hood could keep the utilities at this installation operating when many other businesses could not. Image accessed from: https://www.army.mil/article/253867/lessons_learned_from_21_help_fort_hood_prep_for_winter_storm

ered without any interruptions. However, there were significant challenges due to water breaks, which could have been much more severe without electricity. "Throughout February, we managed to maintain power, which ultimately prevented extensive storm-related damages," Dosa stated on Tuesday (Thorp 2021). He elaborated that the freezing temperatures caused numerous water lines and mains to rupture across Fort Hood and neighboring communities, estimating at least 1,200 water breaks on the base (Thorp 2021). These breaks affected various aspects such as building water lines, fire suppression systems, and water

mains, leading to an unprecedented surge in water usage. Typically, Fort Hood consumed about 2 to 3 million gallons of water daily between January and March. However, during the storm, water usage skyrocketed to 13.5 million gallons in a single day (Thorp 2021).

Having recently privatized its utilities with Dominion Energy handling natural gas, heating, and electricity, and American Water overseeing water and wastewater needs, Dosa commended both companies for their resilience during the extreme weather conditions. Dominion Energy efficiently repaired transformers and restored power swiftly, while American Water tackled over 33 water main breaks, ensuring water usage returned to normalcy (Thorp 2021).

Recovery Efforts

Today, Fort Hood has since recovered from Winter Storm Uri. However, the lessons learned from this storm are embedded into winter storm preparations and planning today. Installation managers are now more aware of what parts of the installation are impacted more heavily by snow, ice, rain, and flooding (U.S. Army 2022). Deploying resources to prohibit the accumulation of ice on roadways, disconnecting water systems that are not necessary for primary users ahead of the storm, identifying maintenance crews that remain on post through the storm to respond to emergency maintenance requests, as well as additional focus on preparations and education to support residence that live on base (U.S. Army 2022).

The precise cost of the severe winter storm is unknown. However, the electric bill alone at Fort Hood during Winter Storm Uri jumped to about \$30 million dollars (Thorp 2021).

Key Takeaways

This case highlights the importance of fortifying military installations against extreme weather events and investing in modernizing infrastructure for enhanced resilience. Despite being situated within the region of Texas heavily impacted by snowfall, freezing temperatures, and ice during 2021 Winter Storm Uri, Fort Hood managed to maintain operational power, avoiding the widespread outages that affected 70 percent of Texas. The impact of aging facilities and limited funding over the past few decades became evident as these systems bore the brunt of the storm. The recently privatized utilities, including water, natural gas, and electricity, played a crucial role in keeping the installation's essential services

operational during the crisis. Incorporating proactive resource deployment, infrastructure upgrades, and community support into future winter storm preparations will be essential for resilience against such climate-driven threats in the future.

2.9 Naval Air Station Sigonella, Italy (2021)

Primary Mission

Naval Air Station Sigonella (NAS Sigonella) is located in eastern Sicily, one of the largest islands in the Mediterranean Sea, and off the coast of mainland Italy (Military One Source 2023d). NAS Sigonella’s primary mission “is to provide operational, command and control, administrative, logistical and advanced logistical support to U.S. and other NATO forces” (Military One Source 2023d). NAS Sigonella supports multi-service, multi-national transient aircraft operating and meeting diverse objectives (Military One Source 2023d). The Augusta Bay Port Facility supports the SIXTH Fleet combat and ships operating in the region (Military One Source 2023d). NAS Sigonella is a critical junction for the U.S. military because it is an in-transit depot for military personnel and cargo throughout Europe, Africa, and Southwest Asia (Military One Source 2023d). NAS Sigonella is separated into two bases, NAS 1 and NAS 2 (Military One Source 2023d). Home to roughly 2,500 military and local civilian personnel, 2,000 military dependents (Military One Source 2023d).

The Event — 2021 Flooding

This rare Mediterranean hurricane, which originated near the Balearic Islands near Spain on October 22, 2021, impacted many Mediterranean countries, with the worst of the effects felt on the Island of Sicily, Italy. On October 24, 2021, NAS Sigonella was hit by a rare Mediterranean hurricane, resulting in 23 inches of rain falling within 48 hours (Bath 2021). This amount of rainfall was equivalent to a year’s precipitation for the region. The historic hurricane caught the installation off guard, leading to the loss of power and dozens of homes being damaged. Additionally, there was a pump failure, exacerbating the flooding and leaving roads impassible for several days. Despite receiving notifications from the Navy’s weather service about the incoming heavy rain, base officials believed they were adequately prepared but were ultimately surprised by the severity of the hurricane. They thought they were ready because of regular maintenance to the lift lumps at Marinai, routine maintenance to the



Figure 24. Flood Preparation at NAS Sigonella. NAS Sigonella personnel deployed sandbags in advance of the storm making landfall. Image accessed from: <https://www.stripes.com/branches/navy/2021-10-28/nas-sigonella-better-prepared-to-face-next-round-of-storms-3406104.html>

stormwater drainage system, and a well-crafted emergency response plan (Bath 2021).

