

The US Military on the Front Lines of Rising Seas

Growing Exposure to Coastal Flooding at East and Gulf Coast Military Bases

HIGHLIGHTS

The US Armed Forces depend on safe and functional bases to carry out their stated mission: to provide the military forces needed to deter war and to protect the security of the country.

The US military and defense budget in fiscal year 2015 was just under \$500 billion. Of that total, about one-third was earmarked for the maintenance and operation of bases, many of which are in the United States.

Given growing exposure to rising seas and storm surge, this analysis finds, the military is at risk of losing land where vital infrastructure, training and testing grounds, and housing for thousands of its personnel currently exist.

The Department of Defense (DOD) maintains more than 1,200 military installations in the United States—sites where the military tests weaponry, conducts training exercises, builds and launches ships, compiles intelligence, develops new technology, and houses critical military commands (Hall et al. 2016). Many of these sites are also where officers, enlisted men and women, and their families live.

Given their central role in national security, such installations have historically been well protected. But sea level rise, increased tidal flooding, and heightened storm surges do not stop for checkpoints. These climate-driven trends are already complicating operations at certain coastal installations (NAS 2011). A roughly three-foot increase in sea level would threaten 128 coastal DOD installations in the United States (43 percent of which are naval installations, valued at roughly \$100 billion) and the livelihoods of the people—both military personnel and civilians—who depend on them (NAS 2011).

To enable decision makers to better understand these threats, how they may unfold this century, and where and when they could become acute, the Union of Concerned Scientists (UCS) has performed a new analysis of 18 military installations along the East and Gulf coasts. We selected these sites for their strategic importance to the armed forces, for their potential exposure to the effects of sea level rise, and because they represent coastal installations nationwide in terms of size, geographic distribution, and service branch. By analyzing their changing



Ships docked in 2013 at Naval Station Norfolk. The largest naval base in the world and home to the US Fleet Forces Command, NS Norfolk, like most of the military bases analyzed here, faces steeply rising flood risks. Here, water levels could rise 4.5 to nearly 7 feet this century, depending on the pace of ice sheet loss.

exposure to different flood types in the absence of preventive measures over the next 100 years, UCS found that these sites are at risk for:¹

- more frequent and extensive tidal flooding;
- land loss as some installation areas are permanently inundated and others flood with daily high tides; and
- deeper and more extensive flooding due to storm surge.

Sea level rise already affects many of the areas studied, with tidal flooding that can shut down roads and damage infrastructure (Spanger-Siegfried, Fitzpatrick, and Dahl 2014; Sweet et al. 2014). UCS found that all but two of the installations studied could flood 100 times each year by midcentury with a moderate rate of sea level rise. By the end of this century, nine installations could lose one-quarter or more of their land area, including currently utilized areas, with a moderate rate of increase and half of their land or more with a faster rate. In that faster-rate scenario, four military installations would lose between 75 and 95 percent of their land area this century. These results point to the need for detailed analysis that can guide site-specific planning.

Two Striking Scenarios for Sea Level Rise

UCS analyzed exposure of each installation’s land areas to tidal flooding, land loss, and storm surge (see Box 1).²

The analysis used two scenarios of sea level rise, developed for the 2014 National Climate Assessment (Parris et al. 2012):

- **Intermediate-high (referred to here as “intermediate”)**—Assumes a moderate rate of ice sheet melt that increases over time and projects an ultimate rise of 3.7 feet above 2012 levels, globally, by the end of this century.
- **Highest**—Assumes more rapid ice sheet loss and projects an ultimate rise of 6.3 feet above 2012 levels, globally, by the end of this century. The highest scenario is especially useful when making decisions with a low tolerance for risk. Moreover, recent studies suggest that ice sheet loss is accelerating and that future dynamics and instability could contribute significantly to sea level rise this century (DeConato and Pollard 2016; Trusel et al. 2015; Chen et al. 2013; Rignot et al. 2011)

The Front Lines of Sea Level Rise

RISING SEAS...

