Union of Concerned Scientists

EXECUTIVE SUMMARY

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

US Navy

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 (DeConto 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?

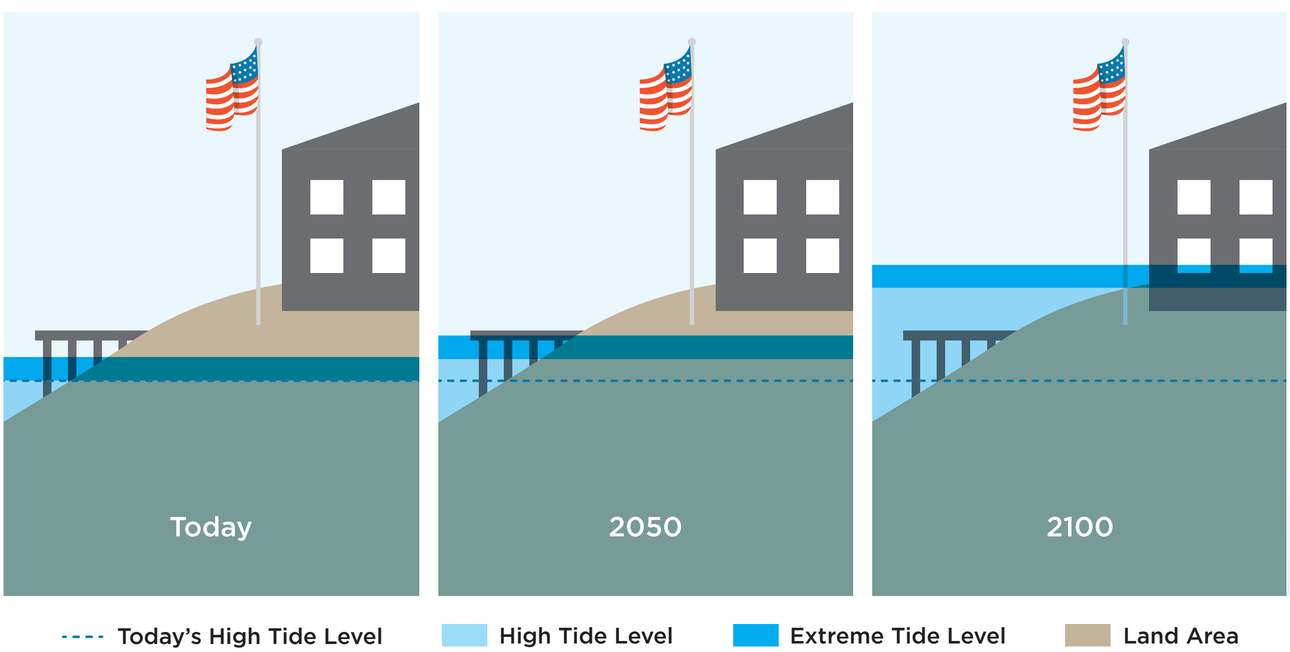
The tides rise and fall twice daily along the East Coast and once daily along the Gulf Coast, inundating and then exposing an area known as the tidal zone. Twice a month (during new and full moons), Earth, sun, and moon align. The combined gravitational pull of the sun and moon during these times exerts 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

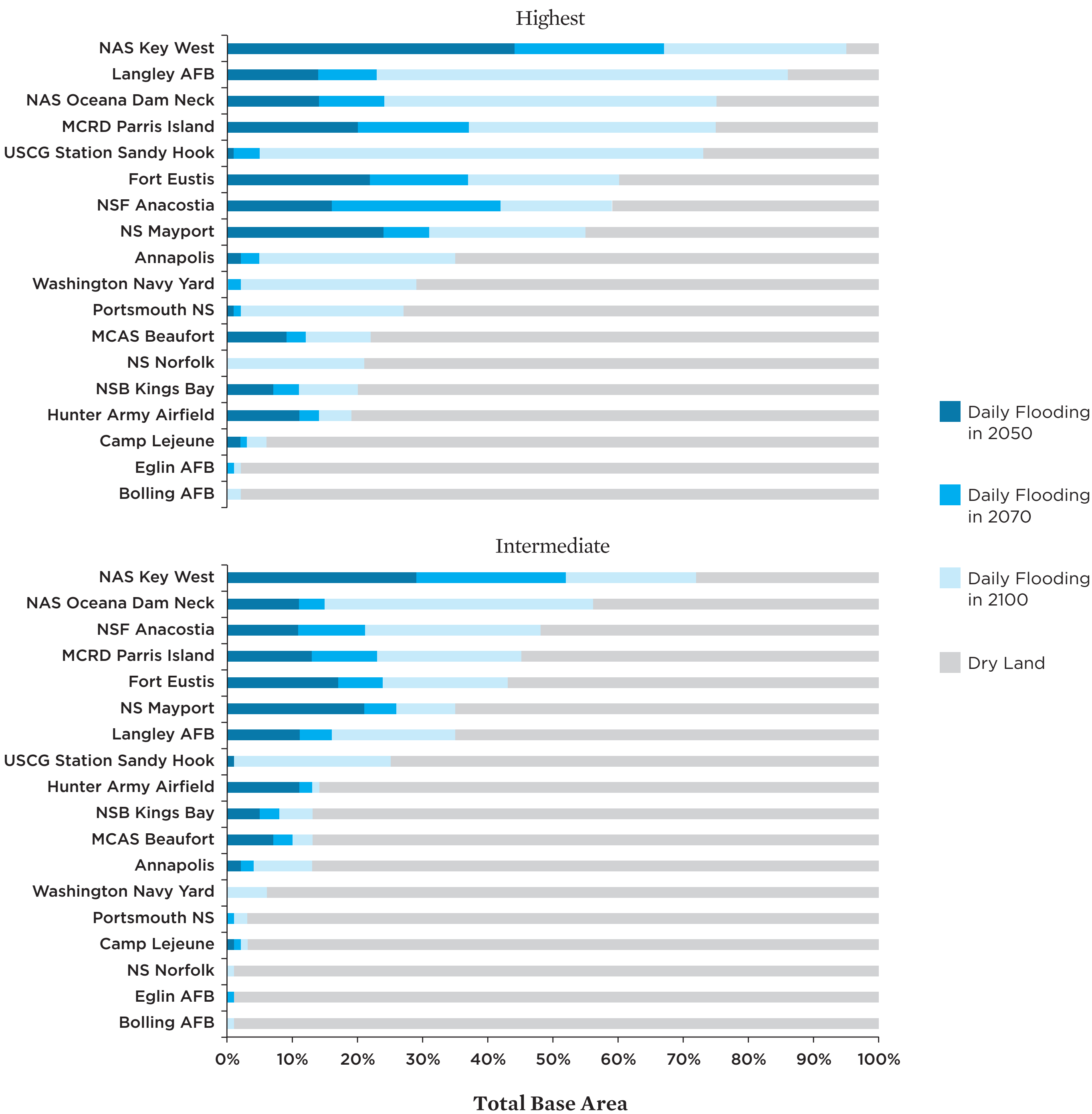
In this analysis, land that is inundated by at least one high tide each day is considered a loss. This is a conservative metric: in reality, far less frequent flooding would lead to land being considered unusable.

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

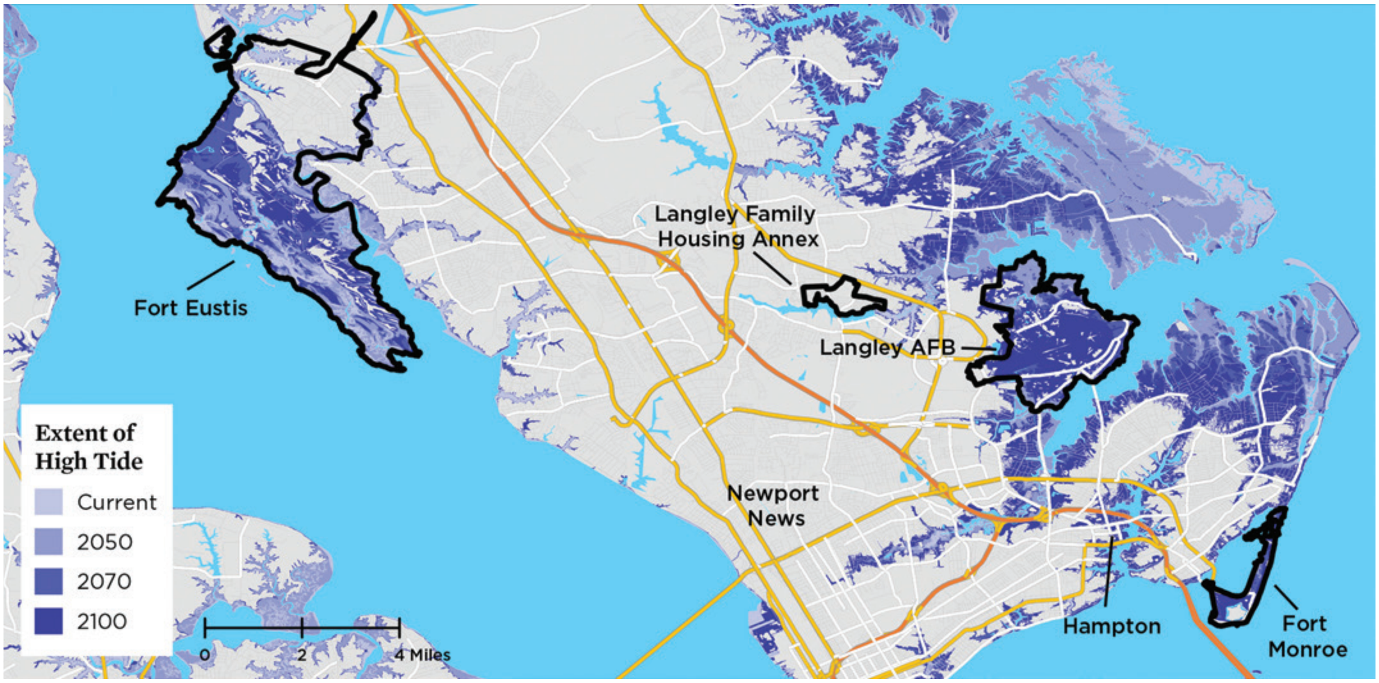
For many military installations, the effects of a low-category storm in 2070 or 2100 would be closer to the effects of a higher-category storm today. For example, in the intermediate scenario, the area exposed to storm surge flooding by a

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 (Cleetus, 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

BOX 2.

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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KEY FINDINGS

The US Military on the Front Lines of Rising Seas

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

HIGHLIGHTS

At four installations studied, (Langley Air Force Base at Joint Base Eustis-Langley, Virginia; Marine Corps Recruit Depot Parris Island, South Carolina; Naval Air Station Key West, Florida; and Naval Air Station Oceana Dam Neck, Virginia), 35 to 70% of land area could be lost in the intermediate scenario and 75 to 90% in the highest scenario by 2100.

The Department of Defense maintains more than 1,200 military installations in the United States: intelligence centers; training grounds; shipyards; airfields; research hubs; and, often, housing for military personnel and their families. Today, sea level rise threatens many of these installations.

The Union of Concerned Scientists (UCS) has performed a new analysis of 18 East and Gulf Coast military installations. In the absence of preventive measures, these sites face three major risks later this century: more frequent and extensive tidal flooding, land loss as some areas are permanently inundated and others flood with daily high tides, and deeper and more extensive storm surge inundation.

Scenarios

UCS examined the 18 installations' exposure to flooding in 2050, 2070, and 2100 using two scenarios of sea level rise:[1]

1. **Intermediate**—projects a global average rise of 3.7 feet above 2012 levels by 2100
2. **Highest**—projects a global average rise of 6.3 feet above 2012 levels by 2100 (Parris et al. 2012)

2050: The March of High Tide over the Next Few Decades

PROJECTED GLOBAL AVERAGE SEA LEVEL RISE BY 2050

- *1.1 feet in the intermediate scenario*
- *1.7 feet in the highest scenario (recommended for decisions with a low risk tolerance)*

By 2050 in both scenarios, sea level rise drives early instances of land loss—defined in this analysis as land that floods with daily tides, making it unusable.

- All but two of the installations would see more than 100 flood events annually in low-lying areas.
- Those areas would be underwater a median of 10 to 25 percent of the year, depending on the scenario.
- Three sites experience a 15 percent or more loss of total current land area in the intermediate scenario and 20 percent or more loss in the highest scenario.

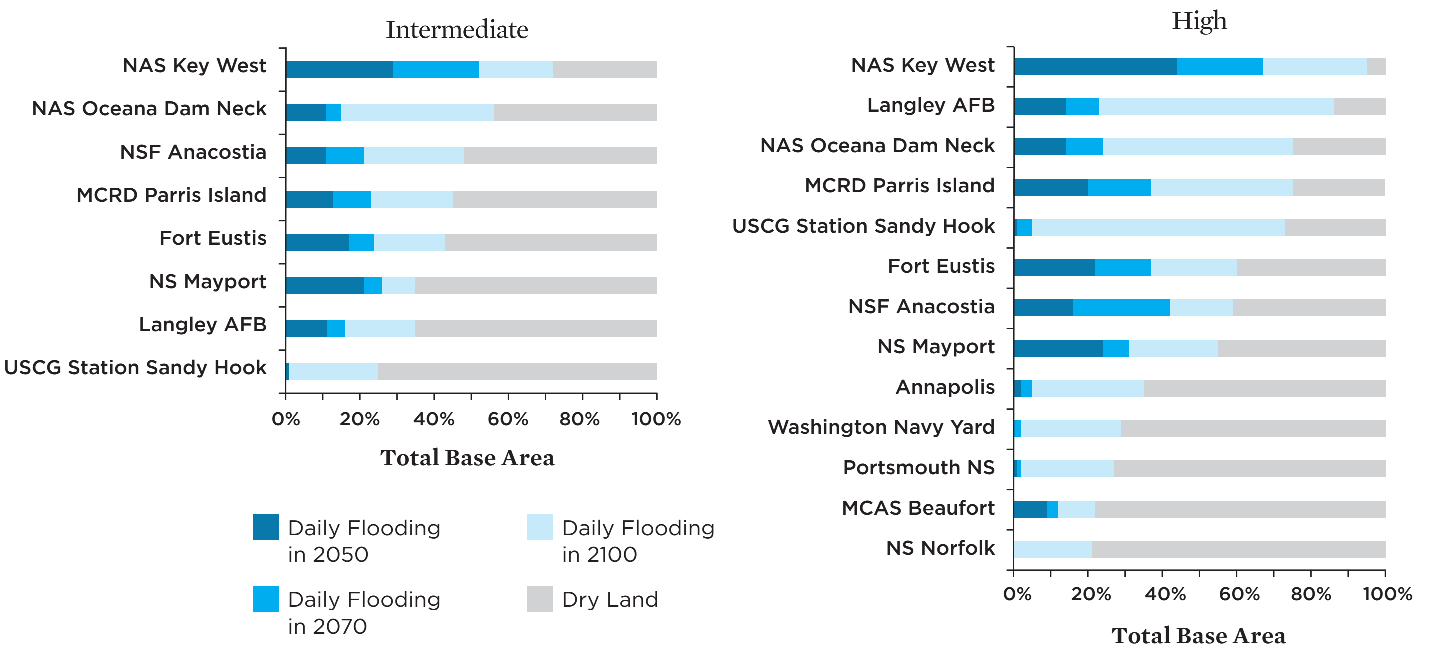
2070: Enhanced Storm Surge

PROJECTED GLOBAL AVERAGE SEA LEVEL RISE BY 2070

- *2.1 feet in the intermediate scenario*
- *3.1 feet in the highest scenario*

Sea level rise increases the military installations' exposure to storm surge—wind pushing ocean water ashore—and strengthens the flooding effects of all storms. In the highest scenario, even Category 1 storms cause extensive flooding:

Most of the 18 Installations Studied Risk Major Land Loss



Above are the 13 (out of 18) military installations that are projected to experience a 20% or greater land loss at some point this century. Some sites face substantial losses under either scenario.

- Exposure of a median quarter of the sites' area to flooding more than five feet deep in 2070, compared to 8 percent of their area today.
- For more than two-thirds of the sites, storm surge flooding in 2070 equivalent to that caused by Category 2 storms today.

2100: Lost Land

PROJECTED GLOBAL AVERAGE SEA LEVEL RISE BY 2100

- *3.7 feet in the intermediate scenario*
- *6.3 feet in the highest scenario*

Both scenarios project substantial land loss at many military installations by the end of this century:

- Half or more of the land at nearly half the installations would become part of the tidal zone—i.e., inundated by daily high tides—in the highest scenario.
- Currently flood-prone areas of most sites would be underwater at all times in the highest scenario.

ENDNOTES

1 *Parris et al. 2012. The intermediate sea level rise scenario assumes ice sheet loss that increases over time, while the highest scenario assumes rapid loss of ice sheets. The latter scenario is particularly useful for decisions involving an especially low tolerance for risk. See: http://scenarios.globalchange.gov/sites/default/files/NOAA_SLR_r3_0.pdf*

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The US Military on the Front Lines of Rising Seas

Exposure to Coastal Flooding at Naval Air Station Key West, Florida

HIGHLIGHTS

With seas rising at an accelerating rate, coastal military installations are increasingly exposed to storm surge and tidal flooding. The Union of Concerned Scientists (UCS) conducted analyses of this changing exposure for 18 military installations along the East and Gulf coasts. Analysis for Naval Air Station (NAS) Key West found that in the second half of this century, in the absence of preventive measures, this installation can expect more frequent and extensive tidal flooding, loss of currently utilized land, and substantial increases in the extent and severity of storm-driven flooding to which it is exposed.

The US Armed Forces depend on safe and functional bases, such as NAS Key West, Florida, to carry out their stated mission: to provide the military forces needed to deter war and to protect the security of the country. A roughly three-foot increase in sea level would threaten 128 coastal Department of Defense (DOD) installations in the United States and the livelihoods of the people—both military personnel and civilians—who depend on them (NAS 2011).

Low-lying Florida faces rising sea levels along its 1,200-mile coastline: water is encroaching from both the Atlantic and the Gulf coasts and up through the Everglades (Oskin 2013). The situation is acute in the Florida Keys, where seas are projected to rise between 3.8 and 6.2 feet over the course of this century. Most of the Keys' land area lies at elevations of three feet or less above sea level (Halley, Vacher, and Shinn 1997).

To enable decision makers to better understand the sea level rise threat, and where and when it could become acute, UCS has performed a new analysis of 18 East and Gulf Coast military installations, including NAS Key West. These sites were selected 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.

UCS projected exposure to coastal flooding in the years 2050, 2070, and 2100 using the National Climate Assessment's midrange or "intermediate-high" scenario (referred to here as "intermediate") and, in light of the low tolerance for risk in

US Navy

THE INLAND MARCH OF HIGH TIDE

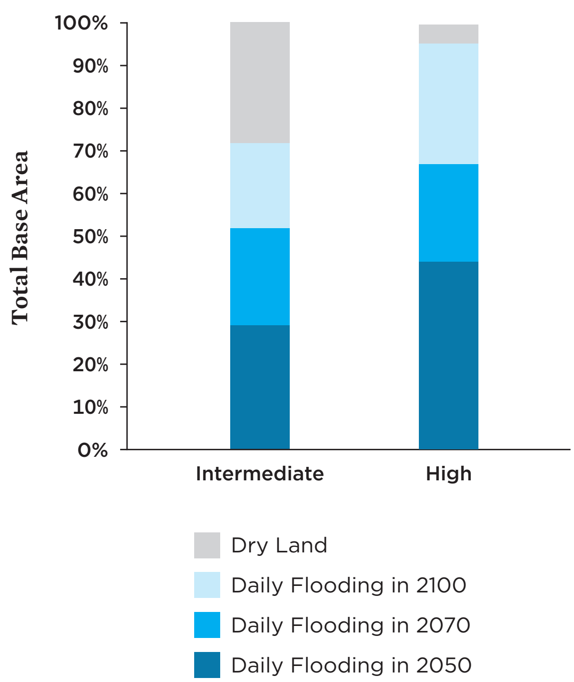
NAS Key West is located in the low-lying Florida Keys. The Keys are uniquely vulnerable to sea level rise because they sit atop porous limestone, which allows salt water to penetrate up through the ground and limits the effectiveness of sea walls and levees. By 2100, between 70% and 95% of the station is projected to be inundated by daily flooding.

some of the military's decisions, a "highest" scenario based on a more rapid rate of increase (Parris et al. 2012).[1] We modeled tidal flooding, permanent inundation, and storm surge from hurricanes.[2] The results below outline potential future flooding to which NAS Key West could be exposed, assuming no new measures are taken to prevent or reduce flooding.[3] This analysis finds the following key results:

TIDAL FLOODING AND LAND LOSS

- **Areas currently unaffected by tidal flooding could flood with each high tide.** Extreme high tides do not typically flood NAS Key West today. But in the intermediate scenario, low-lying areas are inundated 300 times per year by 2050.
- **Flooding during extreme high tides will become more extensive.** In the intermediate scenario, extreme-tide flooding encompasses more than half of NAS Key West's land area by 2050; in the highest scenario, such flooding encroaches on the runways of Boca Chica Field.

FIGURE 1. Major Land Loss Is Projected for NAS Key West



As high tide reaches farther inland, extensive land loss is possible at NAS Key West. Affected land may include developed and undeveloped areas and even wetlands that reside above the current high tide mark. NAS Key West is projected to see substantial loss of currently developed and utilized areas, particularly with the faster rate of sea level rise.

- **Extensive land loss at NAS Key West is possible.** Some parts of NAS Key West are projected to flood with such frequency by 2070 that they would effectively be part of the tidal zone as opposed to dry, usable land. Indeed, given about four feet of sea level rise by the end of the century, as projected in the intermediate scenario, high tides would encompass roughly 70 percent of the station's land area; with just over six feet of rise, as projected in the highest scenario, high tides would encompass 95 percent of the area.

STORM SURGE

- **Sea level rise exposes previously unaffected areas of NAS Key West to storm surge flooding.** Today, about 80 percent of NAS Key West is exposed to flooding by Category 1 storms; in either scenario, 95 percent or more of the base is exposed by 2050.
- **Sea level rise makes storm surge flooding more severe.** The area inundated by five feet or more of seawater during storm surges will increase over the century.

Base Information

NAS Key West is located within the Lower Florida Keys in Monroe County. The low-lying Keys are uniquely vulnerable to sea level rise because they are underlain by porous limestone bedrock, which eliminates the possibility of building sea walls or levees that would hold back the sea.

NAS Key West

Branch:	Navy
Established:	1823
Size (Acres):	5,800
Personnel:	800
Tenant Commands:	30

SOURCE: DOD 2016; MARCOA 2016.

The station's primary facility, Boca Chica Field, lies on Boca Chica Key, four miles northeast of Key West. NAS Key West has several annexes throughout Monroe County, including on Key West itself (DOD 2016).

NAS Key West trains fighter pilots from all branches of the armed forces. The station can house 100 aircraft and more than 800 personnel while also providing port operations for visiting ships (MARCOA 2016). NAS Key West provides key training and support for the nation's military operations and readiness, as it serves all branches of the military. The installation is home to several important commands, including the

It is difficult to defend against gradual sea level rise in the Keys, due to low elevation, and porous limestone that allows salt water to infiltrate up through the ground.

Joint Interagency Task Force South, which combats illicit narcotics trafficking; the US Coast Guard Sector Key West; and the Army Special Forces Underwater Training School (DOD 2016).

Historic Exposure to Storm Surge and Flood Hazards

In any given year, there is an estimated 25 percent chance that Key West will be hit by a tropical cyclone (MCIM 2015). When storms strike, NAS Key West is highly exposed to the surge that can be generated. A Category 1 storm hitting today exposes more than 80 percent of NAS Key West to flooding from storm surge. Category 2 or stronger storms expose more than 95 percent of the base to flooding.

Since 1851, there have been 76 hurricanes that have come within 150 nautical miles of NAS Key West (NOAA n.d.). In 2005, four hurricanes came within 150 nautical miles, including Dennis, Katrina, Rita, and Wilma; most recently, Hurricane Ike passed within this distance in 2008 (NOAA n.d.). Hurricane Wilma pushed water levels nearly five feet above normal and resulted in an estimated $33 million in total damages (City of Key West 2016; MCIM 2015; Kasper 2007).

NAS Key West has considered seawall upgrades for protection of its airfield against storm surge (Barham 2011). It is difficult to defend against gradual sea level rise in the Keys, however; in addition to the hazard presented by South Florida's low elevation, its porous limestone geology allows salt water to infiltrate up through the ground (Monroe County 2011; Miller 1990).

Future (Projected) Exposure to Storm Surge and Flood Hazards

SEA LEVEL RISE

The intermediate scenario projects that NAS Key West will experience nearly four feet of sea level rise and the highest

US Navy

Hurricane Dennis passed just south of Key West in July, 2005. NAS Key West's Truman Annex is shown here, as a Navy security team makes their way through flood waters.

scenario projects over six feet of rise by 2100. This rise will lead to increased exposure to different types of coastal flooding. It also threatens to inundate land and contaminate the region's drinking water (UCS 2015).

TIDAL FLOODING AND LAND LOSS

As sea level rises, tidal flooding associated with extreme tides is expected to become more extensive and frequent. Tidal flooding does not affect critical parts of NAS Key West today. In both the intermediate and highest scenarios, however, such flooding is expected to inundate critical infrastructure, such as the runways at Boca Chica Field, by 2070.

The intermediate scenario projects that, by 2050, tidal flooding could occur roughly 300 times per year in currently flood-prone areas, while in the highest scenario it occurs 560 times per year, with the daily high tide or even more frequently. With such regular flooding, affected areas could become unusable land within the next 35 years. In the highest scenario, NAS Key West's currently flood-prone areas would be underwater 85 percent of the year by 2070.