According to the base commander Capt. Kevin Pickard “...everyone was caught off guard by the strength of the storm...” (Ziezulewicz 2021). As the rain started on the evening of October 24, 2021, it became evident that the pumps that were designed to remove floodwaters over levees and out of the Marinai complex were quickly overwhelmed (Ziezulewicz 2021). The overloading of the pumps was caused by water accumulation on both sides of the berms rendering the pump useless (Ziezulewicz 2021).



Petty Officer 2nd Class Zhijun Miao covers outside vents to prevent flooding of base housing units in preparation of a storm at Naval Air Station Sigonella, Italy, Oct. 28, 2021. Recent storms have flooded streets on base and impacted the power and drinking water supply in Sicily. (Kegan E. Kay/U.S. Navy)

Figure 25. Flood Prevention Measures at NAS Sigonella Base Housing. NAS Sigonella personnel deployed flood prevention measures to the Marinai housing units at the installation prior to the 2021 rare Mediterranean hurricane. Image accessed from: <https://www.stripes.com/branches/navy/2021-10-28/nas-sigonella-better-prepared-to-face-next-round-of-storms-3406104.html>

Event Impacts

Despite flood prevention measures being deployed before the storm, flooding was widespread and profuse. Installation managers deployed sandbags, constructed flood barriers, and installed flood prevention devices to protect on-base family housing as illustrated in Figure 24 and Figure 25 (Bath 2021). Roughly 526 Marinai houses underwent assessment after this hurricane passed, and conditions rendered the area safe (Ziezulewicz 2021). The storm flooded 67 Marinai homes, 61 of which were occupied. Roughly 100 military service members and their families were affected (Ziezulewicz 2021). The affected residents were transported to emergency housing in the area. Some homes took over two feet of water, damaging walls, appliances, and personal property (Ziezulewicz 2021).

This hurricane was much stronger than anticipated, and because of this, problems at



Figure 26. NAS Sigonella Base Housing Flooding after Rare Mediterranean Hurricane. Floodwaters inundated the Marinai housing complex because of power outages, pump failures, and floodwaters over-topping the levees. Image accessed from: https://issuu.com/nas_sigonella/docs/05nov2021/s/13998869

NAS Sigonella cascaded after the storm made landfall (Bath 2021). First, the power outages at the installation occurred. Secondly, the water pumps failed with the power out, leading to the shutdown of the water and wastewater treatment plant. After the water pumps failed that were designed to push floodwaters over the levees and out of the Marinai complex, the Marinai complex became inundated with floodwaters (Bath 2021). Figure 26 shows the extent of flooding within the Marinai housing complex after the storm had passed. Next, the power was restored within 36 hours. After the power was restored, a base-wide alert was issued stating the need to boil water until further notice. After water testing, the “boil water” alert was lifted, indicating no water system contamination occurred (Bath 2021).

Recovery Efforts

NAS Sigonella is no stranger to flooding, with records dating back to 1959 (Military Bases.US Website 2023) NAS Sigonella’s location on a low-lying, flat plain of Catania and two nearby rivers make this installations’ airfield particularly vulnerable to the rainy season (September through December) flood events (Bath 2021). For example, in 2005, floods caused power outages, installation-wide disruptions, and extensive base flooding, including sending 6 feet of water into the base’s Marinai housing complex (Sobczyk 2018). Flooding also happened in 2018 and 2020, and flooding is not unexpected for this installation (Bath 2021). Figure 27 highlights base officials’ efforts to remove the remaining flood

water for the military house complex after the power was restored.



Pumps work on removing water at Marinai housing complex at Naval Air Station Sigonella in Sicily on Saturday, Oct. 30, 2021. (Alison Bath/Stars and Stripes)

Figure 27. Flood Water Remediation at NAS Sigonella. After the power was restored to NAS Sigonella additional pumps were deployed to remove the remaining water in the Marinai housing complex. Image accessed from: <https://www.stripes.com/theaters/europe/2021-10-31/flooding-not-new-to-nas-sigonella-3438814.html>

Today, NAS Sigonella has since recovered from the 2021 flooding. NAS Sigonella 2021 flooding highlighted vulnerabilities at this installation that signal the need for further preparation and planning for future storm impacts. Cost estimates for recovery from this 2021 flooding range from \$1 to \$2 million dollars (The Signature Newsletter 2021). No other publicly available information highlighted specifics to the lessons learned from this storm.

Key Takeaways

Military installations are likely to be subject to unprecedented climate-driven events. The 2021 rare Mediterranean hurricane brought a year's precipitation for the area, catching the installation off guard and resulting in severe inundation. The flooding caused unanticipated power outages, pump failures, and damage to dozens of homes. The incident highlighted the need for proactive measures to safeguard personnel, housing, and critical facilities.