As global temperatures increase, land-based ice melts into the oceans, and seawater expands as it absorbs more heat from the warming atmosphere. Global sea level has risen about eight inches since 1880; while this affects all of the world’s coasts, the East and Gulf coasts of the United States have seen

some of the fastest rates of sea level rise (NOAA 2013; Sallenger, Doran, and Howd 2012; Church and White 2011). Seas rise faster on these coasts for several reasons, including subsidence (the sinking of land) in some of these coastal areas and ocean currents, which are changing along the East Coast in response to North Atlantic warming (Ezer et al. 2013; Yin, Schlesinger, and Stouffer 2009; Milliken, Anderson, and Rodriguez 2008). In the coming decades, the pace of sea level rise is expected to reach levels not seen in more than 100,000 years (Dutton and Lambeck 2012).

FIGURE 1. Bases Studied Span the East and Gulf Coasts



Rising seas present a host of risks—including daily high tide flooding of land and infrastructure, permanent land loss, and destructive storm surges—to the 18 installations analyzed in this study.

BOX 1.

Tidal Inundation and Land Loss: A Closer Look

US military installations, like the country’s heavily built-up coastlines, have been developed out of the reach of high tide. But how will they be affected as high tide reaches higher?

The tides rise and fall twice daily along the East Coast and once daily along the Gulf Coast, inundating and then exposing an area known as the tidal zone. Twice a month (during new and full moons), Earth, sun, and moon align. The combined gravitational pull of the sun and moon during these times exerts a greater force on Earth’s oceans, and high tides become slightly higher than normal and low tides slightly lower. These tides are often called spring tides. Several times a year, during a new or full moon when the moon is closest to Earth, the range of the tides is even greater. These are sometimes called king tides or perigean spring tides. This analysis refers to both spring and king tides as extreme tides. Unlike daily tides, extreme tides can cause coastal flooding.

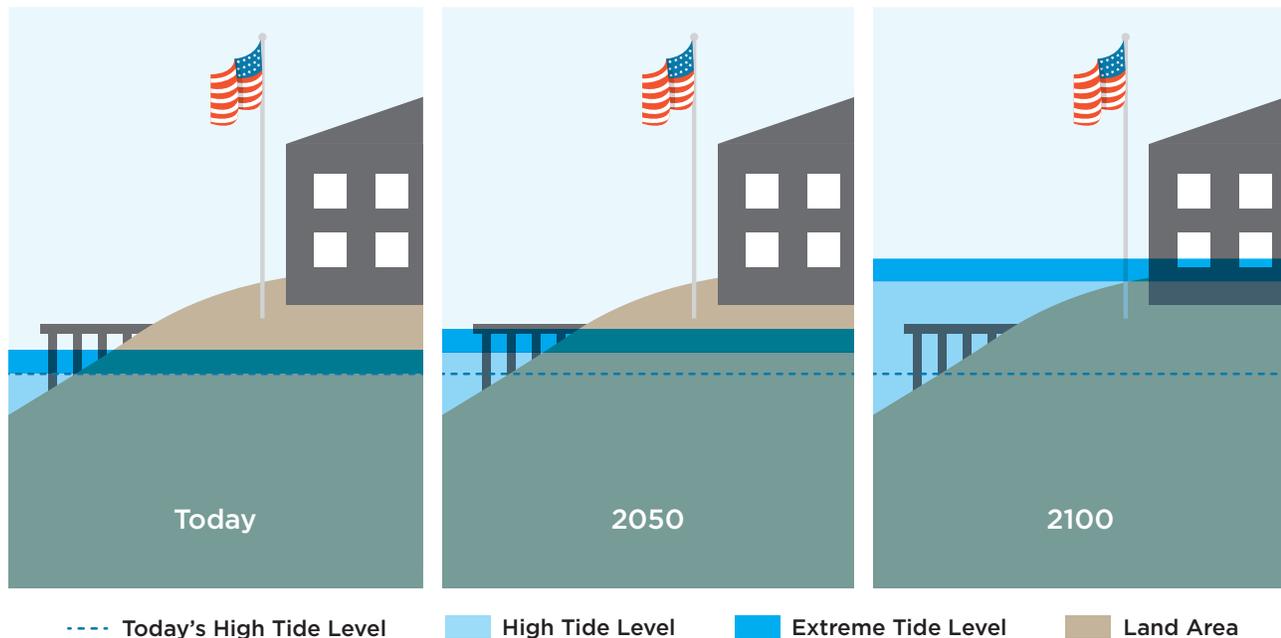
As sea level rises, adding vertical height, and, thus, lateral reach to high tide, local flood conditions can be reached more often, to a greater extent, and for longer time periods when extreme tides occur (Ezer and Atkinson 2014; Church et al.