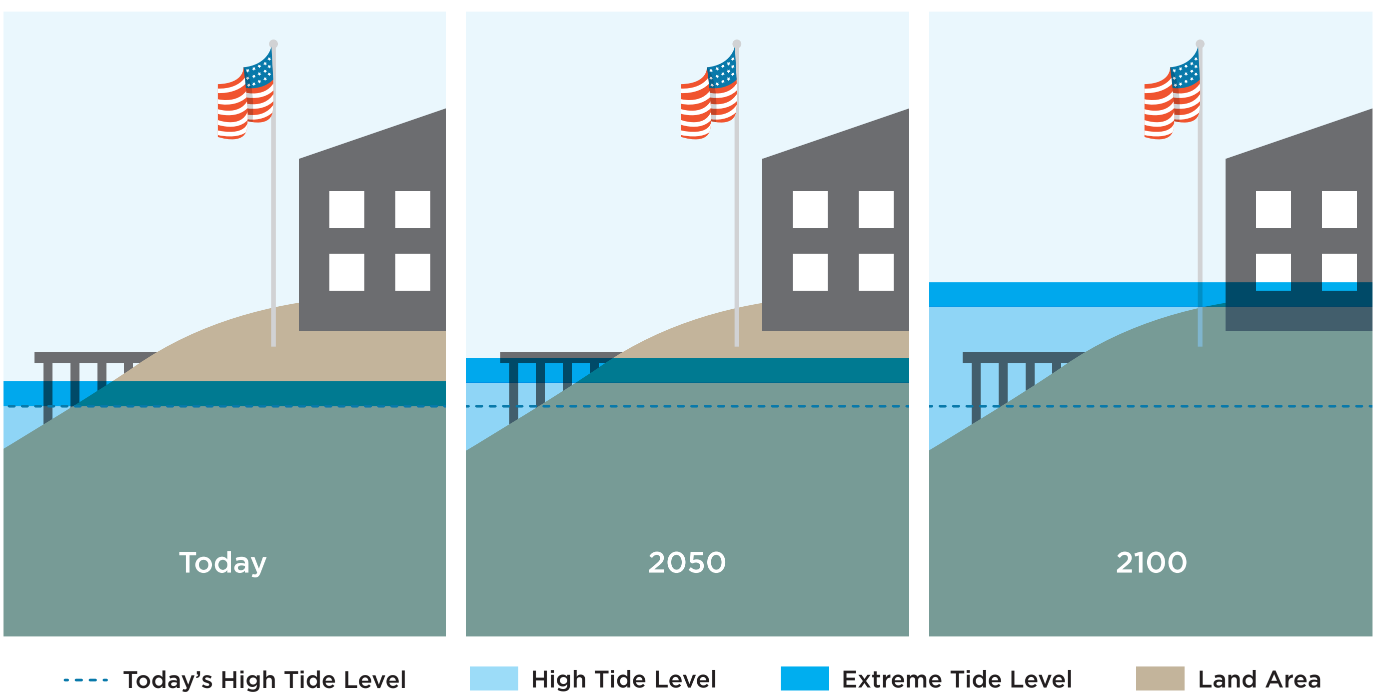
At NAS Key West, the difference between high and low tide is small enough that, with the projected increases in sea

TABLE 1. NAS Key West Could See More than Six Feet of Sea Level Rise by 2100

Year	Intermediate	Highest
2050	1.1	1.7
2070	2.0	3.2
2100	3.8	6.2

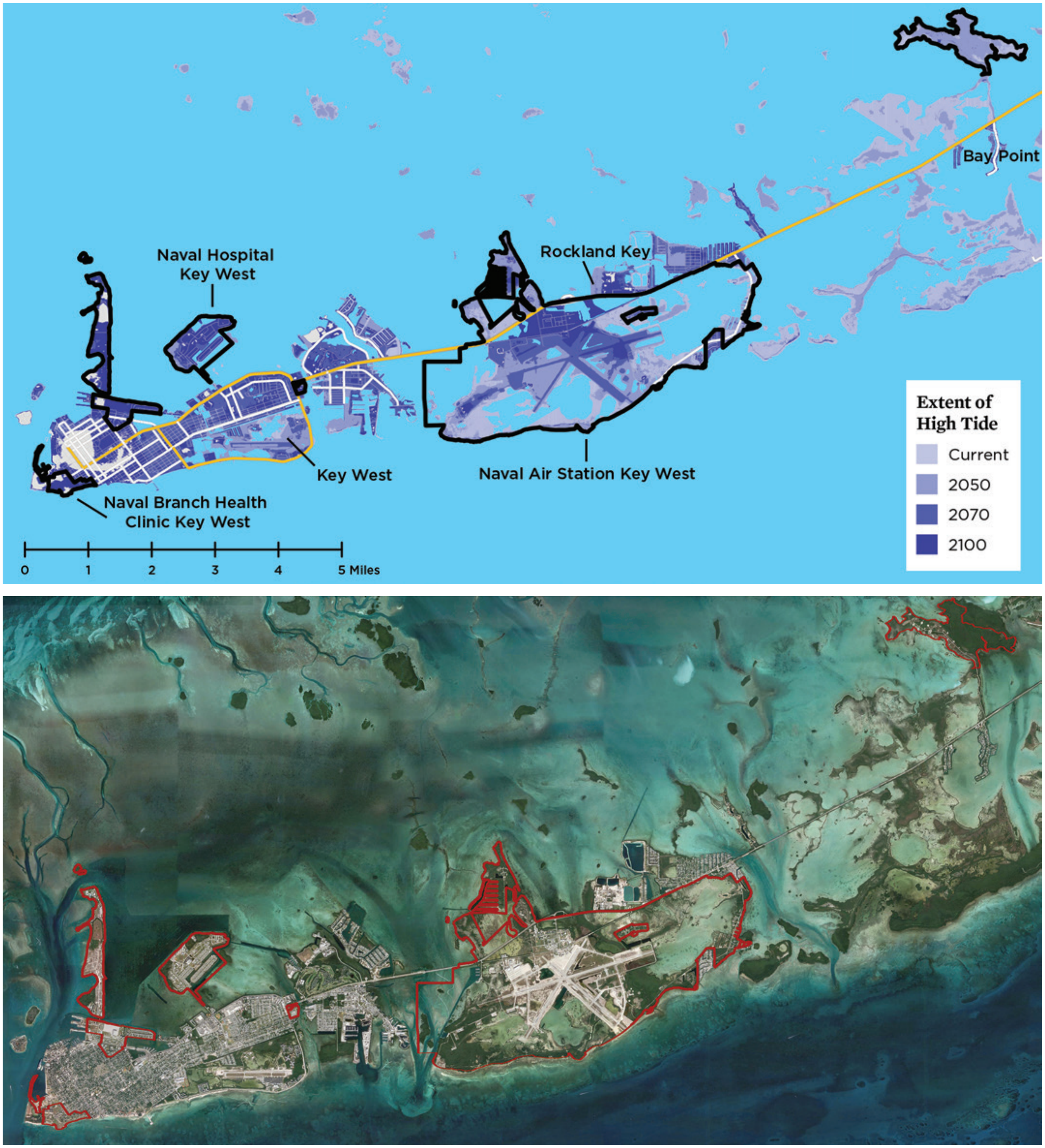
In the intermediate scenario, ice sheet loss increases gradually in the coming decades; in the highest scenario, more rapid loss of ice sheets occurs. The latter scenario is included in this analysis to help inform decisions involving an especially low tolerance for risk. Moreover, recent studies suggest that ice sheet loss is accelerating and that future dynamics and instability could contribute significantly to sea level rise this century (DeConto and Pollard 2016; Trusel et al. 2015; Chen et al. 2013; Rignot et al. 2011). Values shown are local projections that include unique regional dynamics such as land subsidence (see www.ucsusa.org/MilitarySeasRising).

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



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

FIGURE 3. NAS Key West Is Expected to Lose Currently Utilized Land



The projected reach of future daily high tides, shown in the top panel, encompasses currently utilized land at NAS Key West, shown in the bottom panel. The highest scenario is mapped here.

SOURCE: GOOGLE EARTH.

TABLE 2. Low-Lying Areas of NAS Key West Projected to Be Permanently Inundated by 2100

	Intermediate		Highest	
Year	Events per Year	% of Year	Events per Year	% of Year
2012	3 ± 3	0	3 ± 3	4
2050	301 ± 39	13	560 ± 46	41
2070	567 ± 40	60	48 ± 35	85
2100	1 ± 0	100	1 ± 0	100

Projected sea level rise will lead to constant or near-constant flooding around NAS Key West. Shown here are flood events in low-lying, flood-prone areas projected by the intermediate and highest scenarios. Events per year are reported as the average over a five-year period with one standard deviation. Percent of year is reported simply as the average over a five-year period. As flood conditions begin to span multiple high tide cycles, the number of distinct flood events gradually drops toward one, while the duration of flooding increases until it is constant.

level, flood conditions will eventually exist even at low tide. In the highest scenario, flood events begin to span many high tide cycles during the last half of this century. As a result, the number of individual flood events decreases but the duration of flood conditions increases until flooding is essentially constant and the land that was once above the high tide mark is permanently inundated. Beyond today's flood-prone areas, the 6.2 feet of sea level rise projected for the end of the century would mean that nearly all—95 percent—of NAS Key West's land area will become part of the tidal zone.

THE CHANGING THREAT OF HURRICANES

Over time, sea level rise exposes a greater proportion of NAS Key West's area to inundation by Category 1 storms. In both scenarios, areas of the base that are unaffected by storm surge today—such as the Trumbo Point facilities on Fleming Key, north of Key West—will be exposed to flooding by 2050. In both the intermediate and highest scenarios, area exposed to flooding from a Category 1 storm increases from 83 percent today to 95 percent or more in 2050.

[*Beyond today's flood-prone areas, the 6.2 feet of sea level rise projected for the end of the century would mean 95 percent of NAS Key West's land area will become part of the tidal zone.*]

Sea level rise also increases the depth of flooding NAS Key West can expect with major storms. Whereas nearly all the flooding from a Category 1 storm today is five feet deep or less, nearly 80 percent of the base could be exposed to flooding five to 10 feet deep by 2100 according to the intermediate scenario.

WORST-CASE SCENARIOS

A Category 5 storm today exposes virtually all of NAS Key West to storm surge, with the majority of the base being flooded with water 10 to 15 feet deep. Sea level rise will make this catastrophic flooding even more severe. In the highest scenario, 37 percent of the base is exposed to 15-to-20-foot deep flooding in 2070. By 2100, that proportion rises to 80 percent.

Mobilizing on the Sea Level Rise Front Lines

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). Given the Keys' history of exposure to hurricanes, Navy leadership recognizes many of the flood risks NAS Key West faces. The station has flood risk mitigation efforts under way, including maintenance of its seawall and planning measures (Barham 2011).

But here and across US coastal installations there is still far to go: the gap between the military's current sea level rise preparedness and the threats outlined by this analysis 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, including NAS Key West, face all of these risks.

> ***The gap between the military's current sea level rise preparedness and the threats outlined here is large and growing.***

This analysis provides snapshots of potential future exposure to flooding at NAS Key West. For the Navy to take additional action on the front line of sea level rise, however, it 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 planning efforts and to detailed mapping that includes future conditions; support planning partnerships with surrounding communities; and allocate resources for preparedness projects, on- and off-site, many of which will stretch over decades.

Military bases and personnel protect the country from external threats. 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.

ENDNOTES

1 *The intermediate sea level rise scenario assumes ice sheet loss that increases over time, while the highest scenario assumes rapid loss of ice sheets. The latter scenario is particularly useful for decisions involving an especially low tolerance for risk. These results are a small subset of the full analysis. For more information, the technical appendix, and downloadable maps, see www.ucsusa.org/MilitarySeasRising.*

2 *UCS analyzed storm surge depth and exposure extent for each base using the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model, developed by the National Oceanic and Atmospheric Administration (NOAA), for storm events ranging in severity from Category 1 to Category 4, in addition to tidal floods. Both storm surge and flooding during extra-high tides can be significantly exacerbated by rainfall and wave action, neither of which was included in this study.*

3 *This analysis involved consultation with contacts at multiple installations. However, in some instances, 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.*

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FACT SHEET

The US Military on the Front Lines of Rising Seas

Exposure to Coastal Flooding at Eglin Air Force Base, Florida

HIGHLIGHTS

With seas rising at an accelerating rate, coastal military installations are increasingly exposed to storm surge and tidal flooding. The Union of Concerned Scientists (UCS) conducted analyses of this changing exposure for 18 military installations along the East and Gulf coasts. Analysis of Eglin Air Force Base (AFB) found that in the second half of this century, in the absence of preventive measures, the installation can expect the following: frequent and extensive tidal flooding, loss of currently utilized land, and substantial increases in the extent and severity of storm-driven flooding to which it is exposed.

The US Armed Forces depend on safe and functional bases, such as Eglin AFB, Florida, to carry out their stated mission: to provide the military forces needed to deter war and to protect the security of the country. A roughly three-foot increase in sea level would threaten 128 coastal Department of Defense (DOD) installations in the United States and the livelihoods of the people—both military personnel and civilians—who depend on them (NAS 2011).

Low-lying Florida faces rising sea levels along its 1,200-mile coastline: water is encroaching from both the Atlantic and the Gulf coasts and up through the Everglades. Unlike the Miami area, Eglin AFB, located directly on the Gulf Coast of the Florida Panhandle, sees very little tidal flooding today. However, by late this century, as seas are projected to rise between 3.7 and 6.1 feet, the base's Santa Rosa and Okaloosa Island facilities could face significant ocean inundation.

To enable decision makers to better understand the sea level rise threat, and where and when it could become acute, UCS has performed a new analysis of 18 East and Gulf Coast military installations, including Eglin AFB. These sites were selected 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.

UCS projected exposure to coastal flooding in the years 2050, 2070, and 2100 using the National Climate Assessment's midrange or "intermediate-high" scenario (referred to here as "intermediate") and, in light of the low tolerance for

US Air Force

EGLIN AFB'S BARRIER ISLANDS FACE DAILY INUNDATION

While the mainland section of Eglin AFB has limited exposure to sea level rise this century, its barrier islands, Santa Rosa (shown here) and Okaloosa, could face daily tidal flooding late in the century. These islands provide storm surge protection for the mainland. Though not modeled here, their inundation could affect storm surge exposure of the base's mainland.

risk in some of the military's decisions, a "highest" scenario based on a more rapid rate of increase (Parris et al. 2012).[1]

We modeled tidal flooding, permanent inundation, and storm surge from hurricanes.[2] The results below outline potential future flooding to which Eglin AFB could be exposed, assuming no new measures are taken to prevent or reduce flooding.[3] This analysis finds the following key results.

TIDAL FLOODING, PERMANENT INUNDATION, AND LAND LOSS

- **Areas currently unaffected by tidal flooding could flood with each high tide.** Today, extreme high tides do not typically affect Eglin AFB, but low-lying areas of the base are inundated during daily high tides by the end of this century in both sea level rise scenarios.
- **Flooding during extreme high tides will become more extensive**. By 2070, this flooding could affect nearly all of the barrier island facilities within the base.

> ***Some of Eglin AFB's barrier island areas are projected to flood with such frequency by 2070 that they would effectively be part of the tidal zone.***

- **Sea level rise threatens to inundate certain areas permanently.** Some of Eglin AFB's barrier island areas are projected to flood with such frequency by 2070 that they would effectively be part of the tidal zone, as opposed to developed, usable land. Indeed, with 6.1 feet of sea level rise projected by the end of the century, most of the barrier island areas of the base would be effectively lost: they would be underwater during daily high tides.

STORM SURGE

- **Sea level rise exposes previously unaffected areas to storm surge flooding.** Most of Eglin AFB's vast mainland areas remain unaffected by storm surge even with a Category 5 storm in 2100. Nevertheless, in the highest scenario, the barrier island area exposed to storm surge inundation roughly quadruples for Category 1 storms between now and 2100.
- **Sea level rise increases the exposure of Eglin AFB to deeper, more severe flooding.** As sea level rises, the depth of inundation related to storm surge increases, particularly on the base's barrier islands. Over time, the area inundated by five or more feet of seawater during storm surges increases.

Base Information

Eglin AFB is located along the Florida Panhandle between Pensacola and Panama City, on the Choctawhatchee Bay. The base is situated primarily on the mainland but includes portions of Santa Rosa Island and Okaloosa Island, which make up one continuous barrier island located south of the mainland.

Eglin AFB

Branch:	Air Force
Established:	1935
Size (Acres):	463,360
Population:	17,000
Units	50
Annual Budget:	$18.8B
Jobs:	192,000
Replacement Value:	$4.7B

SOURCE: DOD 2016; NFMSP 2016; TEKE 2015.

Eglin AFB primarily supports and conducts research on weapons systems. The more than 50 units at the base, representing every branch of the military, develop and test new weapons and train members of the Armed Forces in their use (USAF 2016). The installation is also home to a Special Forces Group assigned to protect more than 30 countries in Central and South America and the Caribbean (USAF 2016). The base has a population of about 17,000, including active military, civilians, and contractors (DOD 2016).

Providing more than 190,000 jobs and direct defense spending of more than $6.9 billion annually, the military presence in the region is an important part of the local economy (NFMSP 2016). The three counties in which Eglin AFB is located are home to an estimated 11,000 members of the Armed Forces and nearly 60,000 veterans (US Census Bureau 2014).

Historic Exposure to Storm Surge and Flood Hazards

Santa Rosa Island serves as a natural barrier that helps protect the base's mainland facilities from storm surge (Evans et al. 2014). The extensive wetlands surrounding the Yellow

US Army

TRAINING ACTIVITIES ON EGLIN'S BARRIER ISLANDS:
On Okaloosa Island, April 2015, a Green Beret (7th Special Forces Group, Airborne) emerges from the Gulf of Mexico as part of a mock rescue effort. Okaloosa Island, along with nearby Santa Rosa Island, can see significant storm surge from hurricanes and is highly exposed to future flooding.

River in the base's northwest corner also likely provide protection, along with wetlands along the Choctawhatchee River. Very little of Eglin AFB, including the Santa Rosa and Okaloosa Island facilities, experiences routine tidal flooding today.

Overall exposure of the mainland portions of the base to storm surge is fairly low, even given the base's location along the hurricane-prone Gulf Coast (Evans et al. 2014). Storm surge inundation, even for the strongest storms (i.e., Category 5), is limited to areas immediately along the coast or adjacent to river channels. The portions of the base that lie along the Santa Rosa and Okaloosa barrier islands, however, bear the brunt of storm surge from hurricanes, and they are extremely vulnerable to flooding. Today, these areas experience widespread inundation from Category 2 storms and are almost completely inundated by Category 3 and stronger storms. Loss of the barrier islands would expose Choctawhatchee Bay to storm surge, which in turn could expose upland areas and infrastructure to flooding and land loss (Evans et al. 2014).

There have been 58 hurricanes that have come within 150 nautical miles of the base since 1851 (NOAA n.d.; NHC 2010). Hurricanes Ivan and Dennis, both Category 3 storms, affected Santa Rosa Island in 2004 and 2005, respectively (Evans et al. 2014). Ivan had a substantial impact on Santa Rosa Island, damaging over 100 structures with a storm tide (storm surge plus tide) between 8.5 and 13.8 feet (Clark and LaGrone n.d.). Dennis caused a storm surge of six to nine feet (Clark and LaGrone n.d.).

The Air Force estimated that two hurricanes combined caused more than $100 million in damages at Patrick, Eglin, Hurlburt, and Tyndall AFBs in 1995, with some areas submerged in up to 18 feet of water (USAF 2008). During Hurricane Isaac in 2012, the Air Force moved Eglin's F-15 and F-16 fighter jets to Air Force bases in North and South Carolina to protect them from the storm (Clark and LaGrone n.d.).

Future (Projected) Exposure to Storm Surge and Flood Hazards

The intermediate scenario projects that Eglin AFB will experience 3.7 feet of sea level rise locally, and the highest scenario projects 6.1 feet of rise by 2100. In both scenarios, mainland

TABLE 1. Eglin AFB Could See Six Feet of Sea Level Rise by 2100

Year	Intermediate	Highest
2050	1.0	1.7
2070	1.9	3.1
2100	3.7	6.1

In the intermediate scenario, ice sheet loss increases gradually in the coming decades; in the highest scenario, more rapid loss of ice sheets occurs. The latter scenario is included in this analysis to help inform decisions involving an especially 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 (DeConto and Pollard 2016; Trusel et al. 2015; Chen et al. 2013; Rignot et al. 2011). Values shown are local projections that include unique regional dynamics such as land subsidence (see www.ucsusa.org/MilitarySeasRising).

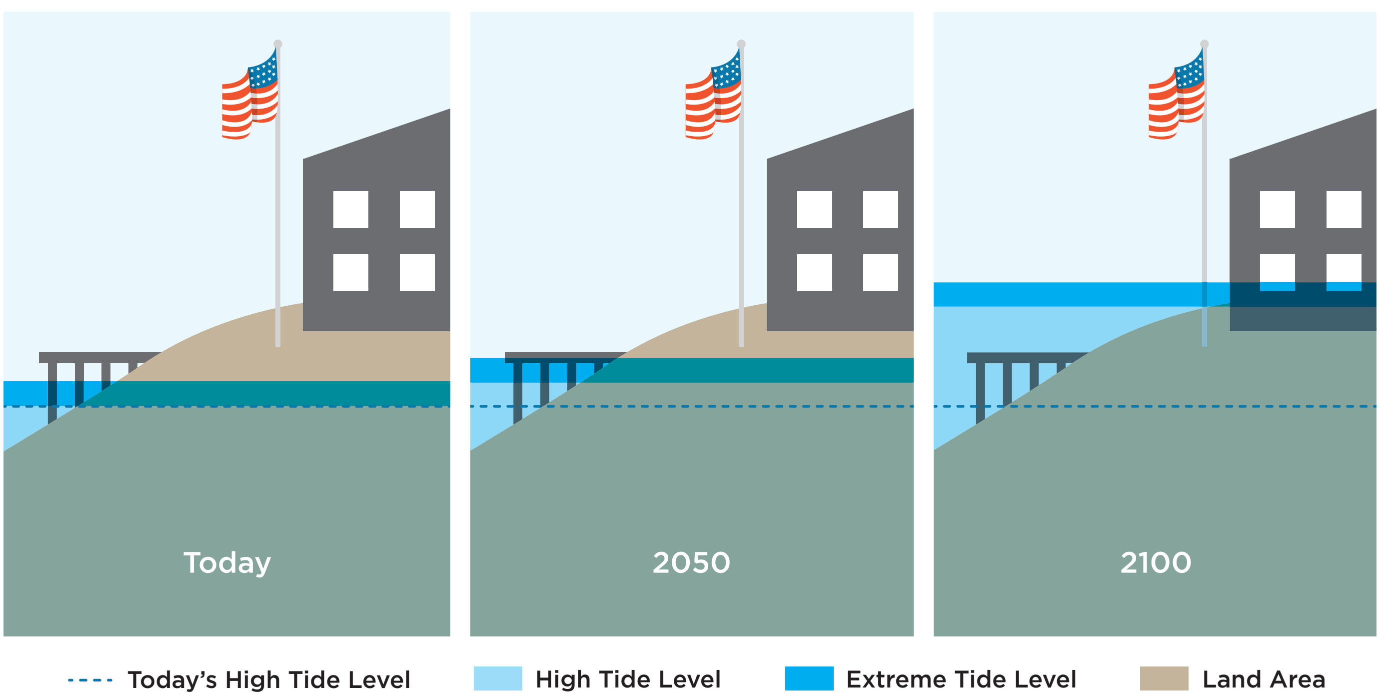
exposure to sea level rise is minimal, with the exception of the low-lying marsh areas along the northwestern border of the base. But Santa Rosa and Okaloosa Islands begin to show inundation at about three feet of sea level rise, and they are nearly completely inundated at six feet. The pace of sea level rise through the end of the century will determine the future viability of the islands: as the rate of sea level rise increases, erosion will exert a greater effect on the islands (Donoghue et al. 2013).

TIDAL FLOODING AND LAND LOSS

As sea level rises, flooding during high tide—uncommon today—is expected to become routine and extensive, particularly on Eglin's low-lying barrier islands. Tidal flooding occurs roughly 160 times per year in the intermediate scenario and roughly 230 times per year in the highest scenario by 2070. By 2100, low-lying areas are inundated not just at high tide, but also for more than 80 percent of the year in the intermediate scenario, and they are constantly inundated in the highest scenario, as outlined in Table 2.

The flooding that occurs during high tide lasts longer as sea level rises. In locations such as Eglin AFB, the difference

FIGURE 1. How Sea Level Rise Causes Tidal Flooding and Land Loss



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

TABLE 2. Rising Flood Frequency in Eglin's Low-Lying Areas

	Intermediate		Highest	
Year	Events per Year	% of Year	Events per Year	% of Year
2012	0 ± 0	0	0 ± 0	0
2050	8 ± 7	0	84 ± 24	5
2070	158 ± 26	12	228 ± 32	71
2100	103 ± 24	83	1 ± 0	100

Sea level rise will lead to constant or near-constant flooding in parts of Eglin AFB. Shown here are flood events in low-lying, flood-prone areas projected by the intermediate and highest scenarios. Events per year are reported as the average over a five-year period with one standard deviation. Percent of year is reported simply as the average over a five-year period. As flood conditions span multiple high tide cycles, the number of distinct flood events gradually drops, but the duration of flooding increases until it is constant. Installations will be affected by this flooding depending on the presence of low-lying land on-site.

between high and low tide is small enough that, with the projected increases in sea level, flood conditions will eventually exist even at low tide. During the last quarter of this century, flood events in this area will begin to span many high tide cycles. As a result, the number of individual flood events decreases, but the duration of flood conditions increases until flooding is essentially constant and land that was once above the high tide line is permanently inundated (see Table 2). Indeed, in the highest scenario, nearly all of Santa Rosa Island is underwater at high tide by the end of the century (see Figure 2, p. 6). Because barrier islands provide a storm surge buffer for the mainland, this trend toward inundation could have implications for the future exposure of mainland Eglin AFB to storm surge.

> ***In a worst-case scenario for the area, roughly 10 percent of Eglin AFB, or more than 43,000 acres, is exposed to storm surge.***

THE CHANGING THREAT OF HURRICANES

Because Eglin AFB is large and its mainland area is protected from storm surge by the barrier islands, there is only a small increase in the percentage of the base's area exposed to flooding as sea level rises. In absolute numbers, however, the increase in exposed area is large. Today, a Category 2 storm exposes about 11,400 acres of the base to storm surge flooding. That area increases by more than 50 percent—to about 17,700 acres—in 2100 in the intermediate scenario. In the highest scenario, the area exposed to storm surge from a Category 2 storm nearly doubles, to about 22,000 acres.

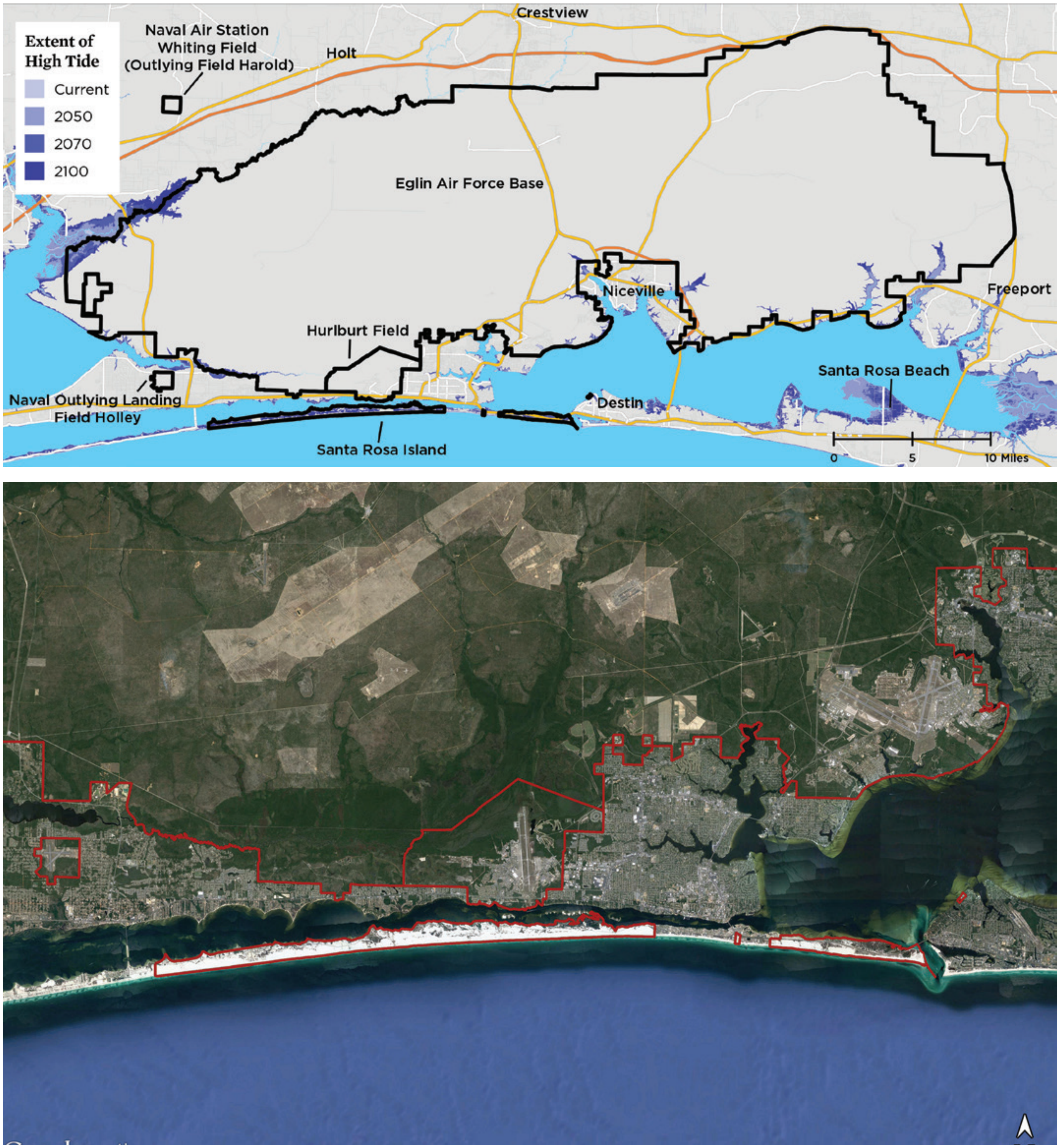
Sea level rise also changes the depth of flooding that the base can expect with major storms. This is particularly evident on Santa Rosa and Okaloosa Islands. Whereas most of the inundation on these islands during a Category 2 storm today is five feet deep or less, in the highest scenario in 2100, most of the inundation on the islands is five to 10 feet deep.