2.10 Naval Air Station Norfolk, Virginia (2022)

Primary Mission

Naval Air Station Norfolk (NAS Norfolk) is in the southeastern Virginia region and the Sewells Point area of the City of Norfolk (Commander, Navy Region Mid Atlantic 2023). The surrounding communities and NAS Norfolk are collectively known as “Hampton Roads” (Commander, Navy Region Mid Atlantic 2023). NAS Norfolk’s primary mission is to support the operational readiness of the U.S. Atlantic Fleet by providing facilities and services to enable mission accomplishment (Commander, Navy Region Mid Atlantic 2023). NAS Norfolk is committed to safety, security, and continuous improvement in quality of life and service for sailors and their families (Commander, Navy Region Mid Atlantic 2023). In the late 1990s, the U.S. Navy underwent “regionalization” to reduce operating costs and improve efficiency. NAS Norfolk and Naval Station in the Hampton Roads region formally became Naval Station Norfolk in 1999 (Encyclopedia Virginia 2023). Additionally, NAS Norfolk is the largest naval complex in the world (Commander, Navy Region Mid Atlantic 2023). This installation supports 75 ships and 134 aircraft alongside 14 piers and 11 aircraft hangers (Military Network Website 2023). This installation is the hub for Naval operations and logistics forward deploying to European and Central Command theaters and to the Caribbean (Military Network Website 2023).

NAS Norfolk is home to the Commander, Naval Air Force, U.S. Atlantic Fleet; Commander, Navy Region Mid-Atlantic; and the Defense Department’s most important supply center (My Base Guide Website 2023). This base harbors dozens of commands and tenant commands. NAS Norfolk is home to roughly 72,000 military and civilian personnel and 5,000 contractors (My Base Guide Website 2023).

The Event — 2022 Thunderstorm

On July 26, 2022, a sudden storm struck with only a 12-minute warning, catching people off guard during a personnel shift change. The storm brought high-speed winds, heavy moisture, and intense thunder and lightning. As a result, at least ten helicopters were damaged by the severe weather conditions. Figure 28 depicts the weather radar imagery from this isolated, sudden, and severe storm event.

On Tuesday afternoon, July 26, 2022, at 3:30 pm, the National Weather Service issued a se-



Figure 28. Satellite Image of Sudden Extreme Weather at NAS Norfolk. Weather radar image of the localized “downburst” or “bomb cyclone” that hit NAS Norfolk with only a 12-minute warning on July 26, 2022. Image accessed from: <https://www.foxweather.com/weather-news/norfolk-navy-station-wind-damage>

vere thunderstorm alert that accompanied a warning of high winds of more than 60mph (LaGrone 2022). Twelve minutes later, at 3:42 pm, high winds hit Chambers Field according to the damage assessment reports (LaGrone 2022). Chambers Field is the location where aircraft are stored at NAS Norfolk.

At least ten helicopters were damaged by this short-notice thunderstorm cell (LaGrone 2022) as depicted in Figure 29. Meteorologists believe this was a localized event called a “downburst” where dry air on either side of sinking cold air forces it downward, causing a thunderstorm downburst (Wulfeck 2022).

Event Impacts

This sudden storm event has critical implications for NAS Norfolk’s missions, operations, and training requirements. These include spending money to fix and rehabilitate aircraft at or near its out-of-service date and training and operation disruptions. Additionally, the Navy has been slow to develop a new airborne mine-hunting platform, and these aircraft were damaged in the storm (LaGrone 2022). Thus, leaving the Navy to fix an antiquated asset instead of investing funds into ensuring the development of the new airborne mine-hunting



Figure 29. Asset Damage at NAS Norfolk. The sudden onset thunder-cell storm resulted in severe damage to multiple helicopters at NAS Norfolk. Image accessed from: <https://news.usni.org/2022/07/27/10-navy-helicopters-suffer-major-damage-several-blown-over-in-sudden-norfolk-storm>

platform.

Recovery Efforts

Retirement of these types of helicopters is on the horizon. However, delays for their primary replacement have moved their out-of-service dates back, again and again, (Tegler 2023). This means that the aircraft damaged in the severe and sudden thunderstorm on July 26, 2022, are not scheduled for replacement. However, the Naval Safety Command has classified this unexpected weather event as a “Class A” mishap, meaning that it resulted in more than \$2.5 million in damages or the total loss of aircraft (Toropin 2022).

Key Takeaways

This incident illustrates the vulnerability of military installations to sudden and localized weather events. Extreme weather events can occur with little warning, and future climate-driven events are likely to be increasingly sudden and severe. In this case, a storm with only 12 minutes of warning significantly damaged at least ten helicopters. With many aircraft near or past their out-of-service dates, the Navy now faces the challenge of allocating funds for repairing and rehabilitating these damaged helicopters instead of investing in other operational capabilities.