2013). Indeed, tidal flooding events—which can lead to impassable roads; flooded residential, industrial, and commercial areas; and damaged facilities, automobiles, and other machinery—have increased fourfold in some East Coast cities since 1970, just 45 years (Sweet et al. 2014). In just the next 35 years, they are projected to increase 10-fold in the intermediate scenario in many locations (Spanger-Siegfried, Fitzpatrick, and Dahl 2014).

And as sea level rises further, the daily high tide line will begin to encompass new areas, shifting the tidal zone onto presently utilized land. To understand better how sea level rise can affect coastal military locations, this analysis explores three questions:

- Tidal flooding frequency: What happens later this century in currently flood-prone, low-lying areas?³
- Tidal flooding extent: When and where does high tide reach beyond historically flood-prone spots to inundate new areas?⁴
- Land loss: When and where is some land effectively ceded to the sea by virtue of daily high-tide inundation?⁵

FIGURE 2. How Sea Level Rise Causes Tidal Flooding and Land Loss



As sea level rises, local flood conditions can happen more often, to a greater extent, and for longer time periods when extreme tides occur. And the daily high tide line can eventually begin to encompass new areas, shifting presently utilized land to the tidal zone. In this analysis, land inundated by at least one high tide each day is considered a loss. This is a conservative metric: in reality, far less frequent flooding would likely lead to land being considered unusable.

...PLUS TIDAL FLOODING...

Today, extra-high tides, strong winds, or a storm system are typically required for coastal flooding to become a problem. But sea level rise is changing that. In the near future, higher seas will mean that periodic extreme tides can reach farther inland and daily high tides can begin to claim low-lying land. (see Box 1, p. 3). With this trend, tidal flooding that is now considered an occasional nuisance will increasingly worsen and alter the map of usable land in coastal military installations, redefining how and where those installations operate.

...AND PERIODIC STORMS

Winds from hurricanes and other storms push ocean water toward the coast over a long expanse: the elevated water level that then hits the shore is known as storm surge. Storm surge can affect large sections of the coast as well as inland areas. With higher sea levels, storm surges will reach farther inland and subject coastal areas to deeper flooding.

A Flooded Future

Many of the bases analyzed face substantial flood risks today, and many are taking action. Langley Air Force Base (AFB), for example, partnered with the National Aeronautic and Space Administration's (NASA) Langley Research Center to develop a high-resolution flood risk mapping tool. It has subsequently implemented multiple flood risk mitigation measures, installing flood barriers at susceptible base entrances, raising electrical equipment, developing a living shoreline, and installing a flood storage and pump system (Rios 2016). Whether these important steps are sufficient to manage future flood risks, though, is unclear.

Each of the 18 military installations we analyzed faces substantially increased risks if effective steps are not taken to reduce the growing exposure to flooding. By the end of this century, most installations can expect a large increase in the frequency of tidal flooding, storm surges that cover greater areas at increased depth, and loss of utilized land area to the sea.

TIDAL FLOODING

Some of the installations analyzed are located in areas where tidal floods currently occur just twice each year or less. Others, like Portsmouth Naval Shipyard in Maine, see little tidal flooding on site today, but flood-prone areas in surrounding communities see multiple flood events each year. Still others, such as the US Naval Academy in Annapolis, Maryland, experience tidal flood events, sometimes many, on site each year. Some of this flooding is disruptive, some isolated and a mere nuisance (Spanger-Siegfried, Fitzpatrick, and Dahl 2014).

Tidal flooding frequency rises steeply as sea levels rise: in the intermediate scenario, the median number of floods per year for all 18 installations jumps from 10 today to roughly

260 in 2050. By 2070, the median rises to about 480 floods per year. And by 2100, low-lying areas in and around most sites begin to experience tidal flooding across multiple high tide cycles, leading to fewer but longer-lasting floods—that is, these areas would be underwater much of the time.

In the highest scenario, changes are starker: by 2050, flood-prone places would experience a median of roughly 370 floods per year—the equivalent of one tidal flood every day. By 2070, the median will rise to roughly 560 per year. And by 2100, more than half of the sites analyzed would see constant flood conditions in currently flood-prone areas—that is, these areas would be underwater at all times.