In a worst-case scenario for the area—a Category 5 storm hitting in 2100 in the highest scenario—roughly 10 percent of Eglin AFB, or more than 43,000 acres, is exposed to storm surge. About 5 percent of the base—nearly 30,000 acres—could experience flooding more than five feet deep. The barrier islands would be exposed to 15-to-20-foot-deep flooding. Even in this worst-case scenario, however, the vast majority of Eglin AFB's mainland facilities are unaffected by flooding.

Mobilizing on the Sea Level Rise Front Lines

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).Recent studies by the DOD, for example, inform Eglin AFB's climate preparedness activities and can help guide the base toward cost-effective investments (Evans et al. 2014; Donoghue et al. 2013).

FIGURE 2. Eglin AFB Is Expected to Face Barrier Island Loss



The reach of future daily high tides, shown on the top panel, encompasses currently utilized land on Eglin AFB's Santa Rosa and Okaloosa Islands, shown on the bottom panel. The highest scenario is mapped here. In this scenario, much of the area shown in purple is permanently inundated.

SOURCE: GOOGLE EARTH.

But here and across coastal installations there is still far to go: the gap between the military's current sea level rise preparedness and the threats outlined by this analysis 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, including Eglin AFB, face all of these risks.

This analysis provides snapshots of potential future exposure to flooding at Eglin AFB. For the base to take action on the front line of sea level rise, however, it 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 planning efforts and to detailed mapping that includes future conditions; support planning partnerships with surrounding communities; and allocate resources for preparedness projects, on- and off-site, many of which will stretch over decades.

Military bases and personnel protect the country from external threats. 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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1 *The intermediate sea level rise scenario assumes ice sheet loss that increases over time, while the highest scenario assumes rapid loss of ice sheets. The latter scenario is particularly useful for decisions involving an especially low tolerance for risk. These results are a small subset of the full analysis. For more information, the technical appendix, and downloadable maps, see www.ucsusa.org/MilitarySeasRising.*

2 *UCS analyzed storm surge depth and exposure extent for each base using the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model, developed by the National Oceanic and Atmospheric Administration (NOAA), for storm events ranging in severity from Category 1 to Category 5, in addition to tidal floods. Both storm surge and flooding during extra-high tides can be significantly exacerbated by rainfall and wave action, neither of which was included in this study.*

3 *This analysis involved consultation with Eglin AFB. However, in some instances, 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.*

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FACT SHEET

The US Military on the Front Lines of Rising Seas

Exposure to Coastal Flooding at Naval Station Mayport, Florida

HIGHLIGHTS

With seas rising at an accelerating rate, coastal military installations are increasingly exposed to storm surge and tidal flooding. The Union of Concerned Scientists (UCS) conducted analyses of this changing exposure for 18 installations along the East and Gulf coasts. Analysis for Naval Station (NS) Mayport found that in the second half of this century, in the absence of preventive measures, this installation can expect more frequent and extensive tidal flooding, loss of currently utilized land, and substantial increases in the extent and severity of storm-driven flooding to which it is exposed.

The US Armed Forces depend on safe and functional bases, such as NS Mayport, Florida, to carry out their stated mission: to provide the military forces needed to deter war and to protect the security of the country. A roughly three-foot increase in sea level would threaten 128 coastal Department of Defense (DOD) installations in the United States and the livelihoods of the people—both military personnel and civilians—who depend on them (NAS 2011).

Low-lying Florida faces rising sea levels along its 1,200-mile coastline: water is encroaching from both the Atlantic and Gulf coasts and up through the Everglades (Climate Central n.d.; Oskin 2013). Seas are projected to rise between 3.7 and 6.1 feet over the course of this century in the area of NS Mayport, which includes the coastal city of Jacksonville. This rise will greatly increase the area's exposure to flooding.

To enable decision makers to better understand the sea level rise threat, and where and when it could become acute, UCS has performed a new analysis of 18 East and Gulf Coast military installations, including NS Mayport. These sites were selected 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.

US Navy

THE INLAND MARCH OF HIGH TIDE
NS Mayport, located at the mouth of the St. Johns River in northern Florida, is home to the US Navy's third-largest fleet. Tidal flooding occurs in this area roughly seven times per year today, but by 2050 could occur 150 to nearly 370 times per year.

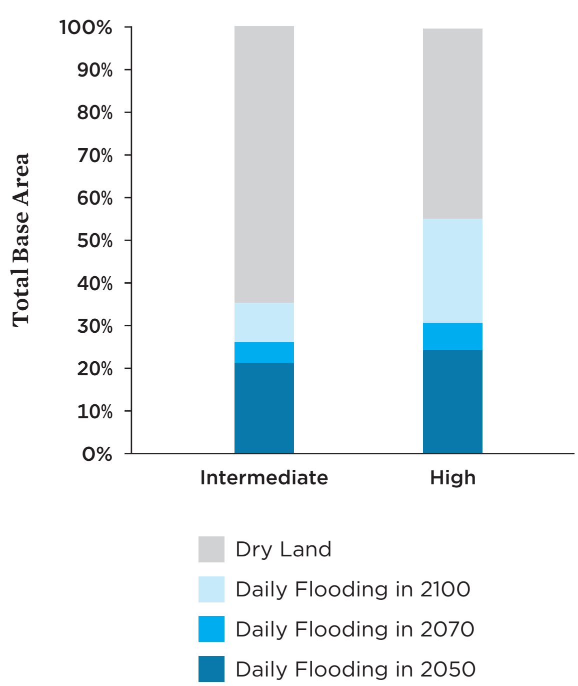
UCS projected exposure to coastal flooding in the years 2050, 2070, and 2100 using the National Climate Assessment's midrange or "intermediate-high" scenario (referred to here as "intermediate") and, in light of the low tolerance for risk of some in the military's decisions, a "highest" scenario based on a more rapid rate of increase (Parris et al. 2012).[1]

We modeled tidal flooding, permanent inundation, and storm surge from hurricanes.[2] The results below outline potential future flooding to which NS Mayport could be exposed, assuming no new measures are taken to prevent or reduce flooding.[3] This analysis finds the following key results:

TIDAL FLOODING AND LAND LOSS

- **Areas currently unaffected by tidal flooding could flood with each high tide.** Today, tidal flooding around NS Mayport affects wetlands and other low-lying areas about seven times per year, on average. But in the intermediate scenario, flood-prone areas could be inundated at least once daily, on average, during high tides by 2070.

FIGURE 1. NS Mayport Could Experience Major Land Loss



As high tide reaches farther inland, extensive land loss is possible at NS Mayport. Affected land may include developed and undeveloped areas and even wetlands that reside above the current high tide mark. In this analysis, installations that are projected to see major land loss, including NS Mayport, see substantial loss of currently developed and utilized areas.

- **Flooding during extreme high tides will become more extensive.** Today, the areas affected by tidal flooding at NS Mayport are primarily wetlands. But in the intermediate scenario, this flooding, though occasional, could encompass a third of the station's current land area by 2070.
- **Substantial land loss at NS Mayport is possible.** Some parts of NS Mayport are projected to flood with such frequency by 2100 that they would effectively be part of the tidal zone, as opposed to dry, usable land. Indeed, given 6.1 feet of sea level rise by the end of the century, as projected in the highest scenario, NS Mayport could lose 55 percent of its current land area to the tidal zone.

STORM SURGE

- **Sea level rise exposes previously unaffected areas of NS Mayport to storm surge flooding.** Sea level rise has a significant effect on the extent of inundation, particularly during Category 1 storms. In 2100 in the intermediate scenario, the area at NS Mayport exposed to flooding from a Category 1 storm would increase by 17 percent; it would increase by nearly 30 percent in the highest scenario.
- **Sea level rise exposes NS Mayport to deeper, more severe flooding.** As sea level rises, the depth of inundation related to storm surge increases. At NS Mayport, this is true across all the storm categories, depth intervals, and sea level rise scenarios in the UCS analysis. By 2100 in the highest scenario, surge inundation from a Category 2 storm is deeper and more severe than from a Category 3 storm today.

Base Information

NS Mayport is located 15 miles east of Jacksonville at the mouth of the St. Johns River. One of two major naval installations in the area, NS Mayport has a well-protected harbor that serves as a busy port.

NS Mayport is home to the US Navy's third-largest fleet (DOD 2016). Its harbor can accommodate 34 ships, including aircraft carriers, and has an 8,000-foot runway that can handle almost all military aircraft (DOD 2016). The station's infrastructure has been valued at $1.3 billion (Barnick et al. 2013).

NS Mayport is an integral part of Duval County's community and economy. Over 15,000 active duty personnel and 32,000 family members live at NS Mayport, and the county itself is home to more than 85,000 veterans (DOD 2016; US Census Bureau 2014). Spending by the DOD drives more than $11 billion of gross regional product and provides 100,000 jobs (Barnick et al. 2013).

NS Mayport

Branch: Navy
Established: 1917
Size (Acres): 3,409
Active Duty: 15,150
Ships: 19
Tenant Commands: 70

SOURCE: CNIC N.D.; DOD 2016.

Historic Exposure to Storm Surge and Flood Hazards

NS Mayport is currently highly exposed to storm surge flooding. A Category 1 storm hitting today exposes more than 60 percent of the station's area to flooding. Storm surge from Category 3, 4, and 5 storms exposes more than 90 percent of the station's area.

Since 1852, there have been 60 recorded hurricanes that have come within 150 nautical miles of NS Mayport (NOAA n.d.). The area's topography is low lying and therefore does not provide an extensive windbreak. The Mayport Basin at the St. Johns River channel entrance has little protection from storm surge (Clune, Englebretson, and Brand 1999). While storms approaching over land from the southwest are not of high concern, hurricanes approaching from the open ocean, from the southeast, are (Clune, Englebretson, and Brand 1999).

Hurricane Dora, striking in 1964, is the only hurricane to have made landfall in Jacksonville since the 1800s (Dumm et al. 2009). Making landfall near St. Augustine, Dora caused a storm surge of five to eight feet along the coasts of Florida and Georgia (NOAA 1964).

With the 6.1 feet of sea level rise projected for the end of the century in the highest scenario, more than half of the station, including developed areas, will flood daily.

TABLE 1. NS Mayport Could See Six Feet of Sea Level Rise by 2100

Year	Intermediate	Highest
2050	1.1	1.7
2070	1.9	3.1
2100	3.7	6.1

In the intermediate scenario, ice sheet loss increases gradually in the coming decades; in the highest scenario, more rapid loss of ice sheets occurs. The latter scenario is included in this analysis to help inform decisions involving an especially 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 (DeConto and Pollard 2016; Trusel et al. 2015; Chen et al. 2013; Rignot et al. 2011). Values shown are local projections that include unique regional dynamics such as land subsidence (see www.ucsusa.org/MilitarySeasRising).

Future (Projected) Exposure to Storm Surge and Flood Hazards

SEA LEVEL RISE

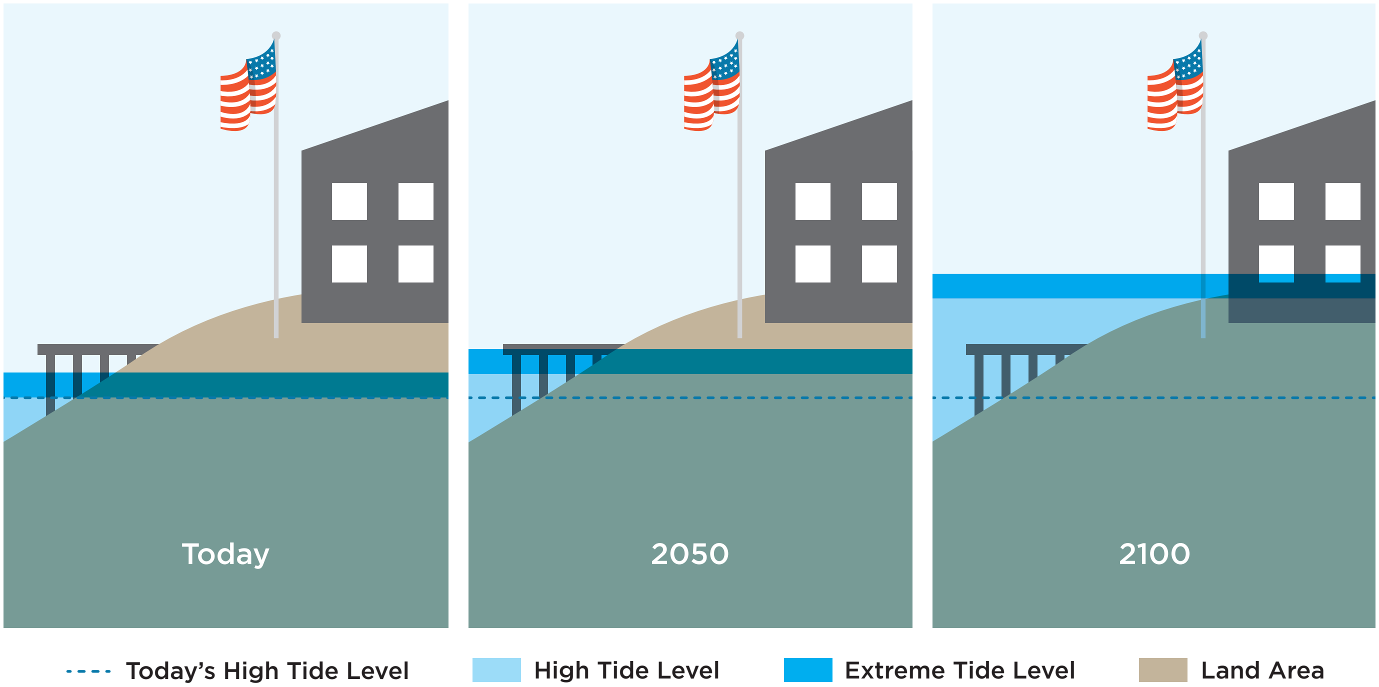
The intermediate scenario projects that NS Mayport will experience 3.7 feet of sea level rise and the highest scenario projects 6.1 feet of rise by 2100. This rise will drive the high tide line inland and lead to increased exposure to different types of coastal flooding.

TIDAL FLOODING AND LAND LOSS

As sea level rises, routine tidal flooding is expected to become both more frequent in low-lying areas and more extensive. Today, tidal flooding around NS Mayport occurs roughly seven times per year. The intermediate scenario projects that, by 2050, tidal flooding could occur roughly 150 times per year, while in the highest scenario it occurs nearly 370 times per year—that is, the base may experience flooding once daily with high tide, on average. With such regular flooding, affected areas could become unusable land within the next 35 years.

Indeed, with the 6.1 feet of sea level rise projected for the end of the century in this scenario, flood-prone areas of NS Mayport will be underwater nearly 90 percent of the year (see Table 2, p. 4), while more than half of the station, including developed areas, will flood daily, becoming part of the tidal zone (see Figure 2, p. 4).

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



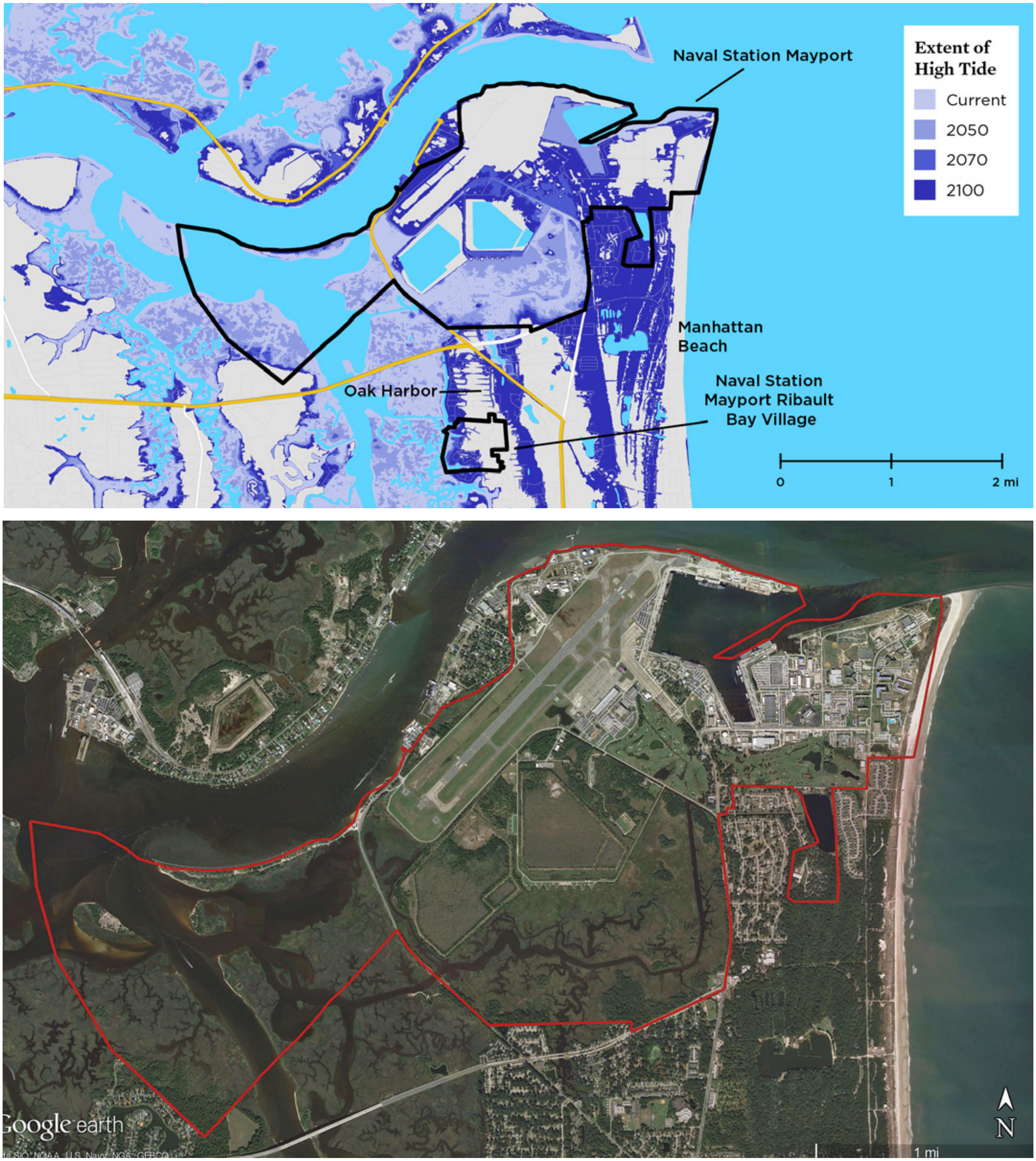
As sea level rises, extreme tides cause local flood conditions to occur more often, to a greater extent, and for longer time periods. And the daily high tide line can eventually begin to encompass new areas, shifting the tidal zone onto presently utilized land. In this analysis, land inundated by at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

TABLE 2. Areas Prone to Flooding Could Be Underwater Most of the Time by 2100

	Intermediate		Highest	
Year	Events per Year	% of Year	Events per Year	% of Year
2012	7 ± 6	0	7 ± 6	0
2050	145 ± 40	4	366 ± 48	11
2070	483 ± 40	16	696 ± 5	39
2100	703 ± 2	48	391 ± 45	88

Sea level rise will lead to constant or near-constant flooding in low-lying areas around NS Mayport. Shown here are flood events projected by the intermediate and highest scenarios. Events per year are reported as the average over a five-year period with one standard deviation. Percent of year is reported simply as the average over a five-year period. As flood conditions begin to span multiple high tide cycles, the number of distinct flood events gradually drops, while the duration of flooding increases. Installations will be affected by this flooding depending on the presence of low-lying land on-site.

FIGURE 3. NS Mayport Is Expected to Lose Currently Utilized Land to the Sea



The projected reach of future daily high tides, shown in the top panel encompasses currently utilized land at NS Mayport, shown on the bottom. The highest scenario is mapped here. In this scenario, the area shown in purple floods with daily high tides.

SOURCE: GOOGLE EARTH. DATA FROM SIO, NOAA, US NAVY, NGA, AND GEBCO.


US Navy

Sailors and marines aboard the USS Iwo Jima, August 2014. NS Mayport is home to both the nation's 3rd largest naval fleet and thousands of active duty service people and their family members (more than 15,000 and 32,000, respectively). Nearby residential areas are among those affected by increased flooding.

THE CHANGING THREAT OF HURRICANES

Given the history of hurricanes affecting the Atlantic coast of Florida, Category 1 and 2 hurricanes are the type most likely to hit NS Mayport. Over time, sea level rise exposes a greater proportion of the station's area to inundation. This is particularly true for Category 1 storms. Today, Category 1 and 2 storms expose about 60 percent and 80 percent of NS Mayport to storm surge flooding, respectively. The area exposed to storm surge from a Category 1 storm rises to 67 percent by 2050 and to 71 percent by 2070 in the intermediate scenario. By 2100, when the intermediate scenario projects local sea level to be 3.7 feet higher than it is now, the area of the station exposed to storm surge flooding is just short of 80 percent for Category 1 storms and more than 90 percent for Category 2 storms. A Category 1 storm in 2100 would cause about the same extent of inundation as today's Category 2 storms. Likewise, a Category 2 storm would cause about the same extent of inundation as today's Category 3 storms.

Sea level rise also makes the depth of inundation more severe for all storm categories and sea level rise scenarios at NS Mayport. Whereas the majority of flooding from a Category 2 storm today would be less than 10 feet deep, more than 25 percent of the station is exposed to flooding 10 to 15 feet deep in 2070 in the intermediate scenario. By 2100, the majority of the flooding from a Category 2 storm would be 10 to 15 feet deep.

Category 3, 4, and 5 hurricanes affecting NS Mayport today all expose more than 90 percent of the station to storm surge flooding. The depth of inundation increases with each storm category. Because flood exposure is already so high, the extent of inundation from these strong hurricanes does not increase substantially as sea level rises. The depth of flooding, however, does. For this region, a Category 4 storm in the highest scenario represents a worst-case scenario. A Category 4 storm today exposes about 50 percent of the station to floods more than 15 feet deep. In the highest scenario, the area exposed to 15 feet or deeper flooding rises to roughly 60 percent in 2050, 65 percent in 2070, and 80 percent in 2100.

Mobilizing on the Front Lines of Sea Level Rise

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). A recent DOD study, for example, informs NS Mayport's climate preparedness activities and can help guide the installation toward cost-effective investments (Donoghue et al. 2013).

But here and across US coastal installations there is still far to go: the gap between the military's current sea level rise preparedness and the threats outlined by this analysis 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, including NS Mayport, face all of these risks.

This analysis provides snapshots of potential future exposure to flooding at NS Mayport. For the base to take action on the front line of sea level rise, however, it 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 planning efforts and to detailed mapping that includes future conditions; support planning partnerships with surrounding communities; and allocate resources for preparedness projects, on- and off-site, many of which will stretch over decades.

Military bases and personnel protect the country from external threats. 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.

ENDNOTES

1 *The intermediate sea level rise scenario assumes ice sheet loss that increases over time, while the highest scenario assumes rapid loss of ice sheets. The latter scenario is particularly useful for decisions involving an especially low tolerance for risk. These results are a small subset of the full analysis. For more information, the technical appendix, and downloadable maps, see www.ucsusa.org/MilitarySeasRising.*

2 *UCS analyzed storm surge depth and exposure extent for each base using the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model, developed by the National Oceanic and Atmospheric Administration (NOAA), for storm events ranging in severity from Category 1 to Category 5, in addition to tidal floods. Both storm surge and flooding during extra-high tides can be significantly exacerbated by rainfall and wave action, neither of which we included in this study.*

3 *This analysis involved consultation with contacts at multiple installations. However, in some instances, 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.*

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The US Military on the Front Lines of Rising Seas

Exposure to Coastal Flooding at Naval Submarine Base Kings Bay, Georgia

HIGHLIGHTS

With seas rising at an accelerating rate, coastal military installations are increasingly exposed to storm surge and tidal flooding. The Union of Concerned Scientists (UCS) conducted analyses of this changing exposure for 18 military installations along the East and Gulf coasts. Analysis for Naval Submarine Base (NSB) Kings Bay found that in the second half of this century, in the absence of preventive measures, this installation can expect substantial increases in the extent and severity of storm-driven flooding to which it is exposed and frequent tidal flooding.:

The US Armed Forces depend on safe and functional bases, such as NSB Kings Bay, Georgia, to carry out their stated mission: to provide the military forces needed to deter war and to protect the security of the country. A roughly three-foot increase in sea level would threaten 128 coastal Department of Defense (DOD) installations in the United States and the livelihoods of the people—both military personnel and civilians—who depend on them (NAS 2011). In the area of Kings Bay, seas are projected to rise between 3.7 and 6.1 feet by the end of this century.

To enable decision makers to better understand the sea level rise threat, and where and when it could become acute, UCS has performed a new analysis of 18 East and Gulf Coast military installations, including NSB Kings Bay. These sites were selected 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.

UCS projected exposure to coastal flooding in the years 2050, 2070, and 2100 using the National Climate Assessment's midrange, or "intermediate-high," scenario (referred to here as "intermediate") and, in light of the low tolerance for risk in some of the military's decisions, a "highest" scenario based on a more rapid rate of increase (Parris et al. 2012).[1] We modeled tidal flooding, permanent inundation, and storm surge from hurricanes.[2] The results below outline potential future flooding to which NSB Kings Bay could be exposed, assuming no new measures are taken to prevent or reduce flooding.[3] This analysis finds the following key results:

US Navy

NO BASE IS AN ISLAND

Low-lying areas around NSB Kings Bay, eventually including roadways, are projected to experience substantial increases in the frequency and extent of tidal flooding. This flooding of neighboring areas will potentially affect the installation itself.

STORM SURGE

- **Sea level rise exposes previously unaffected areas of NSB Kings Bay to storm surge flooding**. In either the intermediate or the highest scenario, the area exposed to flooding during a Category 1 storm in 2100 is equivalent to the area exposed during a Category 2 storm today. In an end-of-century worst-case scenario involving a Category 4 storm, six feet of sea level rise could expose 20 percent more of the base to storm surge flooding than is exposed today.
- **Sea level rise increases the exposure of NSB Kings Bay to deeper, more severe flooding**. A Category 4 storm today would expose almost none of the base to 20-foot storm surge depths. With six feet of sea level rise projected in the highest scenario for late this century, a Category 4 storm would flood nearly 95 percent of the base, and more than half of that area would be under 20 feet or more of water.

TIDAL FLOODING

- **Certain areas face daily high tide flooding**. Today, tidal flooding affects low-lying, mainly wetland areas of NSB Kings Bay, just a couple of times per year on average. This flooding occurs roughly 250 times per year in 2070 in the intermediate scenario and more than 600 times per year in the highest scenario, with flooding occurring during both daily high tides on average.
- **Sea level rise threatens certain areas with permanent inundation**. With such regular flooding, areas that are currently wetlands would be at risk of shifting to open water, depending on the ecosystem's ability to keep up with rising seas. Since wetlands typically provide flood protection to inland areas, their health and integrity have bearing on the vulnerability of the installation itself.

Base Information

NSB Kings Bay is located along the Intracoastal Waterway near the town of St. Marys, Georgia. Roughly one-quarter of the base's approximately 18,000 acres consist of protected wetlands (JDA Camden County 2014). The mainland installation is somewhat protected by Cumberland Island, the state's largest barrier island (JDA Camden County 2014).

As the home for the Navy's Atlantic-based nuclear-powered submarines armed with ballistic or guided missiles, NSB Kings Bay is an important part of the country's strategic defense system (CNIC 2016; DOD 2016). Additionally, the base's Trident Training Facility trains sailors to operate submarines, and the Trident Refit Facility maintains and repairs them.[4]

NSB Kings Bay

Size (Acres):	18,058
Established:	1978
Active Duty:	5,244
Total Workforce:	8,797
Total Economic Impact:	$706 million

SOURCE: CAMDEN PARTNERSHIP 2016; JDA CAMDEN COUNTY 2014.

Camden County is home to nearly 3,400 current members of the Armed Forces and more than 7,000 veterans (US Census Bureau 2014).

Historic Exposure to Storm Surge and Flood Hazards

The Naval Research Laboratory has found that NSB Kings Bay is extremely vulnerable to the effects of a hurricane strike, and it is expected to experience sustained hurricane winds once every 28 years, on average (Handlers and Brand 2004).