2.11 Naval Air Station Key West, Florida (2022)

Primary Mission

Naval Air Station Key West (NAS Key West) is located in the Boca Chica Key in the Florida Keys; this installation (Whats At Florida Keys 2023). NAS Key West's primary mission is to enable and sustain war-fighter readiness from the shore, land, and at sea (Navy Region Southeast Commander 2023). NAS Key West national security mission supports operational and readiness requirements for the Department of Defense, Department of Homeland Security, National Guard units, federal agencies, and allied forces (Navy Region Southeast Commander 2023). NAS Key West has evolved over the years into a state-of-the-art training facility that supports training, exercises, and deployment of air-to-air combat fighter aircraft for all military services (Navy Region Southeast Commander 2023). NAS Key West is in a prime location to patrol the air and sea in the Gulf of Mexico and the Atlantic. Home to roughly 23,000 active-duty military and their families, military retirees, civilian employees, foreign dignitaries, and their families living in the surrounding community (Military One Source 2023c).

The Event — 2022 Hurricane Ian

Hurricane Ian, which originated off the coast of Africa on September 14-15, 2022, brought high winds and heavy rain to Southern Florida. Hurricane Ian, a Category 4 hurricane, made landfall on September 28, 2022, and inched its way inland, ensuing widespread flooding, property damage, and power outages across the Florida Keys (Jacobsohn 2022). The storm prompted civilian and military evacuations (Mongilio 2022). The vulnerable Florida

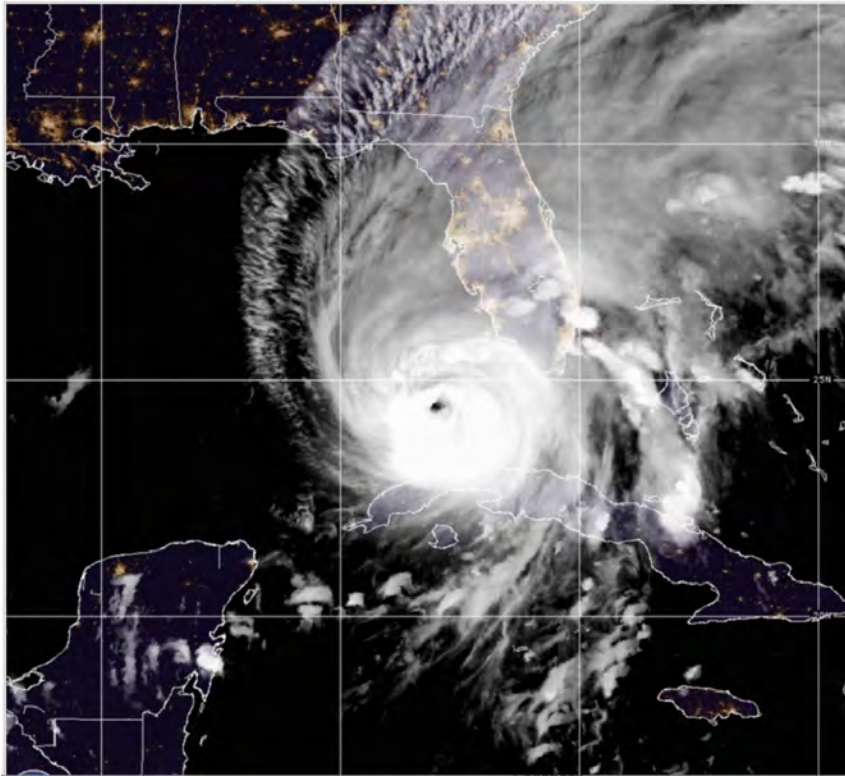


Figure 30. Satellite Image of Hurricane Ian. This figure captures the size and magnitude of Hurricane Ian as it advances toward the Florida coastline. Image accessed from: <https://news.usni.org/2022/09/28/navy-evacuates-naval-air-station-key-west-housing-due-to-hurricane-ian>

coastline was impacted by the catastrophic trifecta of high winds, heavy rain, and “higher than forecasted” storm surge (Vera 2022; Skovlund 2022). Figure 30 illustrates the size of Hurricane Ian as it approached the Florida coastline. Additionally, 5,000 National Guard Troops were activated at the same time that NAS Key West was evacuating (Dickstein 2022).

NAS Key West commanding officer, Capt. Elizabeth Regoli issued a mandatory evacuation of all military personnel and their families in the Truman Annex and Sigsbee Park housing areas after an unexpected storm surge flooded parts of this housing area (Mongilio 2022).

Event Impacts

Figure 31 depicts NAS Key West Truman Annex gate flooded in addition to the surrounding areas, including base housing and other base infrastructure (Skovlund 2022). Service mem-



Naval Air Station Key West's Truman Annex experienced heavy flooding after an estimated 6 inches to a foot of floodwaters soaked through military housing and other base infrastructure. US Navy photo by Mass Communication Specialist 2nd Class Nicholas V. Huynh.

Figure 31. NAS Key West Truman Annex Flooding. This figure highlights the flooding at the Truman Annex gate at NAS Key West which resulted in the gate closure until further notice. Image accessed from: <https://www.coffeeordie.com/ian-key-west-navy>

bers and their families were ordered to evacuate low-lying areas of on-base housing and were moved to Navy Gateway Inn and Suites (Cope 2022). Moreover, in coordination with the commanding officer and volunteers, displaced service members and their families could enjoy a hot meal all without worrying about flooding their homes and possessions (Cope 2022). Despite the evacuations, first responders evacuated an additional 61 military members and their families from base housing after Hurricane Ian passed (Skovlund 2022).