EXTRA-HIGH TIDES; EXTENSIVE FLOODING

A median of just 8 percent of the area of each installation we analyzed floods during extra-high tides today. As sea level rises, that area increases. In the highest scenario, a median of 12 percent of the installations' land area is exposed to this tidal flooding by 2050, 17 percent by 2070, and just under 60 percent by 2100. In the same scenario, eight of the nine installations analyzed in the mid-Atlantic states would see 30 percent or more of their area exposed to tidal flooding by 2100.

LAND LOSS

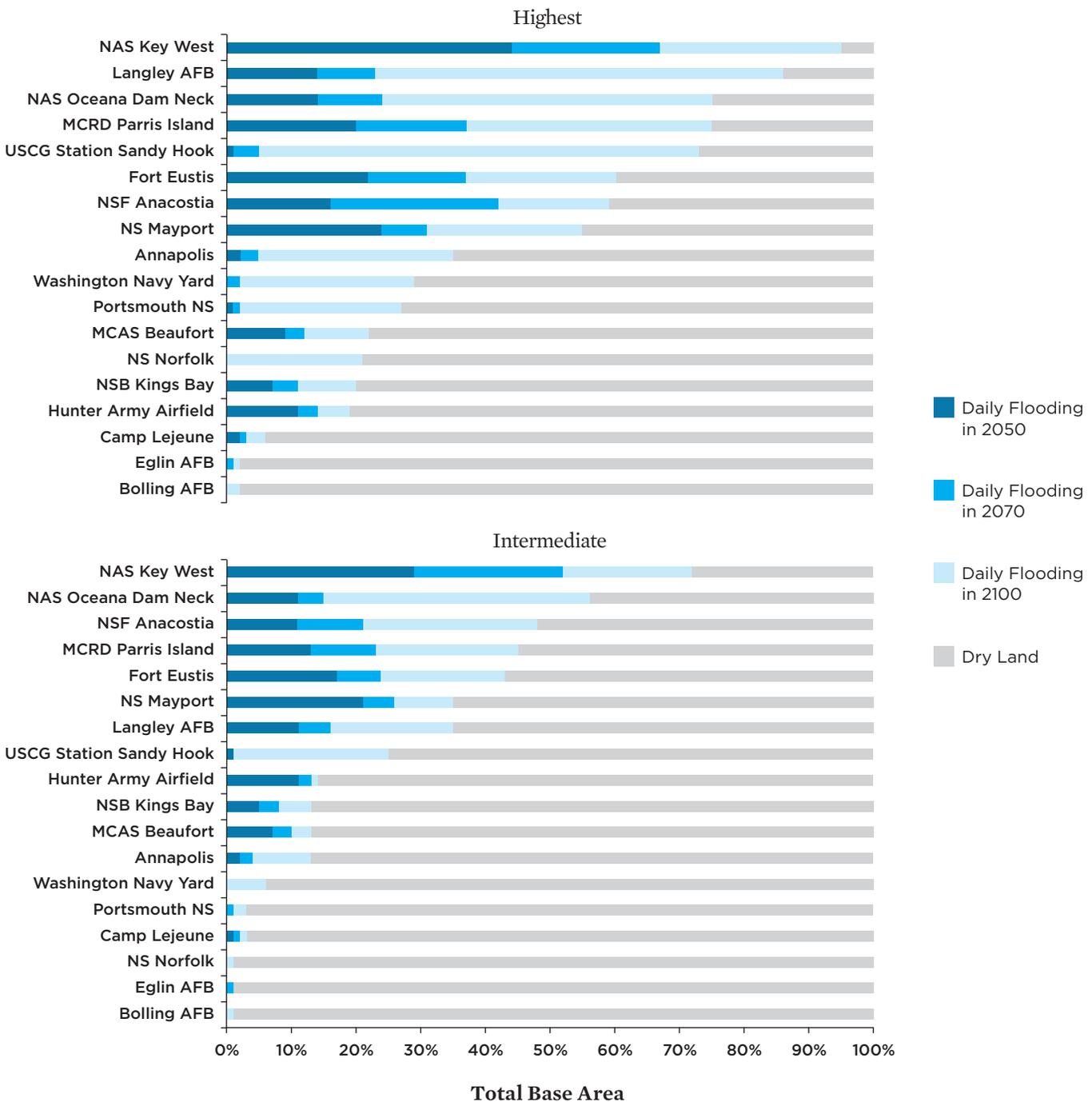
In this analysis, land that is inundated by at least one high tide each day is considered a loss. This is a conservative metric: in reality, far less frequent flooding would lead to land being considered unusable.