Since 1851, there have been 59 hurricanes that have come within 150 nautical miles of the base, of which 26 were within 75 miles (NOAA n.d.). Since 1985, no significant storm surge has occurred in Kings Bay, which is somewhat protected from open ocean swell and waves generated in the deeper areas of the adjacent tidal sounds (Handlers and Brand 2004). Simulations of hypothetical storms using the SLOSH model, however, demonstrate that, despite the region's natural protection, storm surge could significantly affect the area.

Future (Projected) Exposure to Storm Surge and Flood Hazards

SEA LEVEL RISE

The intermediate scenario projects that NSB Kings Bay will experience 3.7 feet of sea level rise and the highest scenario projects 6.1 feet of rise by 2100. This rise will lead to increased exposure to different types of coastal flooding.

TIDAL FLOODING

As sea level rises, flooding associated with extreme tides is expected to become more extensive and frequent. NSB Kings Bay contains large swaths of low-lying marshland, much of which already floods during occasional extra-high tides.

Tidal flooding would occur roughly 250 times per year in the intermediate scenario and more than 600 times per year in the highest scenario by 2070. With the highest scenario, this flooding occurs with both daily high tides on average.

> ***Tidal flooding would occur roughly 250 times per year in the intermediate scenario and more than 600 times per year in the highest scenario by 2070.***

With such regular flooding, affected locations in the region could become unusable land within the next 35 years, and wetland areas would be at risk of shifting to open water, depending on the ecosystem's ability to keep up with rising seas. By 2100 in the highest scenario, NSB Kings Bay's flood-prone areas would be underwater not just at high tide, but more than 60 percent of the year. In both scenarios, tidal flooding is projected to inundate roadways within the southern portion of the base by 2100.

TABLE 1. NSB Kings Bay Projected Sea Level Rise (Feet) in Two Scenarios

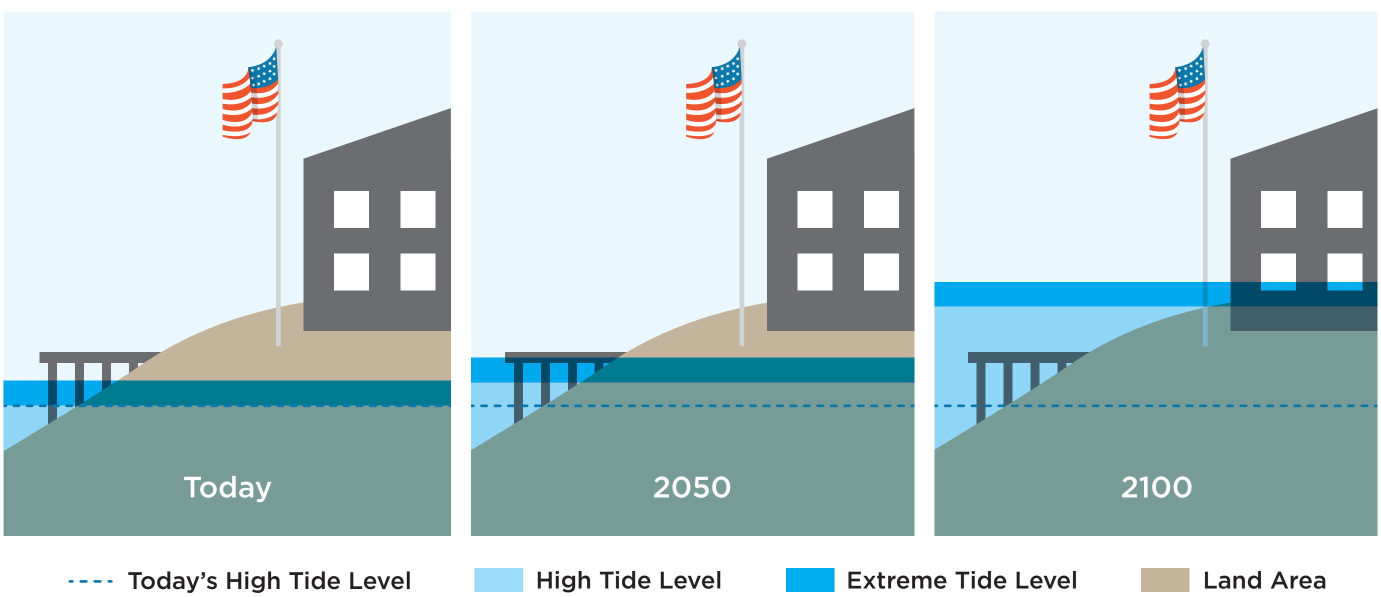
Year	Intermediate	Highest
2050	1.1	1.7
2070	1.9	3.1
2100	3.7	6.1

In the intermediate scenario, ice sheet loss increases gradually in the coming decades; in the highest scenario, more rapid loss of ice sheets occurs. The latter scenario is included in this analysis to help inform decisions involving an especially 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 (DeConto and Pollard 2016; Trusel et al. 2015; Chen et al. 2013; Rignot et al. 2011). Values shown are local projections that include unique regional dynamics such as land subsidence (see www.ucsusa.org/MilitarySeasRising).

THE CHANGING THREAT OF HURRICANES

Sea level rise contributes to greater storm surge and exposes a greater proportion of the base's area to surge from any storm category. Today, a Category 1 storm (the most likely to affect this area) exposes roughly 50 percent of NSB Kings Bay to flooding from storm surge. In the intermediate scenario, an

FIGURE 1. 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.

TABLE 2. Current and Future Tidal Flooding Frequency around NSB Kings Bay

	Intermediate		Highest	
Year	Events per Year	% of Year	Events per Year	% of Year
2012	2 ± 3	0	2 ± 3	0
2050	56 ± 15	1	172 ± 31	4
2070	254 ± 34	6	614 ± 15	23
2100	681 ± 10	31	694 ± 9	61

Shown here are flood events in low-lying, flood-prone areas projected by the intermediate and highest scenarios. Installations will be affected by this flooding depending on the presence of low-lying land on-site. Events per year are reported as the average over a five-year period with one standard deviation. Percent of year is reported simply as the average over a five-year period.

additional 1,000 acres—an area larger than Central Park—will be exposed to flooding from such a storm by 2100. In the highest scenario, the area exposed to flooding during a Category 1 storm in 2100 is equivalent to the area exposed during a Category 2 storm today.

Sea level rise also changes the depth of flooding NSB Kings Bay can expect with major storms. Whereas only about 20 percent of the base is exposed to five feet or more of flooding during a Category 1 storm today, nearly 50 percent of the base will be exposed to such flooding in 2100.

For this region, a Category 4 storm occurring after more than six feet of sea level rise represents the worst-case scenario in our analysis for future storm surge inundation. Today, a Category 4 storm would expose about 75 percent of NSB Kings Bay—including most of its utilized land—to flooding. In 2100 in the highest scenario, roughly 95 percent of NSB Kings Bay would be exposed to storm surge flooding. Of particular note is the fact that more than half of the flooded areas would be under more than 20 feet of water, whereas today almost none of the base would see such depths.

Mobilizing on the Sea Level Rise Front Lines

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).

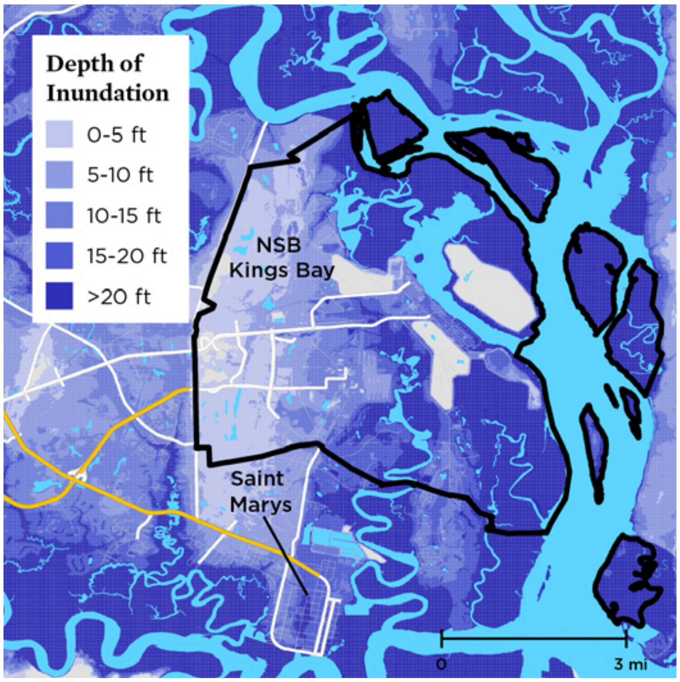
Because of its low elevation and hurricane risk, the military recognizes the need for flood risk planning and mitigation at NSB Kings Bay. The ability to generate power on-site and the presence of backup systems allow NSB Kings Bay to function independently of local utility systems (JDA Camden County 2014). NSB Kings Bay and Camden County have worked together to complete a joint land use study and engaged in hazard mitigation planning to help prepare for natural disasters such as hurricanes (JDA Camden County 2014).

[The gap between the military's current sea level rise preparedness and the threats outlined by this analysis is large and growing.]

But here and across coastal installations there is still far to go: the gap between the military's current sea level rise preparedness and the threats outlined by this analysis 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, including NSB Kings Bay, face all of these risks.

This analysis provides snapshots of potential future exposure to flooding at NSB Kings Bay. For the military to take action on the front line of sea level rise, however, it 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 planning efforts and to detailed mapping that includes future conditions; support planning partnerships with surrounding communities; and allocate resources for preparedness projects, on- and off-site, many of which will stretch over decades.

FIGURE 2. NSB Kings Bay Faces Exposure to Increased Flood Depths



Shown here is the depth of inundation at NSB Kings Bay from a Category 4 storm in 2100 in the highest scenario. Today, almost none of the base would see flood depths over 20 feet. But in 2100, more than half of the flooded areas would be under more than 20 feet of water, affecting developed areas, shown at bottom.

SOURCE: GOOGLE EARTH.

Military bases and personnel protect the country from external threats. 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.

ENDNOTES

1 *The intermediate sea level rise scenario assumes ice sheet loss that increases over time, while the highest scenario assumes rapid loss of ice sheets. The latter scenario is particularly useful for decisions involving an especially low tolerance for risk. These results are a small subset of the full analysis. For more information, the technical appendix, and downloadable maps, see www.ucsusa.org/MilitarySeasRising.*

2 *UCS analyzed storm surge depth and exposure extent for each base using the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model, developed by the National Oceanic and Atmospheric Administration (NOAA), for storm events ranging in severity from Category 1 to Category 5, in addition to tidal floods. Both storm surge and flooding during extra-high tides can be significantly exacerbated by rainfall and wave action, neither of which was included in this study.*

3 *This analysis involved consultation with contacts at multiple installations. However, in some instances, 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.*

4 *NSB Kings Bay has a total of six major commands: Strategic Weapons Facility, Atlantic; Commander Submarine Group Ten; Trident Refit Facility; Trident Training Facility; US Marine Corps Security Force Battalion; and the US Coast Guard Maritime Force Protection Unit. It also has 60 supporting commands and tenants (JDA Camden County 2014).*

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FACT SHEET

The US Military on the Front Lines of Rising Seas

Exposure to Coastal Flooding at Hunter Army Airfield, Georgia

HIGHLIGHTS

With seas rising at an accelerating rate, coastal military installations are increasingly exposed to storm surge and tidal flooding. The Union of Concerned Scientists (UCS) conducted analyses of this changing exposure for 18 military installations along the East and Gulf coasts. Analysis for Hunter Army Airfield (HAAF) found that in the second half of this century, in the absence of preventive measures, this installation can expect frequent and extensive tidal flooding, loss of currently utilized land, and substantial increases in the extent and severity of storm-driven flooding to which it is exposed.

The US Armed Forces depend on safe and functional bases, such as HAAF, Georgia, to carry out their stated mission: to provide the military forces needed to deter war and to protect the security of the country. A roughly three-foot increase in sea level would threaten 128 coastal Department of Defense (DOD) installations in the United States and the livelihoods of the people—both military personnel and civilians—who depend on them (NAS 2011). In the area of HAAF, seas are projected to rise between four and 6.4 feet by the end of this century.

To enable decision makers to better understand the sea level rise threat, and where and when it could become acute, UCS has performed a new analysis of 18 East and Gulf Coast military installations, including HAAF. These sites were selected 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.

UCS projected exposure to coastal flooding in the years 2050, 2070, and 2100 using the National Climate Assessment's midrange or "intermediate-high" scenario (referred to here as "intermediate") and, in light of the low tolerance for risk in some of the military's decisions, a "highest" scenario based on a more rapid rate of increase (Parris et al. 2012).[1] We modeled tidal flooding, permanent inundation, and storm surge from hurricanes.[2] The results below outline potential future flooding to which the airfield could be exposed, assuming no new measures are taken to prevent or reduce flooding.[3] This analysis finds the following key results:

US Army

HAAF AND AN UNFORESEEN RISK

Exposure of HAAF's developed areas to regular tidal flooding is projected to remain fairly low this century. However, the installation's protective wetlands are highly exposed: they risk shifting to open water, depending on the ability of the ecosystem to keep pace with rising seas.

TIDAL FLOODING, PERMANENT INUNDATION, AND LAND LOSS

- **Areas currently affected by occasional tidal flooding could flood with each high tide.** Today, low-lying, flood-prone areas around HAAF experience tidal flooding about 10 times per year. In the intermediate scenario, these areas would experience tidal flooding more than 150 times per year on average by 2050; in the highest scenario, tidal flooding would occur nearly daily by that date. In the highest scenario, flood-prone locations flood twice daily on average and are underwater roughly 30 percent of the time by 2070.
- **Flooding during extreme high tides will become more extensive.** Later this century, the nearby towns of Savannah and Georgetown could experience tidal floods far more extensive than those experienced today. Such flooding could affect transportation routes and other infrastructure important to HAAF.
- **Sea level rise threatens to permanently inundate certain areas.** With such regular flooding, the airfield's protective wetland areas would be at risk of shifting to open water, depending on the ecosystem's ability to keep up with rising seas.

STORM SURGE

- **Sea level rise exposes previously unaffected areas of HAAF to storm surge flooding.** By 2100 in the intermediate scenario, sea level rise increases the area exposed to flooding by a Category 1 storm from 25 percent to over 30 percent; it increases to almost 45 percent in the highest scenario.
- **Sea level rise exposes HAAF to deeper, more severe flooding.** In an end-of-century worst-case scenario, three-quarters of the airfield is exposed to storm surge flooding, and more than half of that flooding is 10 feet or more deep.

Base Information

HAAF is located in a low-lying area of Chatham County, Georgia, about 10 miles south of Savannah. Roughly one-third of the installation consists of wetlands (US Army 2015).

HAAF provides training, administrative, and logistical support to soldiers stationed at nearby Fort Stewart, the largest Army installation on the East Coast (DOD 2016). The airfield is home to the Army's longest East Coast runway (over 11,000 feet) as well as Coast Guard Air Station Savannah, which provides search and rescue coverage of the region (US Army 2015). An important unit stationed at HAAF is the First Battalion of the 75th Ranger Regiment.

Hunter Army Airfield (HAAF)

Branch:	Army
Established:	1929
Size (Acres):	5,496
Active Duty:	5,700
Active Duty Family Members:	5,212
Civilians:	737
Retirees:	6,004
Retirees' Family Members:	9,177

SOURCE: DOD 2016; US ARMY 2015

HAAF is an integral part of Chatham County's community and, more broadly, the economy of southeast Georgia. Together with nearby Fort Stewart, HAAF's total economic contribution in southeast Georgia is estimated at $5.2 billion annually (SGFFSH 2012).

Historic Exposure to Storm Surge and Flood Hazards

Since 1853, 91 coastal storms, including five hurricanes, have affected Chatham County (NOAA n.d.; Chatham County 2012). During that time, 53 hurricanes have passed within 150 nautical miles of the base (NOAA n.d.). The last hurricane to make landfall in Chatham County was the "Sea Islands Hurricane," which hit in 1893. The storm surge may have reached as high as 30 feet, and the hurricane caused an estimated 1,000 to 2,000 deaths (Chatham County 2015; Chatham County 2012). Another hurricane, in 1898, was the last to directly hit the state of Georgia, making landfall on Cumberland Island with peak wind speed of around 135 miles per hour. Damage was valued at over $1 million, with storm surges along most areas of the Georgia coastline leading to fatalities as well as damage to and destruction of crops and boats (Chatham County 2015).

In recent history, however, there has been no record of direct storm surge events affecting HAAF (Chatham County 2012; Bettinger, Merry, and Hepinstall-Cymerman 2010). During this lull, critical resources have been amassed at local installations, raising the risk of damages should a storm strike.

Future (Projected) Exposure to Storm Surge and Flood Hazards

The intermediate scenario projects that HAAF will experience four feet of sea level rise, and the highest scenario projects 6.4 feet of rise, by 2100. This rise will lead to increased exposure to different types of coastal flooding.

TIDAL FLOODING

Today, tidal flooding affects low-lying areas in this region about 10 times per year, on average. At HAAF, mainly wetland areas are affected, but in neighboring Savannah, this flooding can be disruptive to daily lives and the regional economy (City of Savannah n.d.). Savannah, moreover, is a major port, relied upon for the shipment of materials and equipment that support local bases, including the Third Infantry Division at Fort Stewart (US Army 2015).

By 2070, tidal flooding would occur, on average, roughly 440 times per year in the intermediate scenario and roughly 670 times per year in the highest scenario, meaning flooding would occur with more than daily frequency (see Table 2). By the end of the century, flood-prone areas are underwater roughly 40 to 60 percent of the time, depending on scenario. This means that adjacent areas at higher elevation will also be underwater, although for shorter durations.

In both scenarios, tidal flooding is expected to disrupt neighboring communities on which HAAF depends by mid-century and to reach into HAAF by late century, inundating

TABLE 1. HAAF: Projected Sea Level Rise (Feet) in Two Scenarios

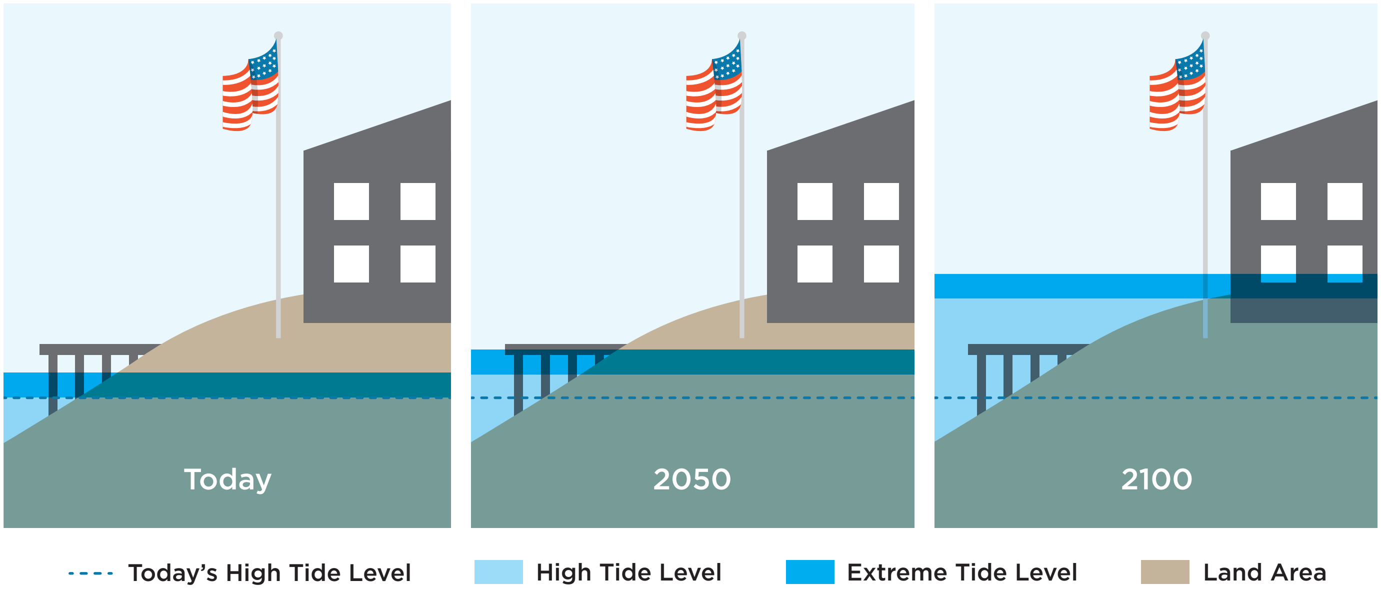
Year	Intermediate	Highest
2050	1.2	1.8
2070	2.1	3.3
2100	4.0	6.4

In the intermediate scenario, ice sheet loss increases gradually in the coming decades; in the highest scenario, more rapid loss of ice sheets occurs. The latter scenario is included in this analysis to help inform decisions involving an especially 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 (DeConto and Pollard 2016; Trusel et al. 2015; Chen et al. 2013; Rignot et al. 2011). Values shown are local projections that include unique regional dynamics such as land subsidence (see www.ucsusa.org/MilitarySeasRising).

TIDAL FLOODING A GROWING PROBLEM AROUND HAAF

Extreme tides in October 2015 drove flooding of Highway 80, about 15 miles from HAAF. Tidal flooding in the region is projected to increase this century and to affect not just current flooding hot spots like this route, but also significant areas of neighboring cities such as Savannah and Georgetown. This may in turn affect HAAF and other bases in the region, given their interdependencies with the cities.

FIGURE 1. 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.

roadways. Beyond nuisance flooding, Savannah and Georgetown could experience widespread disruptive flooding an average of 10 times per year in the latter half of the century.

Without substantial adaptive measures, affected land, including low-lying roadways and neighborhoods, could become unusable in these timeframes; the consequences of flooding on the surrounding region—for example, damage to housing and travel delays affecting the HAAF community of workers and personnel housed off base—could affect HAAF.

Within HAAF itself, wetlands are projected to be inundated later this century, depending on the ecosystem's ability to keep up with rising seas. Because wetlands typically provide flood protection to inland areas, their fate can have a bearing on the rest of the airfield.

THE CHANGING THREAT OF HURRICANES

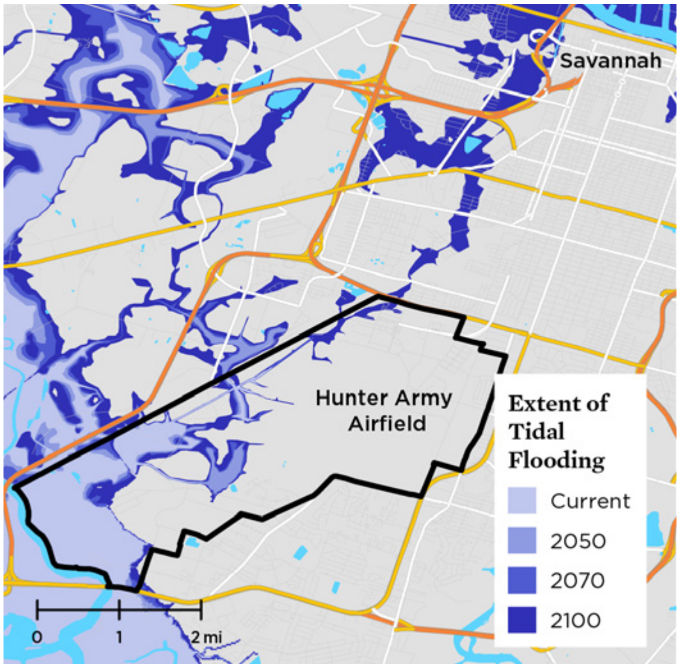
Today, a Category 1 storm exposes 25 percent of HAAF to flooding related to storm surge. In the intermediate scenario,

TABLE 2. Current and Future Tidal Flooding Frequency around HAAF

	Intermediate		Highest	
Year	Events per Year	% of Year	Events per Year	% of Year
2012	10 ± 7	0	10 ± 7	0
2050	152 ± 26	3	327 ± 38	8
2070	438 ± 38	13	671 ± 7	29
2100	698 ± 2	38	702 ± 4	62

Shown here are flood events in low-lying, flood-prone areas projected by the intermediate and highest scenarios. Installations will be affected by this flooding depending on the presence of low-lying land on-site. Events per year are reported as the average over a five-year period with one standard deviation. Percent of year is reported simply as the average over a five-year period.

FIGURE 2. Extreme Tides to Affect Undeveloped HAAF but Developed Savannah



With the higher rate of sea level rise, tidal flooding is projected to inundate parts of Savannah and other developed areas surrounding HAAF about 10 times per year late this century.

SOURCE: GOOGLE EARTH

the area exposed to flooding increases to over 30 percent by 2100; in the highest scenario, it increases to almost 45 percent. In the highest scenario, the extent of inundation resulting from a Category 1 storm in 2100 is equivalent to the extent resulting from a Category 2 storm today.

Sea level rise also changes the depth of flooding that HAAF can expect with major storms. Today, two-thirds of the inundation resulting from a Category 1 storm at HAAF is five feet deep or less. But by 2100 in the intermediate scenario, roughly two-thirds of the flooding at HAAF would be more than five feet deep.

In our analysis, a Category 4 storm in the highest scenario is the worst case for future storm surge inundation in this region. Today, a Category 4 storm would expose just over 65 percent of HAAF to flooding from storm surge. By 2100, almost 75 percent of HAAF would be exposed to storm surge flooding; more than half of that flooding would be more than 10 feet deep.

Mobilizing on the Sea Level Rise Front Lines

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). Army leadership in this region of Georgia is keenly aware that it has been a long time since the last direct hurricane strike, and it is also keenly aware of future flood risks. Chatham County has flood hazard mitigation measures in place, and planning is under way for a flood and hazard mitigation plan that would cover multiple municipal jurisdictions (Chatham County 2015; Chatham County 2012).

But here and across US coastal installations there is still far to go: the gap between the military's current sea level rise preparedness and the threats outlined by this analysis 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, including HAAF, face all of these risks.

This analysis provides snapshots of potential future exposure to flooding at and around HAAF. For the Army to take action on the front line of sea level rise, however, it 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 planning efforts and to detailed mapping that includes future conditions; support planning partnerships with surrounding communities; and allocate resources for preparedness projects, on- and off-site, many of which will stretch over decades.

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Union of Concerned Scientists

FACT SHEET

The US Military on the Front Lines of Rising Seas

Exposure to Coastal Flooding at Marine Corps Recruit Depot Parris Island and Marine Corps Air Station Beaufort, South Carolina

HIGHLIGHTS

With seas rising at an accelerating rate, coastal military installations are increasingly exposed to storm surge and tidal flooding. The Union of Concerned Scientists (UCS) conducted analyses of this changing exposure for 18 military installations along the East and Gulf coasts. Analysis for Marine Corps Recruit Depot (MCRD) Parris Island and Marine Corps Air Station (MCAS) Beaufort, both in South Carolina, found that in the second half of this century, in the absence of preventive measures, Parris Island in particular can expect more frequent and extensive tidal flooding, loss of currently utilized land, and substantial increases in the extent and severity of storm-driven flooding to which it is exposed.

The US Armed Forces depend on safe and functional bases, such as MCRD Parris Island and MCAS Beaufort in South Carolina, to carry out their stated mission: to provide the military forces needed to deter war and to protect the security of the country. A roughly three-foot increase in sea level would threaten 128 coastal Department of Defense (DOD) installations in the United States and the livelihoods of the people—both military personnel and civilians—who depend on them (NAS 2011). In the area around Beaufort, seas are projected to rise between 4.0 and 6.4 feet by the end of this century.

To enable decision makers to better understand the sea level rise threat, and where and when it could become acute, UCS has performed a new analysis of 18 East and Gulf Coast military installations, including MCRD Parris Island and MCAS Beaufort. These sites were selected 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.