In addition to base housing and other support infrastructure on base being flooded, this installation experienced downed trees, damaged vehicles, and debris falling on homes. It washed up on shore (Wiehe 2022). The day after the storm passed, NAS Key West residents and U.S. Navy Seabees began cleaning up military housing and the surrounding areas on base (Wiehe 2022). The damage that this hurricane caused to housing at NAS Key West is seen in Figure 33.



Figure 32. NAS Key West Base Housing Units Flooding. Military family housing units at NAS Key West were also impacted by floodwaters, and military families were ordered to evacuate all low-lying areas. Image accessed from: <https://www.defense.gov/News/Releases/Release/Article/3173718/naval-air-station-key-west-evacuates-impacted-base-housing-due-to-hurricane-ian/>

Recovery Efforts

Since 1992, NAS Key West has experienced 11 hurricanes in addition to Hurricane Ian (National Weather Service 2023b), with multiple hurricanes impacting the installation in a given year (e.g., 2005 Hurricane Dennis, Katrina, and Rita; see National Weather Service 2023b). Roughly 360 facilities make up NAS Key West; almost 200 were damaged from Hurricane Irma (Navy Region Southeast Commander, Southwest Flyer, Jolene Scholl 2018). Significant repair damages include roof failure and replacement, building envelope infiltration requiring re-securing, tear out, dry out, and replacement of destroyed materials (Navy Region Southeast Commander, Southwest Flyer, Jolene Scholl 2018). Hurricane Irma cost the service 101 million dollars in repairs extending well into 2018 (Navy Region Southeast



Figure 33. Debris from Hurricane Ian and Damage to NAS Key West Base Housing. In addition to widespread flooding, the military housing units at NAS Key West were damaged by debris that became airborne during Hurricane Ian. Image accessed from: <https://www.defense.gov/News/Releases/Release/Article/3173718/naval-air-station-key-west-evacuates-impacted-base-housing-due-to-hurricane-ian/>

Commander, Southwest Flyer, Jolene Scholl 2018).

Preliminary reports state that operations, missions, and training disruptions persisted until the first assessments were complete (U.S. Department of Defense 2022). News reports since late September 2022 are non-existent. The status of the NAS Key West is unknown at this time; however, based on historic hurricane damage in Florida, it is safe to say that a degree of mission operations and capabilities were disrupted, ultimately impacting mission readiness. Additionally, the recovery cost at NAS Key West from this climate-driven disaster is unknown; however, the damage cost in Florida overall is estimated to be over \$100 billion (Mulligan and Chesnes 2023).

Key Takeaways

Military installations like NAS Key West that are located in areas prone to hurricanes already expect operational disruptions and potentially long recovery periods. Climate changes have the potential to increase the frequency and severity of such storms, raising questions about how best to prepare and recover from future storms.

2.12 Recent “Flash” Events (2022 - 2024)

There is growing evidence of short-term, intense events that can challenge operational readiness with little to no warning.

USS Harry S. Truman, Mediterranean Sea (2022)

Primary Mission

United States Ship (USS) Harry S. Truman (CVN 75) is currently home-ported at Naval Station Norfolk, Virginia (USS Harry S. Truman Foundation 2023). USS Harry S. Truman’s primary mission is to “provide a wide range of flexible mission capabilities to include maritime security operations, expeditionary power projection, forward naval presence, crisis response, sea control, deterrence, counter-terrorism, information operations and security cooperation” (Commander, Naval Air Forces Atlantic 2023). USS Harry S. Truman is the ninth nuclear-powered aircraft carrier and the eighth in the Nimitz class (Commander, Naval Air Forces Atlantic 2023). The USS Harry S. Truman was christened on September 7, 1996, (Commander, Naval Air Forces Atlantic 2023). Since then, USS Harry S. Truman has conducted eight successful deployments since 1996 (Commander, Naval Air Forces Atlantic 2023). USS Harry S. Truman, at total capacity onboard, carries approximately 90 aircraft and over 5,200 crew members (USS Harry S. Truman Foundation 2023). Figure 24 illustrates the USS Harry S. Truman with a full aircraft flight deck.

The Event — 2022 Heavy Unexpected Extreme Weather

On July 8, 2022, while the USS Harry S. Truman was operating in the Mediterranean Sea, a F/A-18 Super Hornet assigned to Carrier Air Wing (CVW) 1 blew overboard due to unexpected heavy weather (US Navy Office of Information 2022). The incident occurred while the carrier was receiving replenishment at sea. The replenishment-at-sea was safely



Figure 34. USS Harry S. Truman Aerial View. Aerial view of the USS Harry S. Truman with the positioning of her aircraft and a full flight deck. Image accessed from: <https://www.seaforces.org/usnships/cvn/CVN-75-USS-Harry-S-Truman.htm>

terminated through already-established procedures. Only one Sailor suffered minor injuries while conducting this operation and was expected to recover fully (US Navy Office of Information 2022). The after-incident report details that the carrier remains mission capable even after the incident occurred (US Navy Office of Information 2022).