Nearly half of these 18 military installations could see substantial land loss as lowest-lying areas are subjected to permanent inundation (underwater even at low tide) and new areas flood with daily high tides. By 2050, in just 35 years, three installations in Florida and Virginia are projected to lose more than 15 percent of their land area to the sea according to the intermediate scenario. By 2100, nearly half of the sites studied lose 25 percent or more of their land area in the intermediate scenario and 50 percent or more in the highest scenario. The most severely affected installations are Naval Air Station (NAS) Key West in Florida, Joint Base Langley-Eustis and NAS Oceana Dam Neck in Virginia, and Marine Corps Recruit Depot (MCRD) on Parris Island in South Carolina. These installations lose between 75 and 95 percent of their land area, including utilized land and developed areas, by the end of the century in the highest scenario.⁶

STORM SURGES

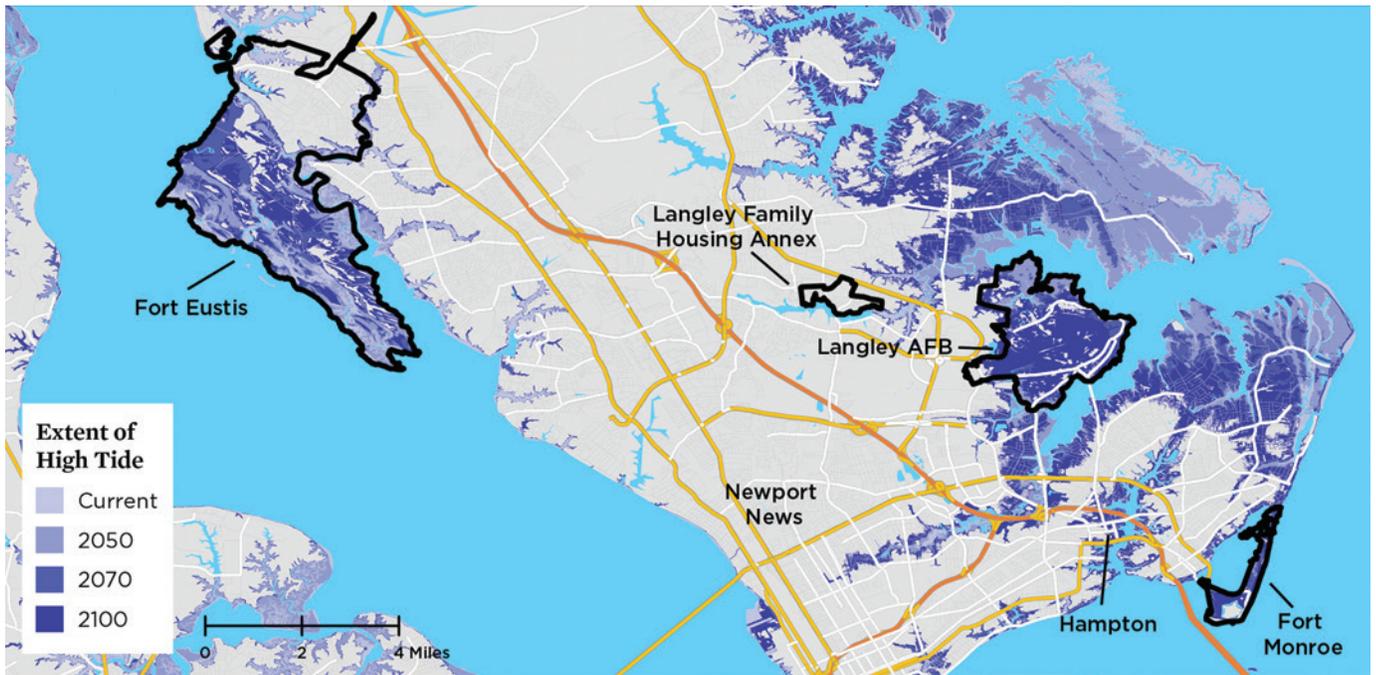
For many military installations, the effects of a low-category storm in 2070 or 2100 would be closer to the effects of a higher-category storm today. For example, in the intermediate scenario, the area exposed to storm surge flooding by a