UCS projected exposure to coastal flooding in the years 2050, 2070, and 2100 using the National Climate Assessment's midrange or "intermediate-high" scenario (referred to here as "intermediate") and, in light of the low tolerance for risk in some of the military's decisions, a "highest" scenario based on a more rapid rate of increase (Parris et al. 2012).[1] We modeled tidal flooding, permanent inundation, and storm surge from hurricanes.[2] The results below outline potential future flooding to which MCRD Parris Island and MCAS Beaufort could be exposed, assuming no new measures are taken to prevent or reduce flooding.[3] This analysis finds the following key results:

US Marine Corps

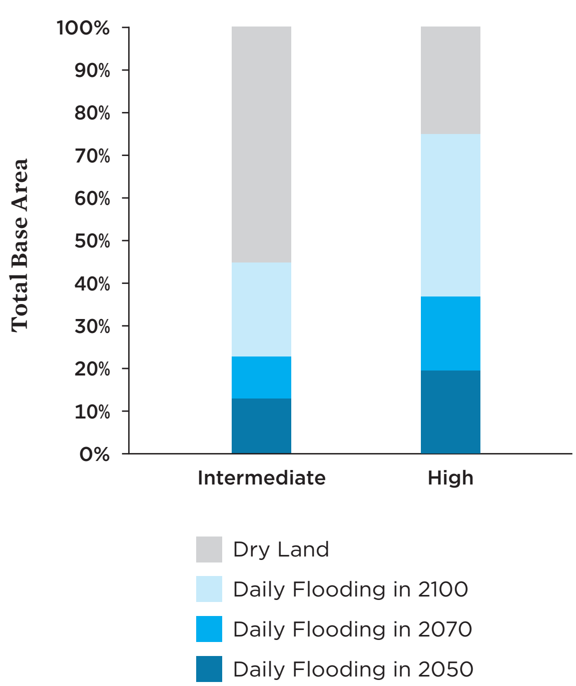
THE INLAND MARCH OF HIGH TIDE

MCRD Parris Island is one of only two installations in the nation where marine recruits are trained. Much of the land consists of marshes and the majority of the base lies less than 10 feet above sea level. With between 4.0 and 6.5 feet of sea level rise expected later this century, major land losses are foreseeable.

TIDAL FLOODING, PERMANENT INUNDATION, AND LAND LOSS

- **Certain areas face daily high tide flooding**. Today, tidal flooding affects low-lying locations around MCAS Beaufort and MCRD Parris Island, including extensive wetland areas, 10 times per year on average. By 2050, the currently flood-prone areas within both bases could experience tidal flooding more than 300 times annually and be underwater nearly 30 percent of the year given the highest scenario.
- **Flooding during extreme high tides will become more extensive**. Later this century, the higher water levels caused by extreme tides could inundate 85 percent of MCRD Parris Island's land, both wetlands and developed areas, roughly 10 times per year given the highest scenario.
- **Extensive land loss at MCRD Parris Island is possible**. Parris Island is already highly prone to flooding. A projected 6.4 feet of sea level rise (the highest scenario) by 2100 would inundate three-quarters of MCRD Parris Island's land, including developed areas, with the daily high tides.

FIGURE 1. Land Loss at MCRD Parris Island



As high tide reaches farther inland, extensive land loss is possible at MCRD Parris Island. Affected land may include developed and undeveloped areas and even wetlands that reside above the current high tide mark. Substantial loss of currently utilized areas is projected.

STORM SURGE

- **Sea level rise exposes previously unaffected areas of MCRD Parris Island and MCAS Beaufort to storm surge flooding**. In this relatively low-lying area, sea level rise will have a substantial effect on the extent of inundation. In 2100 in the intermediate scenario, sea level rise increases the area of MCAS Beaufort exposed to flooding during all categories of storms by about 10 percent compared to today; exposure to flooding increases nearly 15 percent in the highest scenario.
- **Sea level rise exposes MCRD Parris Island and MCAS Beaufort to deeper, more severe flooding**. As sea level rises, the depth of inundation related to storm surge increases. In general, over time, the area inundated by five feet or more of seawater during storm surges increases. In an end-of-century worst-case scenario involving a Category 4 storm, a predicted six feet of sea level rise could double the area exposed to flood depths of 20 feet or more at MCAS Beaufort—from 17 to 34 percent of the installation.

Base Information

MCAS Beaufort and MCRD Parris Island are located in Beaufort County, just south of the city of Beaufort in South Carolina Lowcountry. The region is relatively low lying, particularly MCRD Parris Island, where much of the land consists of marshes and the majority of the installation lies less than 10 feet above sea level. The region is also home to US Naval Hospital Beaufort and a Marine Corps housing complex.

MCAS Beaufort

Branch:	Marine
Established:	1943
Size (Acres):	7,808
MC Squadrons:	7
Navy Squadrons:	2
Marines and Sailors:	700
Civilian Personnel:	600

MCRD Parris Island

Branch:	Marine
Size (Acres):	5,615
Annual Recruits:	19,000

SOURCE: BEAUFORT ONLINE 2016; GLOBAL SECURITY.ORG 2011.

MCAS Beaufort is home to one of the largest military airstrips in the world as well as fighter and attack squadrons belonging to both the Marine Corps and the Navy (Beaufort Online 2016). MCRD Parris Island lies to the south of MCAS Beaufort and is one of only two installations in the nation where marine recruits are trained (Global Security.org 2011).

Historic Exposure to Storm Surge and Flood Hazards

From 1900 to 2009, eight hurricanes struck Beaufort County, including four Category 1, two Category 2, and two Category 3 hurricanes (NHC 2010). The surrounding area has seen a greater amount of hurricane activity: since 1851, 58 hurricanes have tracked within 150 nautical miles of MCRD Parris Island (NOAA n.d.), 37 of them within 75 miles. Current estimation of the annual chance of a hurricane affecting Beaufort County is 13 percent (LCGPD 2009).

Future (Projected) Exposure to Storm Surge and Flood Hazards

SEA LEVEL RISE

The intermediate scenario projects that both installations will experience 4.0 feet of sea level rise and the highest scenario projects 6.4 feet of rise by 2100. This rise will lead to increased exposure to different types of coastal flooding.

TIDAL FLOODING AND LAND LOSS

As sea level rises, extreme tide flooding—flooding that reaches beyond the daily high tide mark—is expected to become more extensive and frequent. Low-lying areas, including large portions of MCRD Parris Island, mainly wetlands, are already exposed to flooding during extra-high tides 10 times per year on average. The frequency of tidal flooding in these areas increases steeply over this century in both scenarios until flood-prone areas flood with each high tide, as outlined in Table 2 (p. 4). Areas currently affected by occasional tidal flooding could flood daily. Depending on the scenario, flood-prone areas in this region experience between 150 and 325 floods, approximately, per year by 2050—compared to less than a dozen today. In the highest scenario, flood-prone areas throughout the region experience flooding with each of the two daily high tides and are underwater roughly 30 percent of the time by 2070. And by late century, 85 percent of the installation's land area would be inundated during extreme tides, approximately 10 times per year (see Figure 3, p. 5).

MCAS Beaufort, with less low-lying land than MCRD Parris Island, will be less directly affected by tidal flooding. Shown here are flood events in low-lying areas projected by the intermediate and highest scenarios. As flood conditions begin to span multiple tide cycles, the rate of increase in distinct flood events slows, but the duration of flooding increases. Events per year are reported as the average over a five-year period with one standard deviation. Percent of year is reported simply as the average over a five-year period.

With about three feet of sea level rise, nearly 40 percent of MCRD Parris Island's land area—including roadways and facilities—would be exposed to flood with each high tide; if sea level rises more than six feet, as projected for the end of the century in the highest scenario, three-quarters of the installation's land area would become part of the tidal zone (see Figure 1). Sitting at a higher elevation, MCAS Beaufort is expected to experience far less of this flooding.

TABLE 1. Beaufort Area Bases: Projected Sea Level Rise (Feet) in Two Scenarios

Year	Intermediate	Highest
2050	1.2	1.8
2070	2.1	3.3
2100	4.0	6.4

In the intermediate scenario, ice sheet loss increases gradually in the coming decades; in the highest scenario, more rapid loss of ice sheets occurs. The latter scenario is included in this analysis to help inform decisions involving an especially 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 (Rignot et al. 2011; Chen et al. 2013; Trusel et al. 2015; DeConto and Pollard 2016). Values shown are local projections that include unique regional dynamics such as land subsidence (see www.ucsusa.org/MilitarySeasRising).

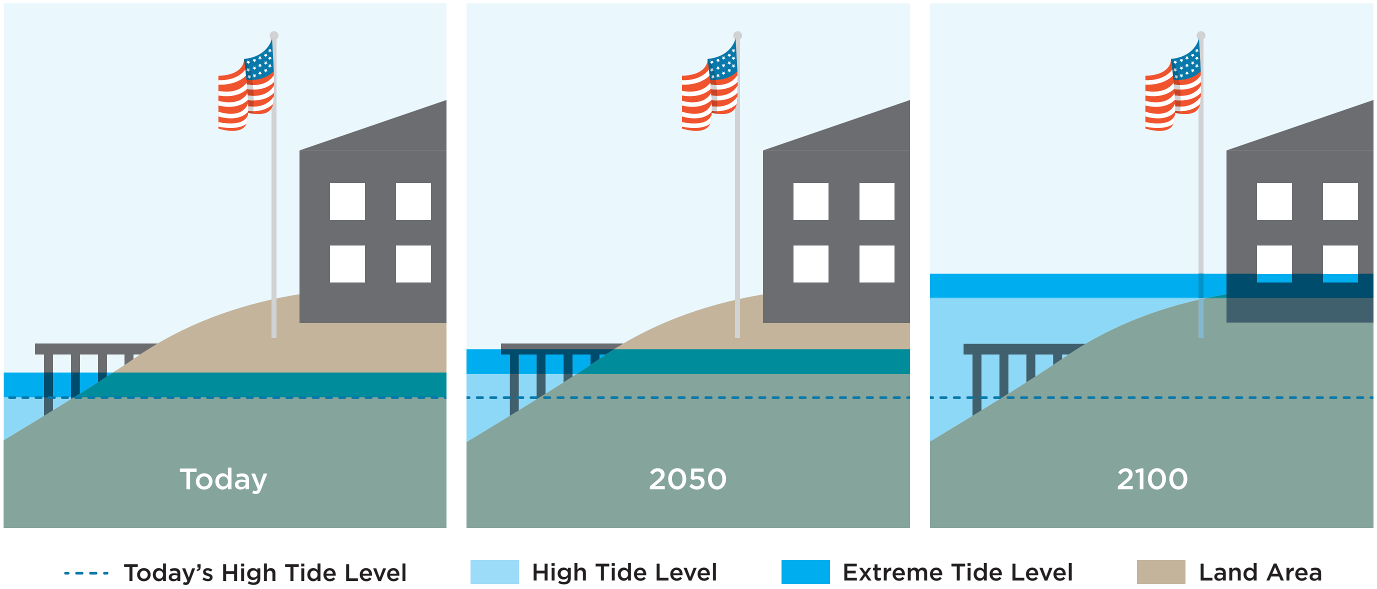
THE CHANGING THREAT OF HURRICANES

MCRD PARRIS ISLAND

Category 1 hurricanes are the most likely type to affect this area. Ninety percent of MCRD Parris Island is exposed to storm surge flooding from a Category 1 storm today. Most of that flooding would be five to 10 feet deep. In the intermediate scenario, over 95 percent of the installation is exposed to storm surge flooding from a Category 1 storm by 2100, the equivalent to the area exposed to flooding during a Category 2 storm today. Flood depth also increases as sea level rises: by 2100, nearly 70 percent of the installation is exposed to flooding 10 to 15 feet deep.

A Category 4 storm hitting in 2100 in the highest scenario is the worst-case scenario for the area in this analysis. All of MCRD Parris Island would be exposed to storm surge. Nearly 90 percent of the flooding would be more than 20 feet deep.

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.

MCAS BEAUFORT

Sea level rise will expose a greater proportion of MCAS Beaufort to inundation caused by a Category 1 storm. This trend is especially clear in the eastern third of the installation. In the intermediate scenario, the area exposed to flooding increases to 45 percent by 2100; in the highest scenario, it increases to roughly 50 percent. In the highest scenario, the area of the base inundated by a Category 1 storm in 2100 is greater than the area inundated by a Category 2 storm today.

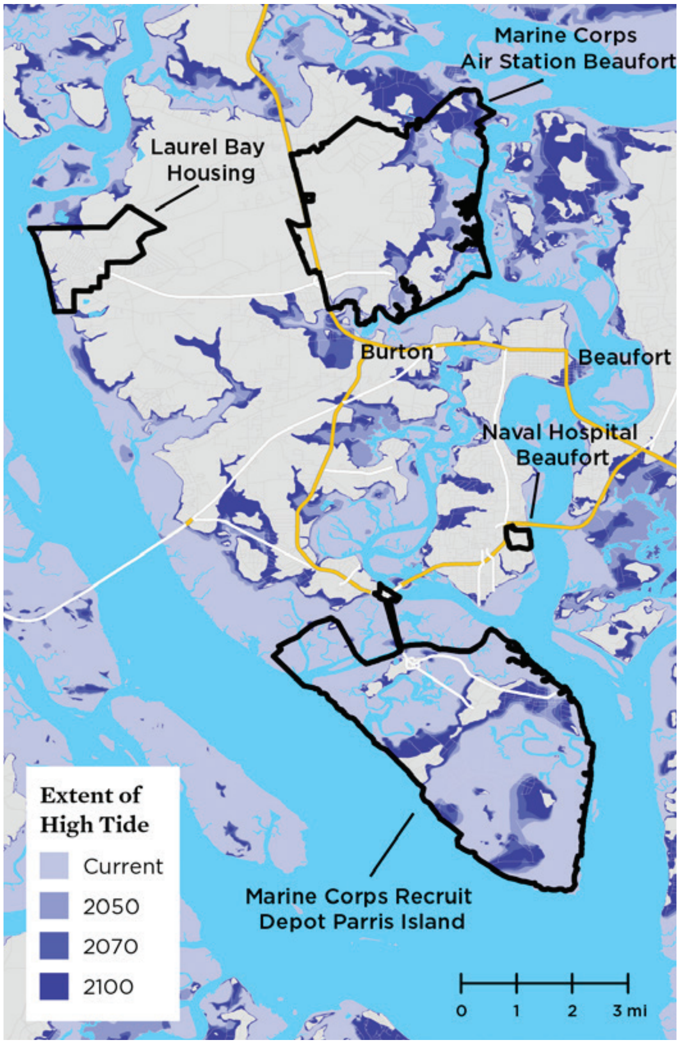
Sea level rise also changes the depth of flooding MCAS Beaufort can expect with major storms. Flooding from a Category 1 storm today would be less than 10 feet deep. By 2100 in the

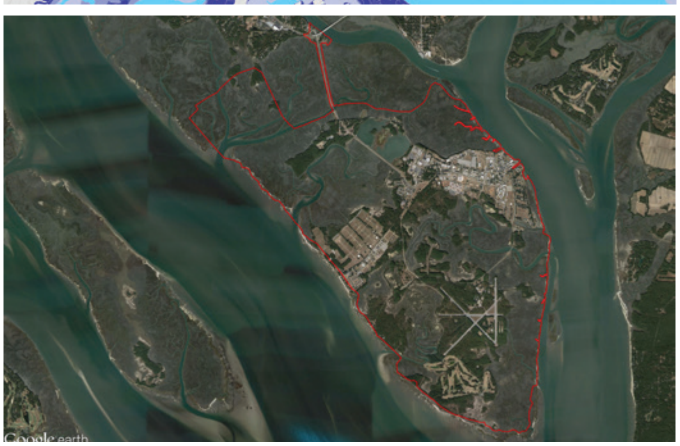
TABLE 2. Current and Future Tidal Flooding Frequency around MCRD Parris Island and MCAS Beaufort

	Intermediate		Highest	
Year	Events per Year	% of Year	Events per Year	% of Year
2012	10 ± 7	0	10 ± 7	0
2050	152 ± 26	3	327 ± 38	8
2070	438 ± 38	13	671 ± 7	29
2100	698 ± 2	38	702 ± 4	62

MCAS Beaufort, with less low-lying land than MCRD Parris Island, will be less directly affected by tidal flooding. Shown here are flood events in low-lying areas projected by the intermediate and highest scenarios. As flood conditions begin to span multiple tide cycles, the rate of increase in distinct flood events slows, but the duration of flooding increases. Events per year are reported as the average over a five-year period with one standard deviation. Percent of year is reported simply as the average over a five-year period.

FIGURE 3. MCRD Parris Island Is Expected to Lose Currently Utilized Land





The projected reach of future daily high tides, shown above, encompasses currently utilized land at MCRD Parris Island, shown below. Mapped here is high tide in the highest scenario.

SOURCE: GOOGLE EARTH.

intermediate scenario, a Category 1 storm would expose nearly 15 percent of the installation to flooding 10 to 15 feet deep.

Today, a Category 4 storm would expose 70 percent of MCAS Beaufort to flooding. A Category 4 storm hitting in 2100 in the highest scenario is the worst-case scenario for the base in this analysis. More than 80 percent of MCAS Beaufort would be exposed to storm surge. Whereas a Category 4 storm today exposes about 17 percent of the installation to flooding 20 or more feet deep, that proportion doubles to 34 percent in the worst-case scenario.

Mobilizing on the Front Lines of Sea Level Rise

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). Local governments are also responding: In 2015, Beaufort County and multiple stakeholders published their Sea Level Rise Adaptation Report, and they have started preparing for rising seas (Beaufort County 2015).

But at MCRD Parris Island and MCAS Beaufort, and across US coastal installations, there is still far to go: the gap between the military's current sea level rise preparedness and the threats outlined by this analysis 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, including MCRD Parris Island and MCAS Beaufort, face all of these risks.

This analysis provides snapshots of potential future exposure to flooding at these two installations, and it highlights the high level of exposure to hazards at MCRD Parris Island. For the Marine Corps to take additional action on the front line of sea level rise, however, it 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 planning efforts and to detailed mapping that includes future conditions; support planning partnerships with surrounding communities; and allocate resources for preparedness projects, on- and off-site, many of which will stretch over decades.

Military bases and personnel protect the country from external threats. 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.

ENDNOTES

1 *The intermediate sea level rise scenario assumes ice sheet loss that increases over time, while the highest scenario assumes rapid loss of ice sheets. The latter scenario is particularly useful for decisions involving an especially low tolerance for risk. These results are a small subset of the full analysis. For more information, the technical appendix, and downloadable maps, see www.ucsusa.org/MilitarySeasRising.*

2 *UCS analyzed storm surge depth and exposure extent for each installation using the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model, developed by the National Oceanic and Atmospheric Administration (NOAA), for storm events ranging in severity from Category 1 to Category 5, in addition to tidal floods. Both storm surge and flooding during extra-high tides can be significantly exacerbated by rainfall and wave action, neither of which was included in this study.*

3 *This analysis involved consultation with contacts at multiple installations. However, in some instances, 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.*

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The Union of Concerned Scientists puts rigorous, independent science to work to solve our planet's most pressing problems. Joining with citizens across the country, we combine technical analysis and effective advocacy to create innovative, practical solutions for a healthy, safe, and sustainable future.

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The US Military on the Front Lines of Rising Seas

Exposure to Coastal Flooding at Marine Corps Base Camp Lejeune, North Carolina

HIGHLIGHTS

With seas rising at an accelerating rate, coastal military installations are increasingly exposed to storm surge and tidal flooding. The Union of Concerned Scientists (UCS) conducted analyses of this changing exposure for 18 installations along the East and Gulf coasts. Analysis for Marine Corps Base Camp Lejeune found that in the second half of this century, in the absence of preventive measures, this installation can expect more frequent and extensive tidal flooding, loss of currently utilized land, and substantial increases in the extent and severity of storm-driven flooding to which it is exposed.

The US Armed Forces depend on safe and functional bases, such as Marine Corps Base Camp Lejeune ("Camp Lejeune"), North Carolina, to carry out their stated mission: to provide the military forces needed to deter war and to protect the security of the country. A roughly three-foot increase in sea level would threaten 128 coastal Department of Defense (DOD) installations in the United States and the livelihoods of the people—both military personnel and civilians—who depend on them (NAS 2011). In the area around Camp Lejeune, seas are projected to rise between 3.7 and 6.1 feet by the end of this century.

To enable decision makers to better understand the sea level rise threat, and where and when it could become acute, UCS has performed a new analysis of 18 East and Gulf Coast military installations, including Camp Lejeune. These sites were selected 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.

UCS projected exposure to coastal flooding in the years 2050, 2070, and 2100 using the National Climate Assessment's midrange or "intermediate-high" scenario (referred to here as "intermediate") and, in light of the low tolerance for risk in some of the military's decisions, a "highest" scenario with a more rapid rate of increase (Parris et al. 2012).[1] We modeled tidal flooding, permanent inundation, and storm surge from hurricanes.[2] The results below outline potential future flooding to which Camp Lejeune could be exposed, assuming no new measures are taken to prevent or reduce flooding.[3] This analysis finds the following key results:

US Marine Corps

NATURAL DEFENSES AT RISK

The extensive mainland portion of Camp Lejeune has limited exposure to sea level rise this century compared to its barrier islands and the low-lying areas along the New River (shown here); these could face daily tidal flooding late this century. The islands provide storm surge protection for the mainland. Though not modeled here, their inundation could affect storm surge exposure of the mainland portion of the camp.

TIDAL FLOODING AND LAND LOSS

- **Certain areas face daily high tide flooding**. Today, tidal flooding within Camp Lejeune affects low-lying locations, mainly wetlands, eight times per year on average. In the highest scenario, flood-prone areas within the camp are underwater nearly 90 percent of the time by 2100.
- **Flooding during extreme high tides will become more extensive**. In the highest scenario, higher water levels caused by extreme tides flood roadways roughly eight times per year by later in this century.
- **Loss of protective barrier islands is possible**. By 2070, in the highest scenario, Camp Lejeune's barrier islands could flood with most high tides and be underwater 35 percent of the time.

STORM SURGE

- **Sea level rise exposes previously unaffected areas of Camp Lejeune to storm surge flooding**. By 2100 in the intermediate scenario, the area in Camp Lejeune exposed to a Category 1 storm surge flooding increases by about 4,000 acres (or 3 percent of the camp); in the highest scenario, it increases by about 7,000 acres (or 5 percent of the camp).
- **Sea level rise exposes Camp Lejeune to deeper, more severe flooding**. In general, over time, the area inundated by 10 feet or more of seawater during storm surges will increase. In an end-of-century worst-case scenario involving a Category 4 storm, six feet of sea level rise in the highest scenario could more than double the area exposed to flooding 20 or more feet deep—from 7 to roughly 20 percent of the camp.

Base Information

Camp Lejeune is located along the New River near Jacksonville, North Carolina. The camp includes several barrier islands that provide a buffer between the Atlantic Ocean and the mainland.

[In 1996, Hurricane Bertha hit Camp Lejeune with winds of up to 108 miles per hour and caused an eight-foot storm surge, leading to $250 to $270 million in damage.]

Camp Lejeune

Branch:	Marines
Established:	1941
Size (Acres):	139,070
Active Duty:	45,622
Family Members:	52,853
Civilian:	5,857
Retirees and Family Members:	27,120

SOURCE: DOD 2016.

Camp Lejeune's mission is to train and maintain combat-ready forces. The majority of the active duty forces at Camp Lejeune are Marines, but the Navy, Army, Air Force, and Coast Guard also have a presence at the installation (USMC n.d.). The camp, which includes amphibious assault training facilities and live fire ranges, is supported by six additional facilities, including Marine Corps Air Station New River (USMC n.d.).

Camp Lejeune is an integral part of both the community and the economy of Onslow County. Including salaries, construction, services, and other expenditures, the annual economic contribution of the camp to the state and surrounding region is over $4 billion (USMC 2013).

Historic Exposure to Storm Surge and Flood Hazards

Since 1842, 104 hurricanes or tropical storms have passed within a 75-mile radius of Onslow County (NOAA n.d.). Of the hurricanes, 16 were direct hits in Onslow County and 24 crossed portions of the county, resulting in approximately $611 million in property damage and $56 million in crop damage (in 2014 dollars) (Onslow County 2015).

In 1996, Hurricane Bertha hit Camp Lejeune with winds of up to 108 miles per hour and caused an eight-foot storm surge, leading to $250 to $270 million in damage (NWS n.d). That same year, Hurricane Fran, a Category 3 storm, also made landfall, followed in 1998 by Category 3 Hurricane Bonnie and, in 1999, Category 2 Hurricane Floyd (Evans et al. 2014). These and subsequent hurricanes caused storm surge and changes to the Onslow Bay Barrier system, the series of barrier islands that protect portions of Camp Lejeune and the New River Estuary (Evans et al. 2014).

While Camp Lejeune's infrastructure is for the most part located on high ground, some infrastructure and training grounds are located in low-lying areas, including the barrier islands (Evans et al. 2014).

Future (Projected) Exposure to Storm Surge and Flood Hazards

The intermediate scenario projects that Camp Lejeune will experience 3.7 feet of sea level rise and the highest scenario projects 6.1 feet of rise by 2100. This rise will lead to increased exposure to different types of flooding.

> ***In both the intermediate and highest scenarios, extreme-tide flooding inundates additional areas, including roadways, by 2070.***

TABLE 1. MCBC Lejeune: Projected Sea Level Rise (Feet) in Two Scenarios

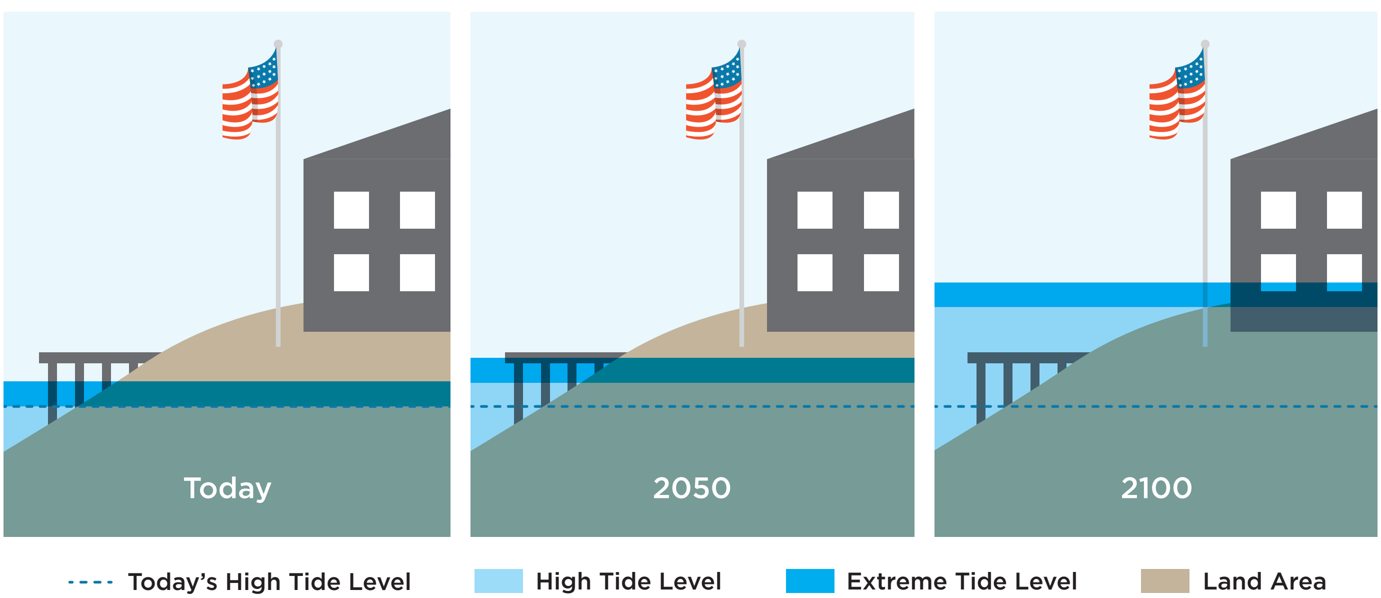
Year	Intermediate	Highest
2050	1.0	1.6
2070	1.9	3.1
2100	3.7	6.1

In the intermediate scenario, ice sheet loss increases gradually in the coming decades; in the highest scenario, more rapid loss of ice sheets occurs. The latter scenario is included in this analysis to help inform decisions involving an especially 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 (DeConto and Pollard 2016; Trusel et al. 2015; Chen et al. 2013; Rignot et al. 2011). Values shown are local projections that include unique regional dynamics such as land subsidence (see www.ucsusa.org/MilitarySeasRising).

TIDAL FLOODING AND LAND LOSS

The vast majority of Camp Lejeune's area is unaffected by tidal flooding today. However, low-lying areas in the region, including on its barrier islands and ocean-facing and river shorelines, experience flooding during extra-high tides about eight times per year on average. As sea level rises, extreme-tide flooding—that which reaches beyond the daily high tide mark—is expected to become more extensive and frequent. In both the intermediate and highest scenarios, extreme-tide flooding inundates additional areas, including roadways, by 2070.