On Monday, August 8, 2022, the F/A-18 Super Hornet that blew off the deck of the USS Harry S. Truman was recovered 9,500 feet under the Mediterranean Sea (LaGrone 2022). A team from the Naval Sea Systems Command’s Supervisor of Salvage and Diving (SUPSALV), recovered the aircraft using a “CURV-21 remotely operated vehicle to attach specialized rigging and lift lines to the aircraft” (LaGrone 2022). The Navy schedule the

transport of the Super Hornet jet back to the mainland U.S. (LaGrone 2022). Considering the current cost of a Boeing F/A-18 Super Hornet, which is about \$67 million, losing such an aircraft in this manner represents a significant monetary and strategic loss for the U.S. Navy.



Figure 35. Recovered Super Hornet from The Mediterranean Sea. This figure captures the Super Hornet that was recovered from the Mediterranean Sea after it blew off the flight deck of the USS Harry S. Truman. Image accessed from: <https://www.dvidshub.net/news/427886/usns-mendonca-transport-recovered-navy-f-18e-aircraft-united-states>

Event Impacts

The damage incurred by this incident included the F/A-18 Super Hornet and minor injuries to one Sailor. The Super Hornet was recovered from the Mediterranean Sea, and the aircraft's damage is unknown, see Figure 35. The Navy articulated that this incident did not cause

any disruptions to operations or missions that the USS Harry S. Truman was charged to carry out.

Recovery Efforts

A report in the Washington Post on July 12, 2022, stated that “the incident raises questions about what kind of weather could have possibly dislodged a jet that weighs more than 32,000 pounds” (Samenow 2022). Although the exact location of where the USS Harry S. Truman was located when the jet plunged into the Mediterranean Sea is unknown, storminess was reported in the area during this time frame. Hence, the Navy should have expected the “heavy, unexpected weather” (Samenow 2022). One theory or speculation is that a “microburst” (violent winds and thunderstorms) may have been responsible for thrusting the parked or in the process of being moved Super Hornet overboard (Samenow 2022). The cost to replace a F/A-18 Super Hornet is \$50 million. However, it is not public knowledge of the extent or severity of damage and associated recovery costs to the Super Hornet.

U.S. Army Garrison-Ronald Reagan Ballistic Missile Defense Test Site, Marshall Islands (2024)

Primary Mission

U.S. Army Garrison-Ronald Reagan Ballistic Missile Defense Test Site (Reagan Test Site) is located approximately 2,300 miles southwest of Hawaii and 4,300 miles away from the continental U.S. (O’Rourke, T.J. and Nelson, J. A. and Volan, J. G. 2012). The Reagan Test Site is on the Roi-Namur island, which is a part of the Kwajalein Atoll, one of 29 atolls in the Marshall Islands U.S. (O’Rourke, T.J. and Nelson, J. A. and Volan, J. G. 2012). Figure 36 illustrates an areal photo of the Reagan Test Site which is an operationally important range and test facility that has been in operation for nearly 60 years (O’Rourke, T.J. and Nelson, J. A. and Volan, J. G. 2012). The primary missions of the Reagan Test Site include testing and evaluating research and development for space and missile programs, conducting continuous space reconnaissance and surveillance operations, as well as supporting the full spectrum of programs such as Patriot, THAAD, AEGIS, and the Hypersonic Test Vehicle as a key element of the Pacific Range (U.S. Army Space and Missile Defense Command

2023). Reagan Test Site, a U.S. Strategic Command, is critical for research, development, and test and evaluation for America’s defense and space programs - making this installation vital to U.S. military force posture worldwide (O’Rourke, T.J. and Nelson, J. A. and Volan, J. G. 2012).



Figure 36. Reagan Test Site Aerial View. Aerial view of the Reagan Test Site with a full view of the island’s runway. Image accessed from: <https://thediplomat.com/2022/02/the-us-is-squandering-its-cofa-advantage-in-the-pacific/>

The Event - Series of Rouge Waves

Hours before, the National Weather Service in Guam issued a High Surf Warning, signaling that dangerously large breaking waves of 10-15 feet could impact the Marshall Islands from Saturday, January 20, 2024, through Sunday, January 25, 2024 (Oberholtz, Chris 2024a). By Saturday night, a series of massive rogue waves flooded most of the Kwajalein Atoll, including critical facilities at the Reagan Test Site (Oberholtz, Chris 2024a). The residual effects of this extreme weather event left most of the island inundated in floodwaters for several days.