FIGURE 3. Land Loss across Bases



As high tide reaches farther inland, significant land loss is possible, in both the intermediate and highest scenarios, at many of the installations analyzed. Dark blue represents the percentage of total base area that floods with daily high tides in 2050; such land is conservatively considered a loss in this analysis. Medium blue represents the additional area that is inundated with high tide by 2070; light blue represents additional area inundated by 2100. Gray represents the percentage of the total base area that remains above the high tide line at the end of the century. Affected land can include developed and undeveloped areas and even wetlands that reside above the current high tide mark. This analysis finds that installations projected to see major land loss will also see substantial loss of currently developed and utilized areas.

FIGURE 4. The Reach of Future Daily High Tides at JB Langley-Eustis



JB Langley-Eustis is just one of the 18 coastal military sites studied for this report. The future high tide line, shown in the top panel, encompasses currently utilized land at Langley AFB, shown in the bottom panel. The highest scenario is mapped here.

SOURCE: GOOGLE EARTH.

BOX 2.

The Local Human Context

The effects of coastal flooding at military installations are likely to reverberate far beyond their boundaries. Indeed, given the mutual dependencies between installations and surrounding communities, their sea level rise risks are closely intertwined. Unpassable roads in Norfolk and stalled public transportation, for example, can complicate travel to and from Naval Station (NS) Norfolk and compromise operations (VIMS 2013). Flooding of local neighborhoods can adversely affect the homes of military personnel, their families, and social networks. And changes in operations and capacity at military bases can hurt the local economy (Lee 2014).

The communities and regions surrounding these 18 military installations vary widely in their demographic and socioeconomic makeup, and by extension, their vulnerability to climate change (US Census Bureau 2014). Socioeconomic risk factors, such as the poverty rate and the minority population percentage, are among several indicators that can help to predict a population's vulnerability to, or "propensity or predisposition to be adversely affected" by, climate stressors as well as its ability to recover in the wake of an event (Cleatus, Bueno, and Dahl 2015; Task Force on Global Climate Change 2015; IPCC 2014). Low-income people are more likely, for example, to be overlooked during emergency response

following disasters (Fothergill and Peek 2004). Minorities can be more vulnerable to climate stressors due to factors such as poor housing quality, community isolation, and cultural barriers (US Census Bureau 2014; Fothergill, Maestas, and Darlington 1999). And while coping with flood disasters is challenging for all communities, those that have multiple stressors often struggle more with recovery (Miller, Hesed, and Paolisso 2015).

Communities around Hunter AFB, Langley AFB, Bolling AFB, Washington Navy Yard, MCRD Parris Island, and NS Norfolk have large percentages of African American and Latino residents as well as relatively high poverty rates. Given these factors, these communities could be more adversely affected by flooding, with potential reverberations for the installations themselves. By contrast, communities surrounding Portsmouth, US Coast Guard Station Sandy Hook, and Oceana NAS Dam Neck Annex have lower socioeconomic risk factors and may be less vulnerable in flood events.

Robust, durable preparedness and adaptation efforts will require close collaboration between the military and surrounding cities and towns, such as the current collaboration between the Navy and the city of Norfolk (100 Resilient Cities 2016).

Category 1 storm in 2100 is equivalent to the area exposed during a Category 2 storm today for nearly 80 percent of the installations analyzed. Half of the sites see Category 2 storm surges shift to Category 3 storm equivalents by the end of the century in the same scenario. In the highest scenario, more than half of the bases would see storm surge from a Category 1 storm in 2070 become equivalent to that produced by a Category 2 storm today.

Planning for Rising Seas

A vital trait of our nation's military is its ability to adapt in response to external threats. Climate change and sea level rise have emerged as key threats of the 21st century, and our military is beginning to respond (Hall et al. 2016; USACE 2015; DOD 2014). Efforts have accelerated over the last five years as the Obama administration rolled out a series of preparatory policies and the military initiated its own sea level rise studies and planning processes (Hall et al. 2016; The White House 2015a; The White House 2015b; USACE 2015; DOD 2014; DHS 2013; The White House 2013; DHS 2011).⁷

But there is far to go: the gap between the military's current sea level rise preparedness and the threats outlined

here is large and growing. Low-lying federal land inundated by rising seas, daily high-tide flooding of more elevated land and infrastructure, and destructive storm surges—most of the installations analyzed face all of these risks, some to extreme degrees.