FIGURE 1. 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.

TABLE 2. Current and Future Tidal Flooding Frequency around Camp Lejeune

	Intermediate		Highest	
Year	Events per Year	% of Year	Events per Year	% of Year
2012	8 ± 7	0	8 ± 7	0
2050	118 ± 21	3	289 ± 23	8
2070	392 ± 27	12	667 ± 12	35
2100	687 ± 12	45	280 ± 21	89

As flood conditions begin to span multiple high tide cycles, the number of distinct flood events gradually drops while their duration increases. Installations such as Camp Lejeune will be affected by this flooding depending on the presence of low-lying, flood-prone land on-site. Events per year are reported as the average over a five-year period with one standard deviation. Percent of year is reported simply as the average over a five-year period.

By 2050, flood-prone areas in this region could experience between 120 and 290 floods per year, approximately, depending on the scenario. In the highest scenario, flood-prone areas throughout the region, notably barrier islands and areas around tidal rivers, experience flooding with nearly each of the two daily high tides and are underwater 35 percent of the time by 2070.

[***Whereas a Category 4 storm today exposes less than 10 percent of the installation to flooding 20 or more feet deep, that percentage rises to about 20 percent in the worst case.***]

In the intermediate scenario, flood-prone areas are inundated close to twice daily by 2100. In the highest scenario, during the last quarter of this century, flood events in this area begin to span many high tide cycles. As a result, the number of individual flood events decreases but their duration increases, until it is essentially constant and the land that was once above the high tide mark, including much of the camp's barrier island, is permanently inundated.

THE CHANGING THREAT OF HURRICANES

Category 1 hurricanes are the most likely type to affect this area.[4] Over time, sea level rise exposes a greater portion of Camp Lejeune to inundation resulting from Category 1 storms. Both today and in the future, the areas most affected by storm surge from a Category 1 hurricane are the installation's barrier islands, its ocean-facing coast, and its river shorelines. A Category 1 storm today exposes 22 percent of the camp's area to flooding from storm surge. In the intermediate scenario, nearly 4,000 additional acres are exposed to flooding such that 25 percent of the installation is exposed by 2100. In the highest scenario, 7,000 acres more than today (about 5 percent more area) are exposed. In both scenarios, the area flooded as a result of a Category 1 storm in 2100 is equivalent to or greater than the area flooded during a Category 2 storm today.

Sea level rise also increases the depth of flooding that Camp Lejeune can expect with major storms. Today, all flooding resulting from a Category 1 storm would be less than 10 feet deep. In 2100 in the intermediate scenario, about 5 percent of the installation experiences flooding 10 or more feet deep when hit by a Category 1 storm.

The worst-case scenario for the region in this analysis is a Category 4 storm hitting in 2100 in the highest scenario. Today, a Category 4 storm exposes 35 percent of Camp Lejeune to flooding. In the worst case, an additional 10,000 acres of the installation, or more than 40 percent total, is exposed to storm surge. Whereas a Category 4 storm today exposes less than 10 percent of the installation to flooding 20 or more feet deep, that percentage rises to about 20 percent in the worst case.

Mobilizing on the Front Lines of Sea Level Rise

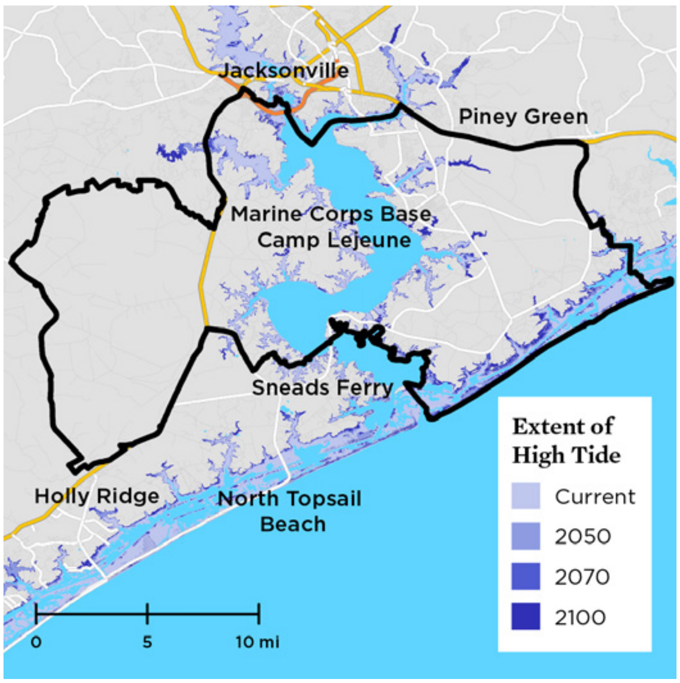
A vital trait of our nation's military is its ability to adapt in response to external threats. Climate change and sea level rise have emerged as key threats of the 21st century, and our military is beginning to respond (Hall et al. 2016; USACE 2015; DOD 2014).

Given the history of hurricanes and coastal storms in Onslow County, Camp Lejeune recognizes its vulnerability to coastal flooding and storm surge. The DOD modeled the potential impacts of storm surge and sea level rise on the barrier island system at Camp Lejeune, which will help the installation plan for cost-effective mitigation measures (Evans et al. 2014). Onslow County recently developed a multihazard mitigation plan that addresses flood risk reduction measures, and the county is working closely with Camp Lejeune on a range of planning and response activities (Onslow County 2015).

But here and across US coastal installations there is still far to go: the gap between the military's current sea level rise preparedness and the threats outlined by this analysis 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, including Camp Lejeune, face all of these risks.

This analysis provides snapshots of potential future exposure to flooding at Camp Lejeune. For the camp to take action on the front line of sea level rise, however, it 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 planning efforts and to detailed mapping that includes future conditions; and allocate resources for preparedness projects, on- and off-site, many of which will stretch over decades.

FIGURE 2. Camp Lejeune Is Expected to Face Barrier Island Loss



The projected reach of future daily high tides, shown on the top, encompasses mainly the barrier islands and land around tidal rivers, as seen in the bottom image. The highest scenario is mapped here. Because barrier islands typically provide storm surge protection to mainland areas, their future inundation could have bearing on mainland exposure.

SOURCE: GOOGLE EARTH.

[The gap between the military's current sea level rise preparedness and the threats outlined by this analysis is large and growing.]

Military bases and personnel protect the country from external threats. 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.

ENDNOTES

1 *The intermediate sea level rise scenario assumes ice sheet loss that increases over time, while the highest scenario assumes rapid loss of ice sheets. The latter scenario is particularly useful for decisions involving an especially low tolerance for risk. These results are a small subset of the full analysis. For more information, the technical appendix, and downloadable maps, see www.ucsusa.org/MilitarySeasRising.*

2 *UCS analyzed storm surge depth and exposure extent for each base using the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model, developed by the National Oceanic and Atmospheric Administration (NOAA), for storm events ranging in severity from Category 1 to Category 4, in addition to tidal floods. Both storm surge and flooding during extra-high tides can be significantly exacerbated by rainfall and wave action, neither of which we included in this study.*

3 *This analysis involved consultation with contacts at multiple installations. However, in some instances, 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.*

4 *Nor'easters are more common in the region and known to generate damaging storm surge. As SLOSH models only hurricanes, lesser storms, such as nor'easters, were not included in this analysis. Increases in surge extent and depth should be expected with these storms as well.*

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FACT SHEET

The US Military on the Front Lines of Rising Seas

Exposure to Coastal Flooding at Naval Air Station Oceana Dam Neck Annex, Virginia

HIGHLIGHTS

With seas rising at an accelerating rate, coastal military installations are increasingly exposed to storm surge and tidal flooding. The Union of Concerned Scientists (UCS) conducted analyses of this changing exposure for 18 military installations along the East and Gulf coasts. Analysis for Naval Air Station (NAS) Oceana Dam Neck Annex, Virginia, found that in the second half of this century, in the absence of preventive measures, this installation can expect more frequent and extensive tidal flooding, loss of currently utilized land, and substantial increases in the extent and severity of storm-driven flooding to which it is exposed.

The US Armed Forces depend on safe and functional bases, such as NAS Oceana Dam Neck Annex ("Dam Neck"), Virginia, to carry out their stated mission: to provide the military forces needed to deter war and to protect the security of the country. A roughly three-foot increase in sea level would threaten 128 coastal Department of Defense (DOD) installations in the United States and the livelihoods of the people—both military personnel and civilians—who depend on them (NAS 2011). In the area of Dam Neck, seas are projected to rise between 4.5 and 6.9 feet by the end of this century.

To enable decision makers to better understand the sea level rise threat, and where and when it could become acute, UCS has performed a new analysis of 18 East and Gulf coast military installations, including Dam Neck.[1] These sites were selected 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.

UCS projected exposure to coastal flooding in the years 2050, 2070, and 2100 using the National Climate Assessment's midrange or "intermediate-high" scenario (referred to here as "intermediate") and, in light of the low tolerance for risk in some in the military's decisions, a "highest" scenario with a more rapid rate of

US Navy

THE INLAND MARCH OF HIGH TIDE

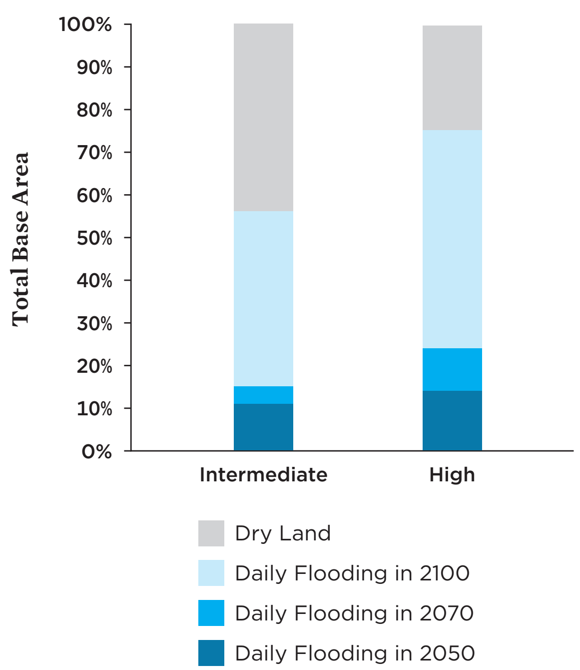
Dam Neck is located on the Atlantic coast in the Hampton Roads area of Virginia, a region where natural subsidence, low-lying topography, and changing ocean circulation patterns contribute to above-average rates of sea level rise. By 2100, between roughly one half and three quarters of the station's land area could be inundated by daily high tides, depending on the pace of sea level rise.

increase (Parris et al. 2012).[2] We modeled tidal flooding, permanent inundation, and storm surge from hurricanes.[3] The results below outline potential future flooding to which Dam Neck could be exposed, assuming no new measures are taken to prevent or reduce flooding.[4] This analysis finds the following key results:

TIDAL FLOODING, PERMANENT INUNDATION, AND LAND LOSS

- **Sea level rise threatens to permanently inundate certain areas**. If the wetland areas of Dam Neck do not naturally adapt to rising seas, they could flood hundreds of times per year by 2050 in either scenario. In the intermediate scenario, these areas are underwater about 95 percent of the year by 2100; in the highest scenario, they are always underwater.
- **Extensive land loss at Dam Neck is possible**. The highest scenario projects 6.9 feet of sea level rise by 2100, which puts 75 percent of Dam Neck underwater during daily high tides—roughly equal to the area exposed to flooding by a Category 1 hurricane today.

FIGURE 1. Dam Neck Will Experience Land Loss



As high tide reaches farther inland at Dam Neck, extensive land loss is possible. Affected land may include developed and undeveloped areas and even wetlands that reside above the current high water mark. In both scenarios, Dam Neck loses currently developed and utilized areas.

STORM SURGE

- **Sea level rise exposes previously unaffected areas of Dam Neck to storm surge flooding**. Dam Neck is highly exposed to storm surge today, with roughly 75 percent of the station exposed to flooding during a Category 1 storm. By 2100, a Category 1 storm under either scenario exposes at least 95 percent of the station to storm surge flooding.
- **Sea level rise exposes Dam Neck to deeper, more severe flooding**. In an end-of-century worst-case scenario involving a Category 4 storm, nearly 60 percent of the installation floods to a depth of 20 or more feet.

Base Information

Dam Neck is located within the Hampton Roads metropolitan area, one of the East Coast's regions most vulnerable to sea level rise because of its low-lying topography and natural subsidence (VIMS 2013). The station, which is part of the larger NAS Oceana, lies along the Atlantic coast and is five miles south of the town of Virginia Beach. Much of Dam Neck's land lies less than six feet above sea level. It is also situated within an East Coast sea level rise hot spot, where these local factors combine with changing ocean circulation patterns to create above-average sea level rise (Sallenger, Doran, and Howd 2012).

Dam Neck

Branch:	Navy
Established:	1941
Size (Acres):	1,100
Personnel:	5,600
Tenant Commands:	12 to 20
Students Annually:	20,000

SOURCE: DOD 2016.

The Navy's pilots receive fleet combat and tactical training at Dam Neck (City of Virginia Beach 2016). The station is also home to the Naval Special Warfare Development Group. Along with NAS Oceana and Naval Auxiliary Land Field Fentress, both located nearby, Dam Neck is responsible for generating more than $1 billion in goods, services, and payroll each year (City of Virginia Beach 2016).

Historic Exposure to Storm Surge and Flood Hazards

The Hampton Roads region has long endured flooding from hurricanes and lesser storms (HRPDC 2011). Because the topography and geology of the region make it naturally vulnerable to sea level rise, coastal flooding problems are worsening (VIMS 2013; HRPDC 2012). Rising seas have already led to problematic high tide flooding in the region (Spanger-Siegfried, Fitzpatrick, and Dahl 2014; Sweet et al. 2014).

Since 1857, 65 hurricanes have passed within 150 nautical miles of the Hampton Roads areas (NOAA n.d.). In 2003, Hurricane Isabel caused a storm surge along the Virginia coast that was four feet or more and caused severe flooding (Beven and Cobb 2014; Murphy 2013).

> ***Dam Neck is particularly vulnerable to sea level rise because of its low-lying topography and natural subsidence.***

Dam Neck conducts beach nourishment along its shoreline every eight years and maintains a large dune that was built to protect upland infrastructure from storm surge (Lauterbach 2016). This may protect the station from surge during certain storm configurations and approaches. But because the dune does not extend along the whole shoreline, parts of the station (especially north and south of the dune) are still exposed to flooding from storm surge as well as from seawater entering through Shipps Bay to the south.

TABLE 1. Dam Neck Could See More than Six Feet of Sea Level Rise by 2100

Year	Intermediate	Highest
2050	1.4	2.0
2070	2.5	3.6
2100	4.5	6.9

In the intermediate scenario, ice sheet loss increases gradually in the coming decades; in the highest scenario, more rapid loss of ice sheets occurs. The latter scenario is included in this analysis to help inform decisions involving an especially 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 (DeConto and Pollard 2016; Trusel et al. 2015; Chen et al. 2013; Rignot et al. 2011). Values shown are local projections that include unique regional dynamics such as land subsidence (see www.ucsusa.org/MilitarySeasRising).

Future (Projected) Exposure to Storm Surge and Flood Hazards

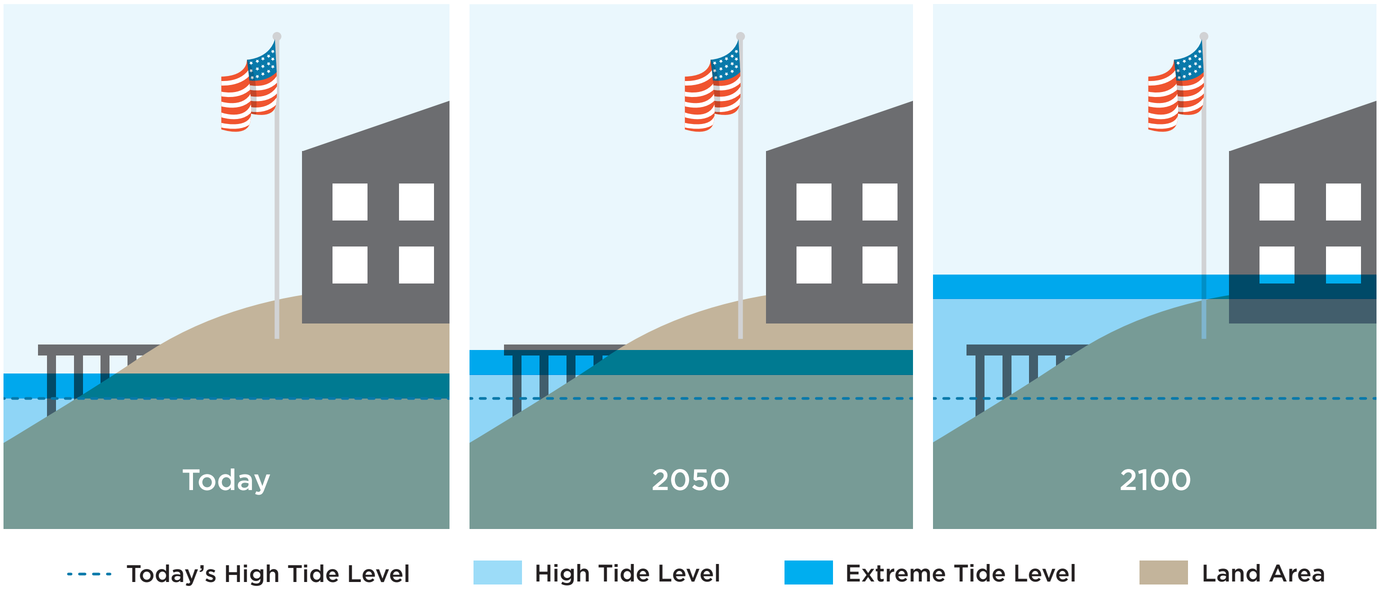
SEA LEVEL RISE

Dam Neck experiences 4.5 feet of local sea level rise by 2100 in the intermediate scenario and nearly seven feet of rise in the highest scenario, which leads to increased exposure to different types of coastal flooding.

US Navy

Marines, sailors, and local elementary school students participate in a beach run at Dam Neck Annex. In the backdrop is the 1 mile-long engineered dune that is maintained to protect the inland infrastructure from storm surge.

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



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

TIDAL FLOODING AND LAND LOSS

Dam Neck's extremely low elevation and susceptibility to flooding from both its immediate coastline and from the south via Shipps Bay greatly expose it to sea level rise and, eventually, land loss.

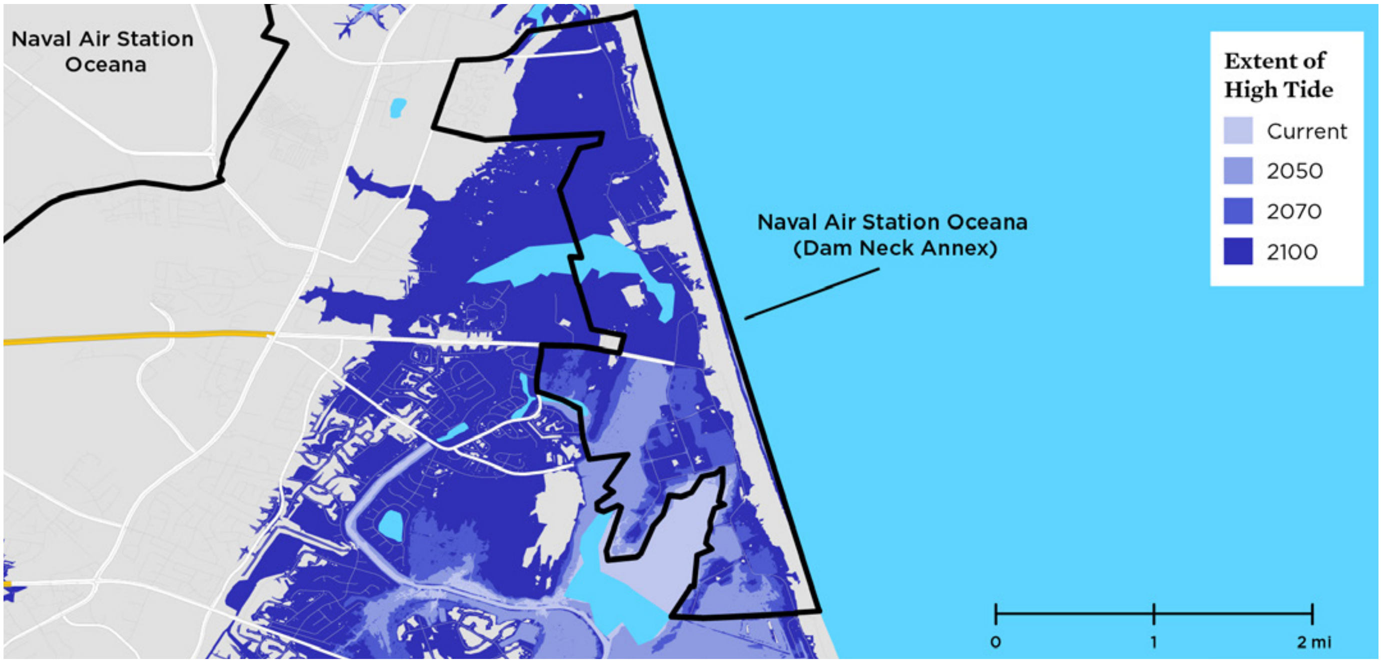
Flood-prone areas in this region experience about nine floods per year today. By 2050, that number rises to roughly 280 in the intermediate scenario and to 540 in the highest scenario. In the highest scenario, about 15 percent of the station's land area is underwater at high tide.

TABLE 2. Flood-Prone Areas Could Be Underwater 100% of the Time by 2100

	Intermediate		Highest	
Year	Events per Year	% of Year	Events per Year	% of Year
2012	9 ± 4	0	9 ± 4	0
2050	276 ± 16	10	538 ± 26	26
2070	641 ±17	40	525 ± 26	77
2100	124 ±27	96	1 ± 0	100

As flood conditions in low-lying areas begin to span multiple high tide cycles, the number of distinct flood events gradually drops toward one, while the duration of floods increases until flooding is constant. Installations such as Dam Neck will be affected by tidal flooding depending on the presence of flood-prone land on-site. Events per year are reported as the average over a five-year period with one standard deviation. Percent of year is reported simply as the average over a five-year period.

FIGURE 3. Dam Neck Is Expected to Lose Currently Utilized Land to the Sea



Future daily high tides, shown on the top, are projected to inundate currently utilized land at Dam Neck, shown on the bottom. The highest scenario is mapped here.

SOURCE: IMAGE © TERRAMETRICS. DATA FROM SIO, NOAA, US NAVY, NGA, AND GEBCO.

During the final decades of the century, flood events in this area will begin to span many high tide cycles. As a result, the number of individual flood events will decrease but the duration of floods will increase. Flooding will be essentially constant and the affected land permanently inundated. In the highest scenario, flood-prone areas throughout the region experience flooding with each of the two daily high tides and are underwater more than 75 percent of the time by 2070. By 2100, high tide engulfs 75 percent of Dam Neck's area—an area equivalent to that flooded by Category 1 hurricanes today.[5]

Extra-high tidal flooding—flooding that reaches beyond the daily tide—is expected to become both more extensive and more frequent. Today, the wetland areas of Dam Neck flood during extra-high tides nine times per year on average. But in both scenarios, those areas are permanently inundated by 2100. Extra-high tides engulf more than 80 percent of the station's land area by that year in the highest scenario.

> ***By 2100, high tide could engulf 75 percent of Dam Neck's area.***

THE CHANGING THREAT OF HURRICANES

Category 1 hurricanes are the most likely type to affect this area.[6] Today, a Category 1 storm exposes roughly 75 percent of the installation to flooding resulting from storm surge; sea level rise increases that exposure. In both scenarios, a Category 1 storm hitting in 2100 causes 95 percent of the station to flood—the area that would flood in a Category 3 storm today.

Flood depth also increases as sea level rises. Today, only 5 percent of the station floods to a depth of five or more feet during a Category 1 storm. But in both scenarios, more than half the station floods to this depth in 2100.

All of Dam Neck is exposed to flooding from Category 3 and Category 4 hurricanes today. While sea level rise will not increase the extent of inundation at the installation from Category 3 or 4 storms, it will affect inundation depth. Today, less than 1 percent of the station experiences flooding 20 or more feet deep during Category 4 storms. In the highest scenario, almost 20 percent of the station experiences this extremely deep flooding by 2070. By 2100, almost 60 percent of the installation floods to a depth of 20 or more feet.

Mobilizing on the Front Lines of Sea Level Rise

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). Recognizing the threat, Dam Neck is managing its flood risks using multiple measures, including beach nourishment and the maintenance of a one-mile-long rock-core dune that helps to protect upland infrastructure (Lauterbach 2016).

But here and across US coastal installations, there is still far to go: the gap between the military's current sea level rise preparedness and the threats outlined by this analysis 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, including Dam Neck, face all of these risks.

This analysis provides snapshots of potential future exposure to flooding at Dam Neck. For the Navy to take action on the front line of sea level rise, however, it will need more


US Navy

Dune management activities at Dam Neck in spring, 2010, when sailors planted 13,000 dune-stabilizing grass plants as part of broader efforts to maintain the dune as an effective storm surge barrier.

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 planning efforts and to detailed mapping that includes future conditions; support planning partnerships with surrounding communities; and allocate resources for preparedness projects, on- and off-site, many of which will stretch over decades.

Military bases and personnel protect the country from external threats. 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.

ENDNOTES

1 *NAS Oceana is a Naval complex that includes several installations. This analysis focuses on Dam Neck Annex only.*

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4 *This analysis involved consultation with Dam Neck. However, 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.*

5 *This flooding does not come directly from the ocean. Rather, seawater inundates the station at high tide via Shipps Bay and the wetlands to the south of the base.*

6 *Nor'easters are more common in the region and known to generate damaging storm surge. As SLOSH models only hurricanes, we did not include lesser storms such as nor'easters in this analysis. Increases in surge extent and depth should be expected with these storms as well.*

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FACT SHEET

The US Military on the Front Lines of Rising Seas

Exposure to Coastal Flooding at Naval Station Norfolk, Virginia

HIGHLIGHTS

With seas rising at an accelerating rate, coastal military installations are increasingly exposed to storm surge and tidal flooding. The Union of Concerned Scientists (UCS) conducted analyses of this changing exposure for 18 military installations along the East and Gulf coasts. Analysis for Naval Station (NS) Norfolk, Virginia, found that in the second half of this century, in the absence of preventive measures, this installation can expect more frequent and extensive tidal flooding, loss of currently utilized land, and substantial increases in the extent and severity of storm-driven flooding to which it is exposed.

The US Armed Forces depend on safe and functional bases, such as NS Norfolk, Virginia, to carry out their stated mission: to provide the military forces needed to deter war and to protect the security of the country. A roughly three-foot increase in sea level would threaten 128 coastal Department of Defense (DOD) installations in the United States and the livelihoods of the people—both military personnel and civilians—who depend on them (NAS 2011). In the area around Norfolk, seas are projected to rise between 4.5 and 6.9 feet by the end of this century.

To enable decision makers to better understand the sea level rise threat, and where and when it could become acute, UCS has performed a new analysis of 18 East and Gulf Coast military installations, including NS Norfolk. These sites were selected 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.

UCS projected exposure to coastal flooding in the years 2050, 2070, and 2100 using the National Climate Assessment's midrange or "intermediate-high" scenario (referred to here as "intermediate") and, in light of the low tolerance for risk in some of the military's decisions, a "highest" scenario based on a more rapid rate of increase (Parris et al. 2012).[1] We modeled tidal flooding, permanent inundation, and storm surge from hurricanes.[2] The results below outline potential future flooding to which NS Norfolk could be exposed, assuming no new measures are

US Navy

TWO IF BY SEA: NS NORFOLK FACES GROWING FLOOD THREATS
NS Norfolk is located in the Hampton Roads area of Virginia, a region where natural subsidence, low-lying topography, and changing ocean circulation patterns contribute to above-average rates of sea level rise. Much of the station is less than 10 feet above sea level. With between 4.5 and nearly 7 feet of sea level rise expected later this century, land loss is foreseeable.

taken to prevent or reduce flooding.[3] This analysis finds the following key results:

TIDAL FLOODING AND LAND LOSS

- **Certain locations could flood with each high tide.** Today, tidal flooding in the Norfolk area affects low-lying areas nine times per year on average. But in the intermediate scenario, such areas in and around the station flood about 280 times per year and spend 10 percent of the year underwater by 2050.
- **The reach of flooding during extreme high tides will expand**. In the intermediate scenario, extra-high tides would expose roughly 10 percent of the station's land area to flooding by 2100; in the highest scenario, exposure reaches nearly 60 percent.
- **Land loss at NS Norfolk is possible**. In the highest scenario, roughly 20 percent of NS Norfolk's land floods daily, becoming part of the tidal zone, by 2100.