Eighty of the approximately 120 personnel living on the base were evacuated, and all other residents on the island were relocated to Kwajalein Atoll until services were restored (Lendon, Brad 2024). Officials say no one was killed, and only one person was injured (Oberholtz, Chris 2024a). Figure 37 shows U.S. Army Garrison – Kwajalein Atoll Commander Col. Drew Morgan, center right, welcoming Roi-Namur evacuees to Kwajalein Island on January 21, 2024 (Lendon, Brad 2024). Roi-Namur is a four-hour boat trip from

Kwajalein (Lendon, Brad 2024). As of this writing, services have not been restored to Roi-Namur or Reagan Test Site.



Figure 37. Reagan Test Site Evacuation. U.S. Army Garrison – Kwajalein Atoll Commander Col. Drew Morgan, center right, welcoming Roi-Namur evacuees to Kwajalein Island on January 21, 2024. Image accessed from: <https://www.foxweather.com/extreme-weather/video-rouge-waves-us-military-roi-namur-marshall-islands>

Reagan Test Site experienced installation-wide impacts from this extreme weather event. Initial assessments of facilities rendered many buildings and assets damaged, including the Café Roi dining facility was heavily flooded in the storm, storage containers were tossed across Roi-Namur by the storm surge that housed essential materials, the Machine Maintenance Shop on Roi-Namur was flooded and rendered inoperable, and the runway was deemed unusable from flooding and debris (Lendon, Brad 2024; Oberholtz, Chris 2024a). Figure 38 depicts the flood damage to the Café Roi.

Recovery Efforts

Following this unprecedented weather event, the Reagan Test Site is currently grappling with significant challenges in its post-disaster recovery efforts. The focus is primarily on the swift restoration of the Roi-Namur runway, a critical step in facilitating the overall recovery process. Col. Drew Morgan, USAG–KA Garrison commander said “Clearing the runway on Roi-Namur and assessing its safety is our top priority now that we have evacuated



Figure 38. Café Roi at Reagan Test Site. Destruction caused by flooding at Café Roi at the Reagan Test Site. Image accessed from: <https://www.foxweather.com/extreme-weather/video-rouge-waves-us-military-roi-namur-marshall-islands>

personnel not required for the initial response efforts” and “once the runway is open, we can move people and equipment back and forth to start the recovery process” (Oberholtz, Chris 2024b). The complex array of logistical challenges arises from the site’s remote location and its indispensable role in advancing national defense research and development initiatives.

Careful planning is now required to restore operational efficiency and strengthen the facility’s ongoing contribution to enhancing the strategic posture of the U.S. military on a global scale.

Key Takeaways

These recent "flash" events illustrate the vulnerability of military operations to short-term, intense events that pose challenges to operational readiness with minimal warning. This event highlights the need for enhanced weather monitoring and preparedness measures to mitigate the risks associated with sudden and severe weather conditions.

3 Discussion

The vignettes in this report demonstrate several key points for the challenges facing military installations related to weather extremes and climate change, both now and in the future.

3.1 Immediate Implications

Many folks think climate change is a distant threat, but it is happening now. A systematic investigation of extreme weather events reveals a pattern that suggests climate change may already be impinging on U.S. military installations. Extreme weather events are causing costly problems, both in terms of disrupted operations and repairs. As summarized in Table 1, the direct costs associated with these incidents range from millions to potentially billions of dollars. The apparent increase in the frequency and intensity of these events suggests that future costs could be even higher.

Concern for military operations and readiness is often focused on military infrastructure, but the consequences of these events often depend on infrastructure outside the fence line. These events illustrate the dependencies of military installations on surrounding civilian infrastructure, including gas, power, water, and transportation routes. These dependencies are often revealed during or after an incident as hidden vulnerabilities in our military infrastructure that reside in the civilian world.

Because climate-driven disasters occur both inside and outside the fence line, there may be limits for installation commanders on the possible safeguards and controls against these vulnerabilities. However, there may be opportunities to increase resilience to climate-related hazard events through community-wide or regional climate resilience efforts.

These events provide differing levels of advanced warning that complicate preparedness and response activities for installation personnel. Table 4 shows that the amount of advanced warning can vary, and in some cases, operators might have little to no time to prepare. These events can last from days to weeks, and perhaps more importantly, the recovery from these types of events can persist from weeks to years.

Installation	Advanced Warning	Event Duration	Recovery Length
Keesler Air Force Base	Days	Hours	Years
Marine Corps Base Camp Pendleton	Minutes	Hours	Weeks to Years
U.S. Army Garrison Fort Wainwright	Minutes	Months	Weeks to Years
U.S. Army Garrison Fort Liberty	Weeks	Days	Years
Tyndall Air Force Base	Days	Hours	Years
Naval Base Ventura County	Minutes	Week	Years
Offutt Air Force Base	Days	Weeks	Years
U.S. Army Garrison Fort Hood	Days	Week	Weeks
Naval Air Station Sigonella	Days	Days	Months
Naval Air Station Norfolk	Minutes	Hours	N/A
Naval Air Station Key West	Days	Days	Years
Flash Events	Minutes	Hours	Weeks to Years

Table 4. Advanced warning, event duration, and recovery length for the disaster events detailed in this study.