In order to plan effectively for the long term, military decision makers with authority over these bases need to understand how sea level rise may permanently alter the landscape of coastal installations and where the threat of storm surge may become intolerable.

This analysis provides snapshots of potential future exposure to flooding. To take action on the front line of sea level rise, however, individual installations will need more detailed analysis and resources to implement solutions. Congress and the DOD should, for example, support the development and distribution of high-resolution hurricane and coastal flooding models; adequately fund data monitoring systems such as our nation's tide gauge network; allocate human, financial, and data resources to detailed mapping and planning efforts at military installations; and, as adaptive measures are identified, allocate resources for these projects, many of which will stretch over decades. Given that rising seas will affect

Mid-Atlantic Installations under Threat

Because of the low elevation and land subsidence in the mid-Atlantic states (New Jersey through Virginia) and the faster rate of sea level rise on the East Coast, military installations in this region must adapt to increased flooding and the risk of land loss sooner than most others. Many of the military installations in this area are of crucial importance to the armed forces: NS Norfolk (Virginia), the largest naval base in the world and home to the US Fleet Forces Command; the US Naval Academy (Maryland), one of the highest-ranked public colleges in the country and a National Historic Landmark; and Joint Base Anacostia-Bolling (Washington, DC), home to the Defense Intelligence Agency.

By 2050, four of the nine coastal mid-Atlantic installations evaluated would lose 10 percent or more of their land area in either scenario.

By 2050, the currently flood-prone areas at most of these sites would flood 260 or more times each year in the intermediate scenario and 470 or more times each year in the highest scenario.

As early as 2070, the number of distinct floods per year would begin to decline in flood-prone places as flood conditions persist across multiple tide cycles and multiple days—that is, these areas simply become part of the sea.

transportation systems, housing, and critical infrastructure both on and off bases, installations will need to engage in regional planning processes that connect with those of surrounding communities, and the federal government should mobilize resources for these processes and for state and local adaptation projects. Well-prepared bases will remain vulnerable if surrounded by unprepared communities.

Military bases and personnel protect the country, often providing rescue services in dangerous floods and other natural disasters. With rising seas, they find themselves on an unanticipated front line. Our defense leadership has a special responsibility to protect the sites that hundreds of thousands of Americans depend on for their livelihoods and millions depend on for national security.

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ENDNOTES

- 1 In some locations, preventive measures may be planned or in place that are not reflected in the analysis; these could affect the degree of current and future flooding.
- 2 The localized sea level rise projections this analysis uses reflect regional factors such as land subsidence. Storm surge extent and depth were assessed using the Sea, Lake, and Overland Surges from Hurricane (SLOSH) model, developed by the National Oceanic and Atmospheric Administration (NOAA), for storm events ranging in severity from Category 1 to Category 5. For more information, see www.ucsusa.org/MilitarySeasRising.
- 3 The frequency of tidal flooding was assessed using water level data from the nearest available tide gauges maintained by NOAA.
- 4 Tidal flooding extent was examined using a spatial analysis of the area of each base that lies below a water level threshold associated with the onset of coastal flooding now and with additional sea level rise.

- 5 Permanent inundation (inundation at all times) and land loss (inundation during a daily high tide) were examined by mapping the present and future extent of the mean higher high water level and determining the percentage of each base that lies below that level now and in the future. For more information, see www.ucsusa.org/MilitarySeasRising.
- 6 It is important to note that the type of land affected varies by base and can include developed and undeveloped areas and even wetlands that reside above the current high water mark. For reasons such as this, additional detailed analysis is needed at each installation. The most severely affected sites would each see substantial loss of currently developed areas. See site specific reports for more information see www.ucsusa.org/MilitarySeasRising.
- 7 These include the Presidential Policy Directive National Preparedness (PPD 8) in 2011, the Presidential Policy Directive on Critical Infrastructure Security and Resilience (PPD 21) in 2013, the DOD Climate Change Adaptation Roadmap in 2014, and the Executive Order on Preparing the United States for the Impacts of Climate Change (EO 13653) and Executive Order—Planning for Federal Sustainability in the Next Decade (EO 13693) in 2015.

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