STORM SURGE

- **Sea level rise exposes previously unaffected areas of NS Norfolk to storm surge flooding.** In the intermediate scenario, the area exposed to flooding resulting from a Category 1 storm more than triples by 2070.
- **Higher sea levels allow lower-intensity storms to produce greater surge.** In the intermediate scenario, storm surge flooding resulting from a Category 1 storm hitting in 2100 affects a greater area than does surge flooding resulting from Category 2 storms today.
- **Sea level rise exposes NS Norfolk to deeper, more severe flooding.** Today, a Category 4 storm exposes about 80 percent of the station to flooding, and that flooding is less than 10 feet deep. In the highest scenario, a Category 4 storm hitting in 2100 exposes 95 percent of the base to flooding more than 10 feet deep.

Base Information

NS Norfolk is located in the city of Norfolk and within the Hampton Roads metropolitan area—a sea level rise hot spot, where natural subsidence, low-lying topography, and changing ocean circulation patterns contribute to above-average rise (Sallenger, Doran, and Howd 2012). NS Norfolk lies directly on the water, with the Elizabeth River to the west and Willoughby Bay to the north. Much of NS Norfolk lies less than 10 feet above sea level (Connolly 2015).

NS Norfolk is the largest naval installation in the world (DOD 2016). It is the home of the US Fleet Forces Command, which trains naval forces and defends a massive area including the Atlantic Ocean and parts of the Pacific Global Security.org 2011.

More than 22,000 military personnel live in the city of Norfolk; they make up 11 percent of the population. An additional 28,000 veterans live in Norfolk (US Census Bureau 2014).

NS Norfolk

Branch:	Navy
Established:	1917
Size (Acres):	3,798
Population:	6,700
Ships:	75
Aircraft:	134
Piers:	13
Hangars:	11

SOURCE: DOD 2016.

[The growing problem of flooding in the city of Norfolk has affected real estate values, necessitated elevating roads.]

Historic Exposure to Storm Surge and Flood Hazards

Since 1857, 65 hurricanes have passed within 150 nautical miles of the Hampton Roads area (NOAA n.d.). In 2003, Hurricane Isabel, a Category 2 storm, flooded about 6 percent of NS Norfolk (Li, Lihwa, and Burks-Copes 2013). In 2011, Hurricane Irene, a Category 1 storm, brought a 7.5-foot storm surge to NS Norfolk (NOAA et al. 2013). The seawall and bulkhead at NS Norfolk provide some protection from storm surge, as does a floodgate that prevents flooding of the east end of the station (HRHP n.d.; Quality Enterprises n.d.). However, Category 2 hurricanes can raise water levels enough to seriously affect the station's four harbor installations (Gilmore and Brand 1999).

In addition, the persistent and growing problem of flooding in the city of Norfolk has affected real estate values, necessitated elevating roads, and transformed former parks into wetlands (Applegate 2014; Brangham 2012; Fears 2012). Access roads leading to the base are sometimes affected by flooding (VIMS 2013).

Future (Projected) Exposure to Storm Surge and Flood Hazards

SEA LEVEL RISE

The intermediate scenario projects that the Hampton Roads area will experience 4.5 feet of sea level rise and the highest scenario projects nearly seven feet of rise by 2100. With the highest scenario, portions of NS Norfolk would be inundated with each high tide.

TIDAL FLOODING AND LAND LOSS

As seas rise, the frequency of extreme tides and the reach of daily high tides grow. In the intermediate scenario, low-lying locations in and around NS Norfolk experience roughly 280 tidal floods per year by 2050; in the highest scenario, they experience 540. With such regular flooding, these areas could become unusable land within the next 35 years. Though daily operations at NS Norfolk itself may not be compromised, the station depends on the surrounding communities and infrastructure, which will be heavily affected.

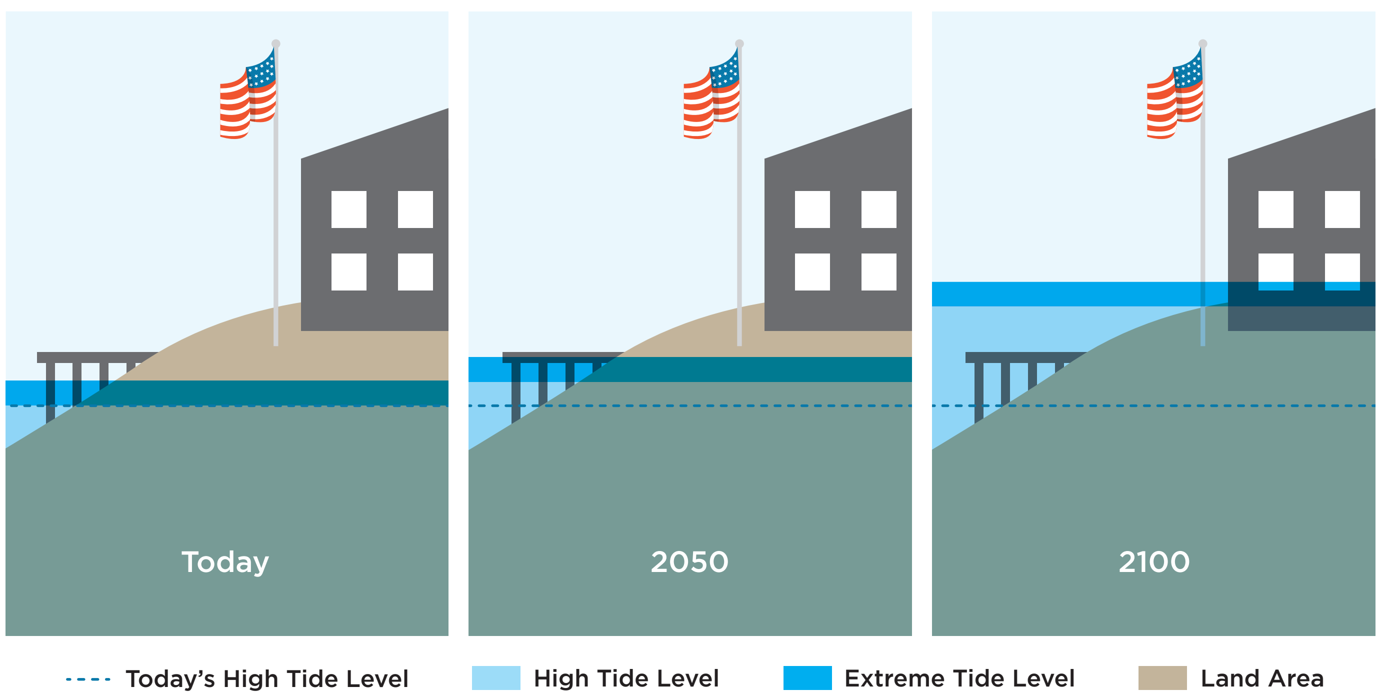
In the intermediate scenario, flood-prone areas throughout the region experience flooding twice daily on average and

TABLE 1. Hampton Roads Area Bases Could See More than Six Feet of Sea Level Rise by 2100.

Year	Intermediate	Highest
2050	1.4	2.0
2070	2.5	3.6
2100	4.5	6.9

In the intermediate scenario, ice sheet loss increases gradually in the coming decades; in the highest scenario, more rapid loss of ice sheets occurs. The latter scenario is included in this analysis to help inform decisions involving an especially 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 (DeConto and Pollard 2016; Trusel et al. 2015; Chen et al. 2013; Rignot et al. 2011). Values shown are local projections that include unique regional dynamics such as land subsidence (see www.ucsusa.org/MilitarySeasRising).

FIGURE 1. How Sea Level Rise Causes Tidal Flooding and Land Loss



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

are underwater 40 percent of the time by 2070. In the highest scenario, portions of NS Norfolk not currently prone to flood, particularly on the northern and eastern shores, flood with extra-high tides. In the highest scenario, nearly 60 percent of the station's land area, including roadways, is exposed to tidal flooding by 2100.

As sea level rises, the flooding that occurs during daily high tides lasts longer. During the last quarter of this century, floods in the NS Norfolk area will begin to span many high tide cycles. As a result, the number of individual flood events will decrease but the duration of flood conditions will increase until flooding is essentially constant and the affected land permanently inundated. By the end of the century, flood-prone areas in and around NS Norfolk are underwater nearly constantly in both scenarios.

But it is not only today's flood-prone areas that are affected by sea level rise. Indeed, with the nearly seven feet of sea level rise projected for the end of the century by the highest scenario, roughly 20 percent of NS Norfolk's currently utilized land area would flood daily, becoming part of the tidal zone.

THE CHANGING THREAT OF HURRICANES[4]

A Category 1 hurricane is the most likely type to affect this area. Today, such a storm exposes roughly 10 percent of NS Norfolk to storm surge flooding. In the intermediate scenario, local sea level is projected to rise by just over two feet by 2070; a Category 1 storm then exposes 35 percent of the station to flooding. The exposed area more than doubles between 2070 and 2100 to roughly 75 percent.

[*By the end of the century, flood-prone areas in and around NS Norfolk are underwater nearly constantly in both scenarios.*]

In the intermediate scenario, the area inundated by a Category 1 storm hitting in 2100 is substantially larger (about 15 percent) than the area inundated by a Category 2 storm today. In addition, the area under water five or more feet deep increases from less than 10 percent today to about 15 percent.

For the mid-Atlantic region, the worst-case scenario considered in this analysis is a Category 4 storm occurring in the highest sea level rise scenario. Even without sea level rise, 100 percent of NS Norfolk is exposed to flooding from Category 3 and Category 4 hurricanes today. While sea level rise will not increase the extent of inundation from Category 3 or 4 storms at the installation, it will affect flood depth.

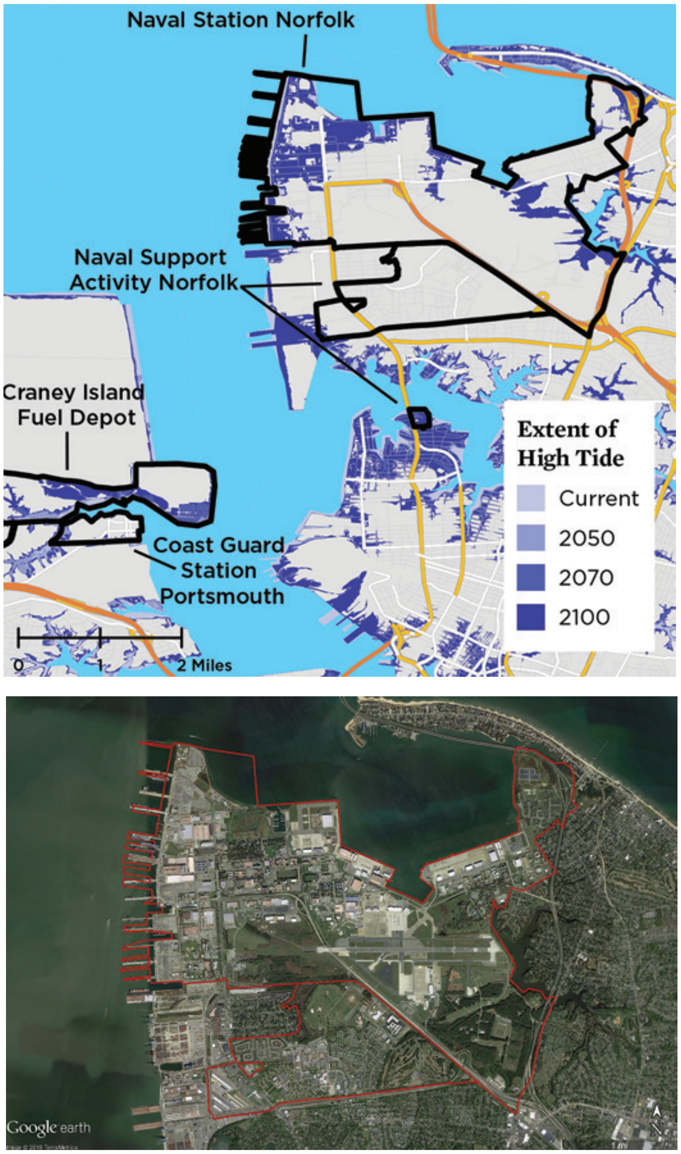
Today, most of the station (roughly 80 percent) is exposed to flooding less than 10 feet deep in a Category 4 storm. In the highest scenario, 55 percent of the station is exposed to flooding more than 10 feet deep by 2070. By 2100, 95 percent of the station experiences this depth of flooding.

TABLE 2. Flood-Prone Areas Could Be Underwater at All Times by 2100

	Intermediate		Highest	
Year	Events per Year	% of Year	Events per Year	% of Year
2012	9 ± 4	0	9 ± 4	0
2050	276 ± 16	10	538 ± 26	26
2070	641 ±17	40	525 ± 26	77
2100	124 ± 27	96	1 ± 0	100

Shown here are flood events in low-lying areas projected by the intermediate and highest scenarios. Events per year are reported as the average over a five-year period with one standard deviation. Percent of year is reported simply as the average over a five-year period. As flood conditions span multiple tide cycles, the number of distinct flood events drops but the duration of flooding increases until it is constant. NS Norfolk will be affected by this flooding depending on the presence of exposed, low-lying land on-site.

FIGURE 2. Daily High Tides Will Reach Farther Inland



The reach of future daily high tides, shown at top, is projected to inundate currently utilized parts of NS Norfolk, shown at bottom. The highest scenario is mapped here.

SOURCE: IMAGE @TERRAMETRICS.

Mobilizing on the Front Lines of Sea Level Rise

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).

[The gap between the military's current sea level rise preparedness and the threats outlined by this analysis is large and growing.]

Recognizing the threat in the vital Hampton Roads region, the Navy is working with the US Army Corps of Engineers, Virginia Institute of Marine Sciences, municipalities, universities, and the private sector to develop solutions to the adverse effects that can be expected with sea level rise (Rios n.d.). It is incorporating sea level rise projections into its development and infrastructure planning and into its project requirements and project design (Rios n.d).

In response to rising seas and persistent tidal flooding, NS Norfolk has been raising some of its piers—at a cost of $60 million each—and restoring others (Fears 2011). The station is planning a $250 million restoration project that includes demolishing two of its 100-year-old piers and rebuilding one new pier (Faithful+Gould n.d.) at NS Norfolk. The DOD, along with other federal agencies and local stakeholders (Hampton Roads Planning District Commission, Norfolk, and Virginia Beach), is participating in an innovative study in Hampton Roads to address recurrent flooding and sea level rise (Connolly 2015).

But here and across coastal US installations there is still far to go: the gap between the military's current sea level rise preparedness and the threats outlined by this analysis 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, including NS Norfolk, face all of these risks.

This analysis provides snapshots of potential future exposure to flooding at NS Norfolk. For the Navy to take additional action on the front line of sea level rise, however, it 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 planning efforts and to detailed mapping that includes future conditions; support planning partnerships with surrounding communities; and allocate resources for preparedness projects, on- and off-site, many of which will stretch over decades.

TABLE 3. All of NS Norfolk Could Flood with Category 1 and 2 Storms by Late Century

	Intermediate: Percent of base exposed					Highest: Percent of base exposed			
	Today	2050	2070	2100		Today	2050	2070	2100
Cat 1	11	19	35	78	Cat 1	11	27	66	99
Cat 2	62	83	94	100	Cat 2	62	90	99	100
Cat 3	98	99	100	100	Cat 3	98	100	100	100
Cat 4	100	100	100	100	Cat 4	100	100	100	100

The reach of storm surge associated with a Category 1 storm expands greatly with sea level rise. Today, just over 10 percent of the station area would be expected to flood during Category 1 storms. The flooded area increases to roughly 80 percent in 2100 in the intermediate scenario and to nearly 100 percent in the highest scenario.

US Navy

Hurricane Isabel, shown here battering cars in an NS Norfolk fleet parking lot, weakened to a tropical storm as it passed over Virginia on September 18, 2003, but it' storm surge did significant damage to military installations nonetheless.

Military bases and personnel protect the country from external threats. 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.

ENDNOTES

1 *The intermediate sea level rise scenario assumes ice sheet loss that increases over time, while the highest scenario assumes rapid loss of ice sheets. The latter scenario is particularly useful for decisions involving an especially low tolerance for risk. These results are a small subset of the full analysis. For more information, the technical appendix, and downloadable maps, see www.ucsusa.org/MilitarySeasRising.*

2 *UCS analyzed storm surge depth and exposure extent for each base using the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model, developed by the National Oceanic and Atmospheric Administration (NOAA), for storm events ranging in severity from Category 1 to Category 4, in addition to tidal floods. Both storm surge and flooding during extra-high tides can be significantly exacerbated by rainfall and wave action, neither of which we included in this study.*

3 *This analysis involved consultation with NS Norfolk. However, 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.*

4 *Nor'easters are common in the region and known to generate damaging storm surge. As SLOSH models only hurricanes, we did not include lesser storms such as nor'easters in this analysis. Increases in surge extent and depth should be expected with these storms as well.*

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FACT SHEET

The US Military on the Front Lines of Rising Seas

Exposure to Coastal Flooding at Joint Base Langley-Eustis, Virginia

HIGHLIGHTS

With seas rising at an accelerating rate, coastal military installations are increasingly exposed to storm surge and tidal flooding. The Union of Concerned Scientists (UCS) conducted analyses of this changing exposure for 18 military installations along the East and Gulf coasts. Analysis for Joint Base (JB) Langley-Eustis found that in the second half of this century, in the absence of preventive measures, this installation can expect more frequent and extensive tidal flooding, loss of currently utilized land, and substantial increases in the extent and severity of storm-driven flooding to which it is exposed.

The US Armed Forces depend on safe and functional bases, such as JB Langley-Eustis, Virginia, to carry out their stated mission: to provide the military forces needed to deter war and to protect the security of the country. A roughly three-foot increase in sea level would threaten 128 coastal Department of Defense (DOD) installations in the United States and the livelihoods of the people—both military personnel and civilians—who depend on them (NAS 2011). In the area around JB Langley-Eustis, seas are expected to rise between 4.5 and 6.9 feet by the end of this century.

To enable decision makers to better understand the sea level rise threat, and where and when it could become acute, UCS has performed a new analysis of 18 East and Gulf coast military installations, including JB Langley-Eustis. These sites were selected 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.

US Air Force

THE INLAND MARCH OF HIGH TIDE

JB Langley-Eustis is located in the Hampton Roads area of Virginia, an area where natural subsidence, low-lying topography, and changing ocean circulation patterns contribute to above-average rates of sea level rise. Much of the joint base itself is less than 10 feet above sea level. As a result, in the highest scenario, as much as 60 percent of Fort Eustis and nearly 90 percent of Langley AFB could be inundated by daily high tides by 2100.

UCS projected exposure to coastal flooding in the years 2050, 2070, and 2100 using the National Climate Assessment's mid-range, or "intermediate-high," scenario (referred to here as "intermediate") and, in light of the low tolerance for risk in some of the military's decisions, a "highest" scenario based on a more rapid rate of increase (Parris et al. 2012).[1] We modeled tidal flooding, permanent inundation, and storm surge from hurricanes.[2] The results below outline potential future flooding to which JB Langley-Eustis could be exposed, assuming no new measures are taken to prevent or reduce flooding.[3] This analysis finds the following key results:

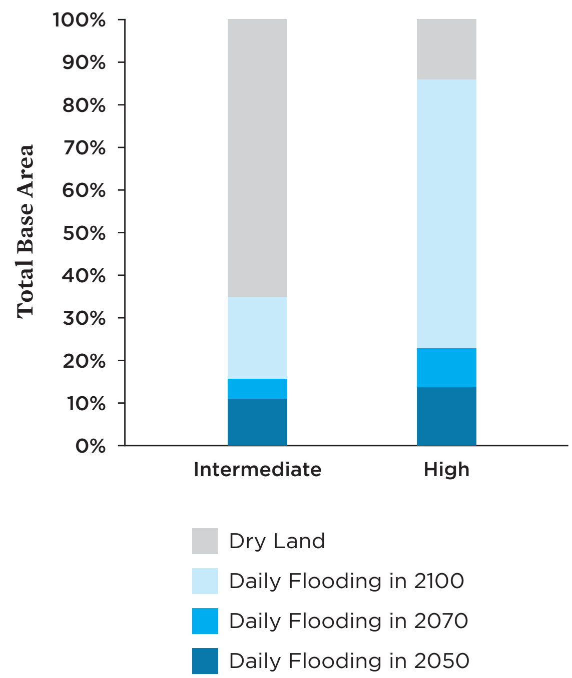
TIDAL FLOODING, PERMANENT INUNDATION, AND LAND LOSS

- **Flooding during extreme high tides will become more extensive, affecting new areas.** Today, routine tidal flooding affects mainly wetland portions of JB Langley-Eustis, roughly nine times per year. But in the intermediate scenario, such flooding could expand to affect roadways and other areas within the installation by 2050.
- **Flood-prone locations could flood with each high tide.** By 2050 in the highest scenario, tidal flooding occurs roughly 540 times per year—on average, more than once per day—in currently flood-prone places. Barring any natural adaptation of the wetlands, these and other low-lying areas could be inundated for more than 75 percent of the year by 2070.
- **Extensive land loss at JB Langley-Eustis is possible**. As the lowest-lying areas come to be underwater most of the time, the daily reach of high tide will inundate more elevated areas. In the highest scenario, roughly 60 percent of Fort Eustis and nearly 90 percent of Langley Air Force Base (AFB) would become part of the tidal zone, flooding daily, by the end of the century.

STORM SURGE

- **Sea level rise exposes additional, previously unaffected areas of JB Langley-Eustis to storm surge flooding.** By 2050 in the intermediate scenario, the area at Langley AFB exposed to flooding from a Category 1 storm increases by more than 30 percent to about 85 percent; it increases to about 65 percent at Fort Eustis.
- **Sea level rise means that later this century, storms in a lower category can produce surge associated today with a higher category.** By 2100 in the intermediate scenario, the area of JB Langley-Eustis exposed to storm surge flooding from a Category 1 storm is greater than that exposed by today's Category 2 storms. Similarly, in terms of the area exposed to flooding, a Category 2 storm surge in 2100 is equivalent to surge from a Category 3 today.
- **Sea level rise exposes JB Langley-Eustis to deeper, more severe flooding.** Today, the majority of the flooding these bases experience during Category 1 storms is five feet deep or less. By 2100 in the intermediate scenario, such a storm will expose more than 30 percent of Langley AFB to flooding five to 10 feet deep. While only about 5 percent of Fort Eustis is exposed to flooding five to 10 feet deep today during a Category 1 storm, the proportion rises to 20 percent in 2050 and to more than 40 percent in 2100.

FIGURE 1. Langley AFB Will Experience Land Loss



As high tide reaches farther inland, extensive land loss is possible at Langley AFB. Losses are substantial but smaller at Fort Eustis. Affected land can include developed and undeveloped areas and even wetlands that reside above the current high tide mark. Our analysis shows that installations projected to see major land loss, including Langley AFB, will also see substantial loss of currently developed and utilized areas.

Base Information

JB Langley-Eustis is located near the city of Newport News, Virginia, and is within the Hampton Roads metropolitan area, one of the East Coast regions most vulnerable to sea level rise because of its low-lying topography and natural subsidence

(VIMS 2013). Much of the region, including JB Langley-Eustis, lies below 10 feet in elevation (Connolly 2015). It is also situated within an East Coast sea level rise hot spot, where these local factors combine with changing ocean circulation patterns to create above-average sea level rise.

JB Langley-Eustis is made up of Langley AFB and Fort Eustis. The two installations, which were joined in 2010, are separated by nearly 20 miles. Langley AFB provides combat airpower to the nation and borders Langley Research Center, a historically pivotal aviation facility. Fort Eustis has, since World War II, provided Army transportation training and logistics. It is also the headquarters for the US Army Training and Doctrine Command, which oversees the training and leadership development of Army forces (DOD 2016).

With a population including active duty military, contractors, civilians, and their families, JB Langley-Eustis is an integral part of the local community (DOD 2016). The installation is a critical component of the local economy as well, contributing an estimated $2.4 billion annually (JB Langley-Eustis 2013).

JB Langley-Eustis

Established:	2010
Active Duty:	8,000
Guard/Reservists:	400
Family Members:	10,000
Students:	12,000

Langley AFB

Branch:	Air Force
Established:	1916
Size (Acres):	463,360
Units	50
Annual Budget:	$18.8B
Jobs:	192,000
Replacement Value:	$4.7B

Fort Eustis

Branch:	Army
Established:	1918
Size (Acres):	7,940

SOURCE: DOD 2016.

[With a population including active duty military, contractors, civilians, and their families, JB Langley-Eustis is an integral part of the local community.]

Historic Exposure to Storm Surge and Flood Hazards

Owing to its mid-Atlantic location, the Hampton Roads region has long endured flooding from hurricanes and lesser storms (HPRDC 2011). Because the topography and geology of the region make it naturally vulnerable to sea level rise, coastal flooding problems are on the rise (HPRDC 2012). Rising seas over the past few decades have meant that the region increasingly experiences problematic tidal flooding as well (Spanger-Siegfried, Fitzpatrick, Dahl 2014).

Since 1857, there have been 65 hurricanes that have come within 150 nautical miles of the Hampton Roads area (NOAA n.d.). Langley AFB maintains both a seawall, which helps to protect housing along the easternmost shore, and a robust, riprap-reinforced shoreline with plantings on the remaining eastern and north/northeastern coast. Both help control erosion (Figiera 2016)

While these measures provide protection during normal storms, they do not prevent flooding during severe nor'easters or hurricanes. In 2003, when Hurricane Isabel (Category 1) caused a storm surge of five to eight feet in the region, Langley AFB was largely underwater (Connolly 2015). The damage to Langley AFB from Isabel was estimated at more than $160 million, and about 200 facilities at the base were affected (Connolly 2015). A recent assessment showed that a 4.5-foot rise in water levels would close or block an estimated 62 roadways and 14 installation gates that serve the military in the Hampton Roads region (Belfield 2013).

Future (Projected) Exposure to Storm Surge and Flood Hazards

SEA LEVEL RISE

The intermediate scenario projects that the Hampton Roads area, including JB Langley-Eustis, will experience 4.5 feet of sea level rise, and the highest scenario projects nearly seven feet of rise by 2100. This rise will lead to increased exposure to different types of coastal flooding.

TIDAL FLOODING AND LAND LOSS:

Routine flooding during high tides, which currently occurs an average of nine times per year, is a persistent issue in the Hampton Roads area, regularly disrupting transportation and business. As sea level rises, this flooding is expected to become both more extensive and more frequent at both bases. In the intermediate scenario, such flooding could close roadways within Fort Eustis by 2050.