It is tempting to think that better forecasting will prevent the catastrophic consequences of these events, but the future is not going to be like the past. Forecasts will be imperfect, and warnings are likely to be incomplete or unavailable. Hazards with traditionally seasonal activity (e.g., increased hurricane activity during the summer) can perhaps be anticipated; however, changes in climate are now creating higher risk during times outside of normal periods. This complicates the ability to anticipate potential events and clouds the signals associated with early warning. Moreover, there is growing evidence to suggest that when it comes to climate-driven events and infrastructure, *surprise is inevitable* (Alderson et al. 2022). The bottom line is that installation emergency response plans will always be limited, and installations must learn how to prepare for surprise events.

Complete understanding of these events and their effects is often possible only in hindsight. It is tempting to say that the ability to adapt and effectively respond to climate-driven disasters requires installation managers to understand the complexity of these events. However, the consequences of these disruptive events are highly interconnected to other systems at the installation and in the community. These events tend to have considerable

uncertainty in the moment, with "the fog of war" being an apt description for the way in which the real uncertainties, tensions, and demands faced at the time of the incident are much greater than when analyzed after the fact (Woods et al. 2010). Moreover, the dynamic nature of these systems means that any mental model for understanding how these systems interact is bound to become outdated and stale over time (Woods 2018b).

These disruptive events exacerbate existing tensions related to the allocation of limited resources on installations. Climate-driven disasters have not only strained the U.S. military's resources but have also triggered a diversion of funding away from critical areas such as equipment modernization, personnel training, and technological advancements geared toward enhancing national defense capabilities. At the same time, immediate needs for preventive maintenance or repairs in aging infrastructure are often sidelined for investments in operational readiness, exacerbating the potential for disruptive events. The financial toll of repairing and fortifying military bases post-disaster often leads to a reallocation of funds initially earmarked for essential maintenance, upgrades, or new developments. This diversion of funds creates a trade-off between addressing immediate infrastructure damage caused by climate-related events and ensuring ongoing preparedness for potential conflicts or warfighting capabilities. As these climate-related events become more frequent and severe, the strain on military funding has the potential to jeopardize our ability to maintain readiness for potential conflicts or security threats.

The tension between efficiency and flexibility remains a persistent challenge in our use of resources. Bureaucratic expectations to allocate budgeted resources efficiently ahead of time also make it very difficult to hold funds in reserve for dealing with surprises. Yet these extreme events call upon the use of emergency and/or reserve resources. Despite a long history of dealing with emergencies, there has been limited success in incorporating these types of contingent budget mechanisms into this fight.

3.2 Future Considerations

The vignettes in this report support the idea that we need to rethink how we make our installations more resilient in the presence of extreme weather and climate-driven disruptions.

The ability to respond to climate-driven events depends on what we can do, not what we have. Having resources is not enough if we are unable to put them into action when the time comes. This is consistent with the notion that resilience should be thought of as a verb (Woods 2018a). It also challenges the way we think about how we invest our limited resources.

We should be investing in our adaptive capacity—the capacity to adapt to challenges ahead, when the exact challenge to be handled cannot be specified completely in advance. Climate-driven extreme weather events are only one of the many challenges facing our military installations. Our infrastructures and installations must also deal with (1) growing system complexity, stimulated by new technologies and opportunities; (2) new conflicts and threats, as others ‘hijack’ capabilities for their own purposes; and (3) changes in tempos of activity at each installation and across the entire military (Woods and Alderson 2021). This capacity needs to be practiced to be effective. One way to do this is to conduct exercises that rehearse how systems and people respond to adverse conditions. For example, “black start” exercises that shut off power to installations reveal gaps between what an installation thinks it has in terms of resilience and what it can actually do (Poulin et al. 2020).

If surprise is inevitable, how we respond could be as important as how we prepare. Resilience is more than being able to withstand disruptive events (i.e., *robustness*), and it is more than being able to recover function quickly (i.e., *rebound*); it needs to be about how to reconfigure our systems to *extend* functionality to support our missions, as well as how we continue to *adapt* our systems over time (Woods 2015). Continual efforts are required to create innovative training programs and exercises to “improve the capacity of infrastructure managers to sense, anticipate, adapt to, and learn from surprise” (Alderson et al. 2022).

4 Conclusion

This study extends the preliminary scholarship on climate-driven disasters and their associated impacts on critical military infrastructure. The twelve vignettes in this study highlight the current vulnerabilities faced by the U.S. military at its installations.

However, this list of stories is growing—extreme weather and climate-driven events are occurring more often with unexpected consequences. As a result, we expect the DoD will experience new and emerging impacts on installations, with some events potentially happening multiple times a year.

The question becomes: *can we improve the way our installations sense, anticipate, adapt, and learn from these events so the impacts on our operations are minimized?* We need to accelerate ongoing efforts that explore how to do this if we are to keep pace with the changes that are already taking place.

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