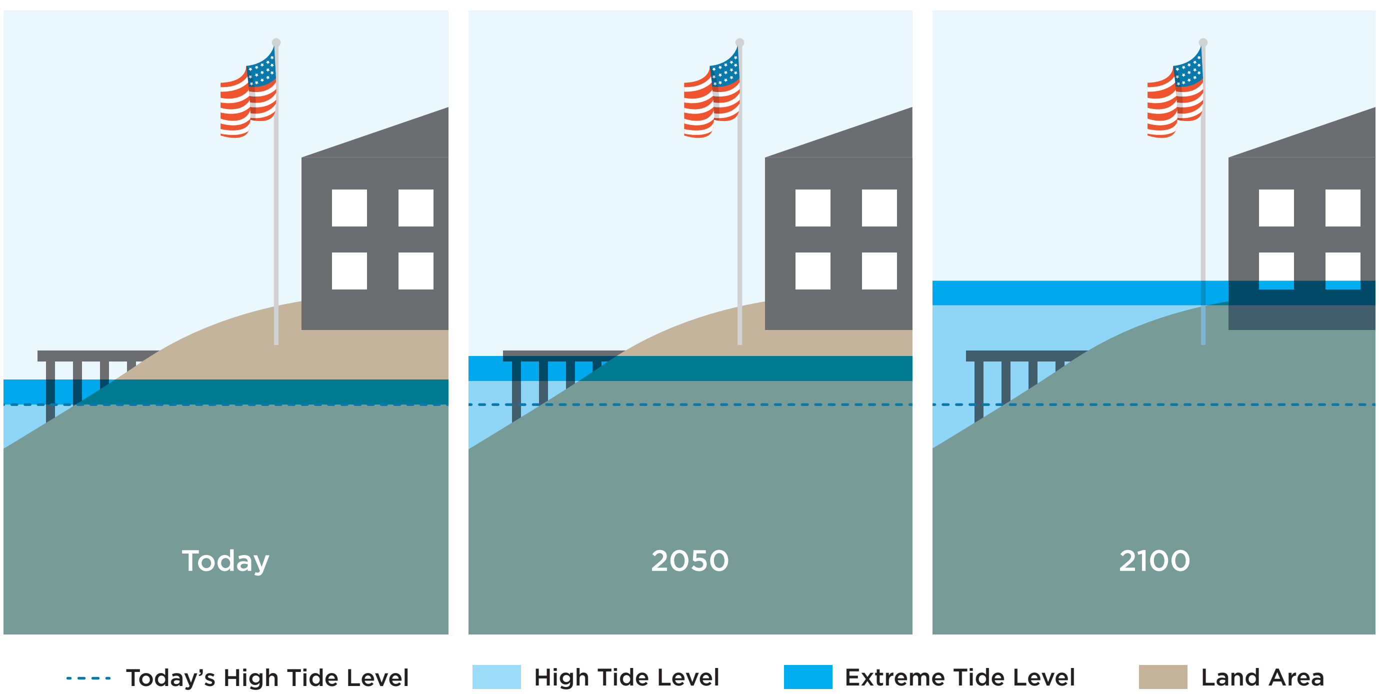
Areas currently affected by occasional tidal flooding could flood daily. The intermediate scenario projects that tidal flooding could occur an average of nearly 280 times per year by 2050. Without substantial adaptive measures, affected areas such as roadways and low-lying neighborhoods could become unusable land within the next 35 years. In 2050, the affected areas at the installations would still largely be wetlands, but the consequences of frequent flooding in the surrounding region—for example, damage to housing and

TABLE 1. Hampton Roads Area Bases Could See More than Six of Sea Level Rise by 2100

Year	Intermediate	Highest
2050	1.4	2.0
2070	2.5	3.6
2100	4.5	6.9

In the intermediate scenario, ice sheet loss increases gradually in the coming decades; in the highest scenario, more rapid loss of ice sheets occurs. The latter scenario is included in this analysis to help inform decisions involving an especially 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 (DeConto and Pollard 2016; Trusel et al. 2015; Chen et al. 2013; Rignot et al. 2011). Values shown are local projections that include unique regional dynamics such as land subsidence (see www.ucsusa.org/MilitarySeasRising).

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



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

travel delays affecting the joint base community of workers and personnel housed off base—could affect JB Langley-Eustis nonetheless.

The intermediate scenario shows flood-prone areas in the region flooding roughly 640 times per year—or with each of the two daily high tides, on average—and being underwater more than 75 percent of the time by 2070. More than a quarter of Langley AFB's land area would be exposed roughly nine times per year to flooding during extreme tides.

In this analysis, land that is inundated by at least one high tide each day is considered a loss and part of the tidal zone. According to this metric, 60 percent of Fort Eustis's land area would be lost by 2100 in the highest scenario, as would nearly 90 percent of Langley AFB's land area (see Figure 3, p. 6).

Around JB Langley-Eustis, the difference between high and low tide is small enough that, eventually, land will be permanently inundated—that is, flooded even at low tide. During the last quarter of this century, flood events in this area will begin to span many tide cycles. As a result, the number of individual flood events will decrease, but the duration of flood conditions will increase until flooding is essentially constant and the land that was once above the high tide mark is permanently inundated. In either scenario, flood-prone areas at these installations and in the surrounding region are constantly or near-constantly underwater by 2100 (see Table 2).

THE CHANGING THREAT OF HURRICANES

Category 1 storms are the most likely type of hurricane to affect this area.[4] Today, a Category 1 hurricane exposes about 50 percent of Langley AFB to flooding from storm surge. In the intermediate scenario, the area exposed to flooding at Langley AFB jumps to roughly 85 percent in 2050. By 2100, Langley AFB will be nearly 100 percent exposed to flooding from a Category 1 hurricane. The exposure of Fort Eustis will rise as well, from roughly 60 percent today to close to 80 percent in 2100 in the intermediate scenario.

Sea level rise also changes the depth of flooding Langley AFB and Fort Eustis can expect with major storms. Today, more than 90 percent of the inundation resulting from a Category 1 storm at Langley AFB is five feet deep or less. As this relatively shallow flooding becomes more extensive over time, so does the proportion of the base exposed to five to 10-foot flood depths. While less than 5 percent of Langley AFB is exposed to flooding five to 10 feet deep resulting from a Category 1 storm today, the intermediate scenario shows that more than 30 percent of the base will be exposed to such flooding in 2100. Similarly, at Fort Eustis, only about 6 percent of the base is exposed to flooding five to 10 feet deep today during a Category 1 storm. That exposure will rise to 20 percent in 2050 and to more than 40 percent in 2100.

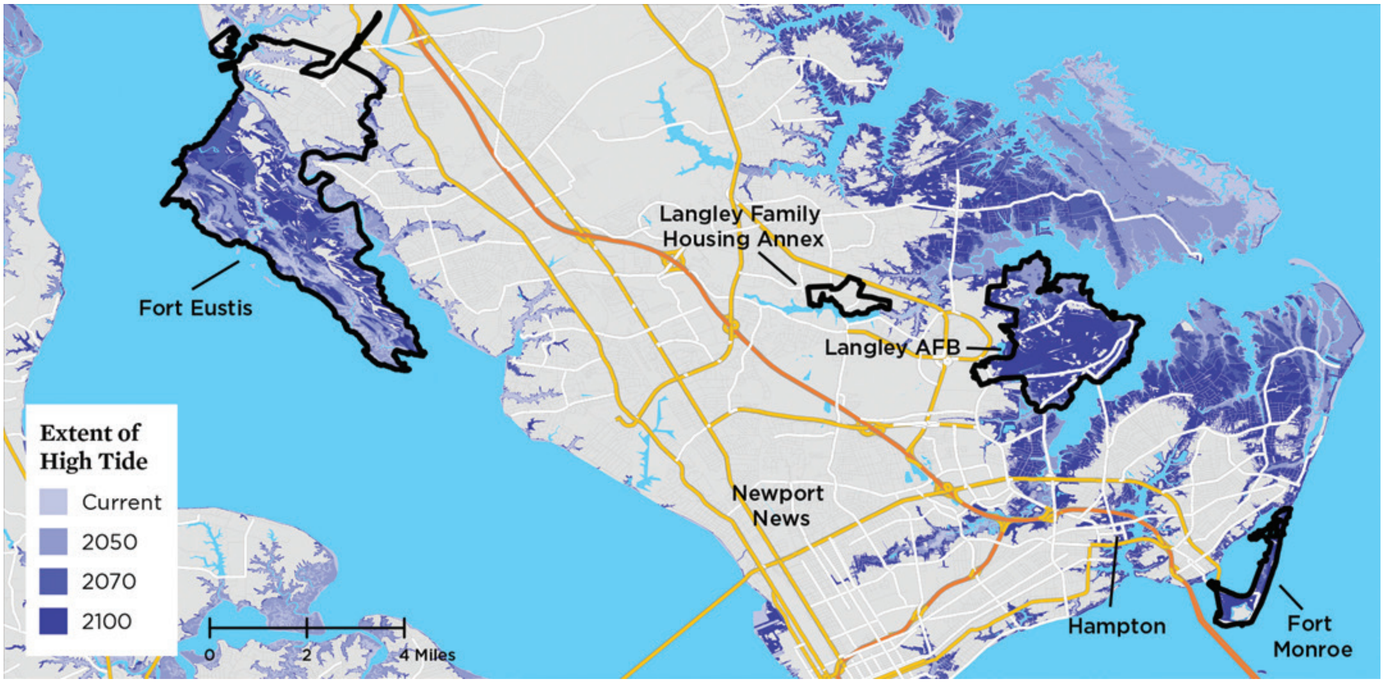
For the mid-Atlantic region, a Category 4 storm represents a worst-case scenario. Both sections of JB Langley-Eustis are highly exposed to storm surge from a Category 4 storm today, with 80 percent of Fort Eustis and 100 percent of Langley AFB at risk of flood. Because flood exposure is already so high at each base, the percentage of flood exposure does not increase substantially for a Category 4 storm as sea level rises, but the depth of inundation does. At Langley AFB, 75 percent of the base is exposed to flooding 10 to 15 feet deep today. In the highest scenario, almost 100 percent of the base will be exposed to flooding 15 feet deep or more by 2100.

TABLE 2. Areas Prone to Flooding Could Be Permanently Inundated by 2100

	Intermediate		Highest	
Year	Events per Year	% of Year	Events per Year	% of Year
2012	9 ± 4	0	9 ± 4	0
2050	276 ± 16	10	538 ± 26	26
2070	641 ±17	40	525 ± 26	77
2100	124 ± 27	96	1 ± 0	100

Sea level rise will lead to constant or near-constant flooding in the Hampton Roads area. Shown here are flood events in low-lying, flood-prone areas projected by the intermediate and highest scenarios. Events per year are reported as the average over a five-year period with one standard deviation. Percent of year is reported simply as the average over a five-year period. As flood conditions span multiple high tide cycles, the number of distinct flood events drops, but the duration of flooding increases until it is constant. Installations will be affected by this flooding depending on the presence of low-lying land on site.

FIGURE 3. The Reach of Future Daily High Tides at JB Langley-Eustis



The reach of future daily high tides, shown in the top panel, encompasses currently utilized land at JBLE. Langley AFB's developed area is shown in the bottom panel. The highest scenario is mapped here.

SOURCE: GOOGLE EARTH.

Similarly, a Category 4 storm today exposes 70 percent of Fort Eustis to flooding 10 or more feet deep. By 2100, 70 percent of the base will be exposed to flooding of 15 or more feet deep. As early as 2070, close to 10 percent of Fort Eustis will be exposed to flooding more than 20 feet deep—a level of flooding not projected for any portion of the base for a Category 4 storm today.

Mobilizing on the Front Lines of Sea Level Rise

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).

> ***The gap between the military's current sea level rise preparedness and the threats outlined by this analysis is large and growing.***

Recognizing its vulnerability to sea level rise and coastal flooding, JB Langley-Eustis has been working closely with regional stakeholders on preparedness and resilience efforts (Steinhilber, Whitelaw, and Considine 2015). Low-lying Langley AFB has already taken numerous steps to alleviate the effects of tidal flooding on base facilities. After Hurricane Isabel in 2003, Langley AFB raised electrical transformers and HVAC units and removed mechanical rooms from basements in most of its facilities (Figiera 2016). It installed integrated flood barriers at entrances to numerous flood-susceptible facilities and has a powerful pump system to remove water from the installation grounds and reduce infiltration and other damage to facilities (Figiera 2016). Langley AFB also partnered with NASA's Langley Research Center to develop a flood tool to accurately predict (at individual building level) inundation based on storm surge data collected by a nearby buoy (Figiera 2016). It uses these data to focus flood prevention efforts on at-risk facilities, thereby maximizing the use of labor and other resources during storm preparations.

But here and across US coastal installations there is still far to go: the gap between the military's current sea level rise preparedness and the threats outlined by this analysis 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, including JB Langley-Eustis, face all of these risks.

This analysis provides snapshots of potential future exposure to flooding at JB Langley-Eustis. For the joint base to take action on the front line of sea level rise, however, it 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 planning efforts and to detailed mapping that includes future conditions; support planning partnerships with surrounding communities; and allocate resources for preparedness projects, on- and off-site, many of which will stretch over decades.

Military bases and personnel protect the country from external threats. 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.

ENDNOTES

1 *The intermediate sea level rise scenario assumes ice sheet loss that increases over time, while the highest scenario assumes rapid loss of ice sheets. The latter scenario is particularly useful for decisions involving an especially low tolerance for risk. These results are a small subset of the full analysis. For more information, the technical appendix, and downloadable maps, see www.ucsusa.org/MilitarySeasRising.*

2 *UCS analyzed storm surge depth and exposure extent for each base using the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model, developed by the National Oceanic and Atmospheric Administration (NOAA), for storm events ranging in severity from Category 1 to Category 4, in addition to tidal floods. Both storm surge and flooding during extra-high tides can be significantly exacerbated by rainfall and wave action, neither of which was included in this study.*

3 *This analysis involved consultation with JB Langley-Eustis. However, in some instances, 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.*

4 *Nor'easters are more common in the region and known to generate damaging storm surge. As SLOSH models only hurricanes, we did not include lesser storms, such as nor'easters, in this analysis. Increases in surge extent and depth should be expected with these storms as well.*

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Union of Concerned Scientists

FACT SHEET

The US Military on the Front Lines of Rising Seas

Exposure to Coastal Flooding at Joint Base Anacostia-Bolling and Washington Navy Yard, Washington, District of Columbia

HIGHLIGHTS

With seas rising at an accelerating rate, coastal military installations are increasingly exposed to storm surge and tidal flooding. The Union of Concerned Scientists (UCS) conducted analyses of this changing exposure for 18 military installations along the East and Gulf coasts. Analysis for Joint Base Anacostia-Bolling (JBAB) and Washington Navy Yard found that in the second half of this century, in the absence of preventive measures, this installation can expect the following: more frequent and extensive tidal flooding, loss of currently utilized land, and substantial increases in the extent and severity of storm-driven flooding to which it is exposed.

The US Armed Forces depend on safe and functional bases, such as JBAB and Washington Navy Yard, Washington, DC, to carry out their stated mission: to provide the military forces needed to deter war and to protect the security of the country. A roughly three-foot increase in sea level would threaten 128 coastal Department of Defense (DOD) installations in the United States and the livelihoods of the people—both military personnel and civilians—who depend on them (NAS 2011). In the area of these two installations, seas are projected to rise between four and 6.4 feet by the end of this century.

To enable decision makers to better understand the sea level rise threat, and where and when it could become acute, UCS has performed a new analysis of 18 East and Gulf Coast military installations, including JBAB and Washington Navy Yard. These sites were selected 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.

UCS projected exposure to coastal flooding in the years 2050, 2070, and 2100 using the National Climate Assessment's midrange or "intermediate-high" scenario (referred to here as "intermediate") and, in light of the low tolerance for risk in some of the military's decisions, a "highest" scenario with a more rapid rate of

US Navy

THE INLAND MARCH OF HIGH TIDE

Washington Navy Yard is located in southeastern Washington, DC, along the northern shore of the Anacostia River. Largely spared tidal flooding today, the Navy Yard could see 30 percent of its current land area flood daily by the end of the century, depending on the rate of sea level rise.

increase (Parris et al. 2012).[1] We modeled tidal flooding, permanent inundation, and storm surge from hurricanes.[2] The results below outline potential future flooding to which JBAB and Washington Navy Yard could be exposed, assuming no new measures are taken to prevent or reduce flooding.[3] This analysis finds the following key results:

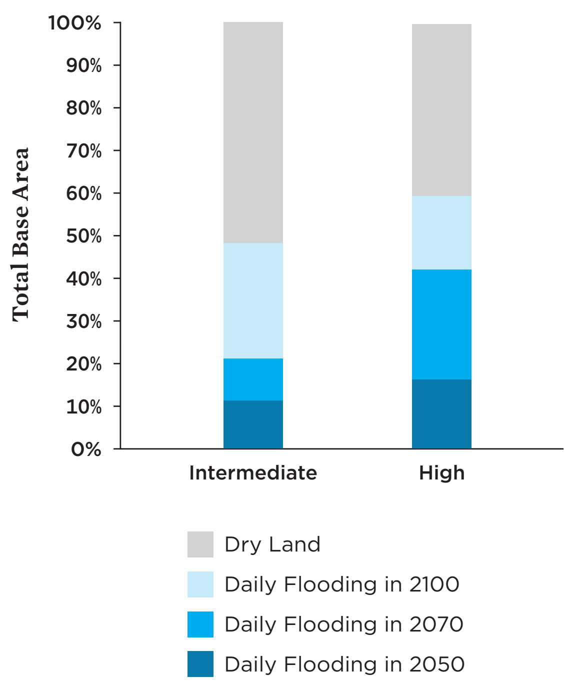
TIDAL FLOODING, PERMANENT INUNDATION, AND LAND LOSS

- **Areas currently unaffected by occasional tidal flooding could flood more often than daily.** Naval Support Facility (NSF) Anacostia, the northern half of JBAB, is currently affected by flooding during extra-high tides more than 40 times per year on average. By 2050, flood-prone areas could experience 450 to 600 floods per year, depending on the scenario.
- **Flooding during extreme high tides will become more extensive.** Extreme high tides do not typically flood the Washington Navy Yard today. But in the highest scenario, roughly 40 percent of Washington Navy Yard is inundated by the end of this century during the extra-high tides that affect the area more than 40 times per year on average.
- **Extensive land loss at NSF Anacostia is possible.** In the intermediate scenario, which projects four feet of sea level rise by the end of the century, roughly 50 percent of NSF Anacostia's land area—primarily developed, utilized land—floods daily, effectively becoming part of the tidal zone.

STORM SURGE

- **Sea level rise exposes previously unaffected areas of JBAB and Washington Navy Yard to storm surge flooding.** In the intermediate scenario, the area of Washington Navy Yard exposed to flooding increases by 25 percent or more during Category 1 and 2 storms by 2100.
- **Sea level rise exposes JBAB and Washington Navy Yard to deeper, more severe flooding.** Over time, the area inundated during storm surges by seawater five feet or more deep increases.

FIGURE 1. NSF Anacostia May Experience Major Land Loss



As high tide reaches farther inland, extensive land loss is possible at NSF Anacostia. Losses may be substantial but smaller at Washington Navy Yard and insubstantial at Bolling Air Force Base (AFB). Affected land may include developed and undeveloped areas. NSF Anacostia is projected to see substantial loss of currently developed and utilized areas.

Base Information

JB ANACOSTIA-BOLLING

JBAB is located in the southeastern portion of Washington, DC, along the Potomac and Anacostia rivers. It is situated within an East Coast sea level rise hot spot, where natural subsidence, low-lying topography, and changing ocean circulation patterns contribute to above-average sea level rise (Sallenger, Doran, and Howd 2012).

JBAB comprises NSF Anacostia and Bolling AFB. The major tenant command on JBAB is the Defense Intelligence Agency, the DOD combat support agency that provides military intelligence information to combat and noncombat military missions (DIA n.d.). The US Naval Research Laboratory and the White House Communications Agency are also located at JBAB. Bolling AFB provides administrative support to the Air Force and is the home of the 11th Wing, "The Chief's Own" (The Military Zone n.d.).

WASHINGTON NAVY YARD

Washington Navy Yard is also located in southeastern Washington, DC, along the northern shore of the Anacostia River. Like JBAB, it lies within a hot spot of elevated rates of sea level rise.

Founded in 1799, the Navy Yard is the oldest US Navy shore facility (Global Security.org 2013). Originally a shipbuilding facility, the installation now provides administrative and ceremonial functions. Washington Navy Yard is also home to the Commander, Navy Infrastructure Command (CNIC), which manages coastal installations for the US Navy,

JB Anacosta-Bolling

Branch:	Navy and Air Force
Established:	2010
NSF Anacostia:	1917
Bolling AFB:	1948
Size (Acres):	956
NSF Anacostia (Military):	1,898
NSF Anacostia (Civilians):	1,362
Bolling AFB (Military):	11,893
Bolling AFB (Civilians):	1,638
Defense Intelligence Agency:	16,500
Naval Research Lab (Military):	354
Naval Research Lab (Civilians):	4,578
Tenant Units:	48

SOURCE: DOD 2016; MILITARYLIFE 2016; MILITARY ZONE N.D.; DIA N.D.

Washington Navy Yard

Branch:	Navy
Established:	1799
Size (Acres):	86
Military:	1,209
Commands:	5

SOURCE: : CNIC 2016; KARKLIS AND VOGEL 2013; MILITARYLIFE 2016.

and several other tenant commands, including the Naval Facilities Engineering Command and the Naval Inspector General (CNIC 2016). While the workforce does include Navy and Marine Corps personnel, the majority of employees are civilians, including Navy contractors, engineers, lawyers, and procurement officials (Karklis and Vogel 2013).

Historic Exposure to Storm Surge and Flood Hazards

Category 1 storms are the most likely hurricane threat to the Washington, DC, area. Since 1851, there have been eight Category 1 storms and two Category 2 storms that have tracked within 150 miles of the District; no Category 3 or higher storms have been recorded (DOEE 2015).

In August 2011, Hurricane Irene (Category 1) produced a storm surge of one to 2.5 feet in the northern Chesapeake Bay region (NWS 2011). In September 2003, Hurricane Isabel (Category 2) produced moderate to major river flooding in the Potomac River Basin and caused record tidal flooding and damage to the Naval District along the Anacostia, including damage to marinas and the flooding of cars and buildings (NWS 2003).[4]

While less than 1 percent of the southern portion of JBAB currently floods during Category 1 storms, about 45 percent of the northern portion of NSF Anacostia floods during the same storms; the area lies so low that when it rains, water encroaches from both the river and inland.

JBAB has few remaining natural flood buffers as a result of land filling, construction of hard flood control structures along the rivers, and construction of buildings and paved areas (DON 2010). A 2.4-mile levee system along the Anacostia River provides some protection to JBAB from river flooding caused by large volumes of storm water (ASCE 2016). However, the levee is “decertified,” as it does not provide risk reduction against the authorized maximum flood discharge level from the Potomac and Anacostia rivers (ASCE 2016). The base has three powerful sump pumps and a spillway designed to handle large storms (Oliphant 2016). JBAB and other DC facilities depend on the District’s Blue Plains sewage treatment plant located just south of JBAB. While the management of Blue Plains is working to fortify the plant, it too is exposed to coastal flooding and storm surge.

Future (Projected) Exposure to Storm Surge and Flood Hazards

SEA LEVEL RISE

The intermediate scenario projects that the Washington, DC, area will experience four feet of sea level rise, and the highest scenario projects 6.4 feet of rise by 2100. This rise will affect the frequency and extent of tidal flooding and increase the risk of land loss.

JB Anacostia-Bolling

TIDAL FLOODING AND LAND LOSS

Routine flooding during high tides is a persistent issue in the Washington, DC, area. This flooding, which currently occurs an average of 43 times annually, can be disruptive to transportation and business. The central portion of NSF Anacostia, in the northern half of JBAB, experiences such flooding in its low-lying areas.

In the intermediate scenario, tidal flooding occurs roughly 450 times per year and in the highest scenario 600 times per year by 2050. In the highest scenario, this flooding occurs, on average, twice daily with high tides. With such regular flooding, affected areas could become unusable within the next 35 years.

With the highest scenario, JB Anacostia-Bolling's flood-prone areas would be underwater not just at high tide, but for over 70 percent of the year by 2070. In locations such as NSF Anacostia, the difference between high and low tide is small enough that, with the projected increases in sea level, inundation in flood-prone areas will eventually exist even at low tide. During the last quarter of this century, flood events in this area will begin to span many high tide cycles. As a result, the number of individual flood events will decrease but the duration of flood conditions will increase until flooding is essentially constant and land that was once above the high tide mark is permanently inundated. In the highest scenario, roughly half of NSF Anacostia becomes part of the tidal zone, flooding daily.

THE CHANGING THREAT OF HURRICANES

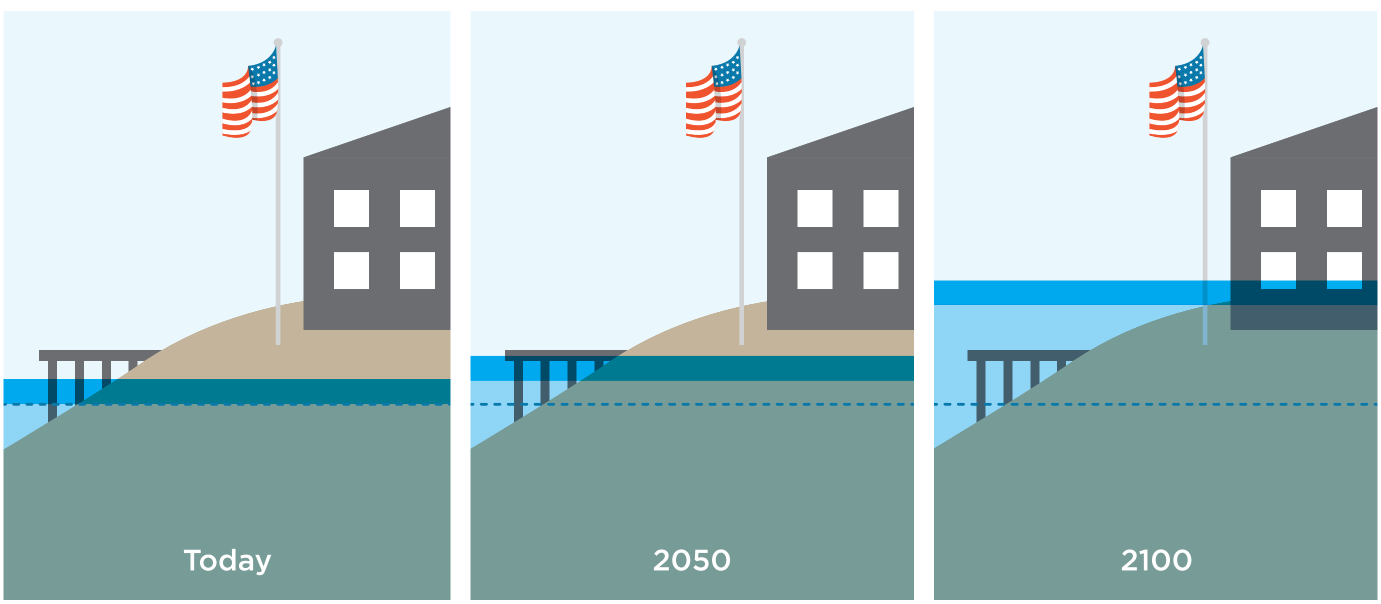
Category 1 hurricanes are the most likely type to affect this area.[5] Over time, sea level rise exposes a greater proportion of each base's area to inundation caused by a Category 1 storm. This trend is especially clear in the projections for the northern section of JBAB, the NSF Anacostia area, where the area exposed to storm surge flooding increases in the intermediate scenario to 65 percent and in the highest scenario to roughly 75 percent by 2100. In each of these scenarios, the area in

TABLE 1. Washington, DC, Area Bases: Projected Sea Level Rise (Feet) in Two Scenarios

Year	Intermediate	Highest
2050	1.2	1.8
2070	2.1	3.3
2100	4.0	6.4

In the intermediate scenario, ice sheet loss increases gradually in the coming decades; in the highest scenario, more rapid loss of ice sheets occurs. The latter scenario is included in this analysis to help inform decisions involving an especially 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 DeConto and Pollard 2016; Trusel et al. 2015; Chen et al. 2013; Rignot et al. 2011). Values shown are local projections that include unique regional dynamics such as land subsidence (see www.ucsusa.org/MilitarySeasRising).

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.

TABLE 2. Flood-Prone Areas Could Be Underwater at All Times by 2100

	Intermediate		Highest	
Year	Events per Year	% of Year	Events per Year	% of Year
Current	43 ± 13	1	43 ± 13	1
2050	456 ± 24	18	606 ± 15	34
2070	641 ± 11	42	559 ± 29	73
2100	257 ± 20	91	1 ± 0	100

Sea level rise will lead to constant or near-constant flooding around JBAB and Washington Navy Yard. Shown here are flood events in low-lying areas projected by the intermediate and highest scenarios. Events per year are reported as the average over a five-year period with one standard deviation. Percent of year is reported simply as the average over a five-year period. As flood conditions span multiple high tide cycles, the number of distinct flood events drops but the duration of flooding increases until it is constant. Installations will be affected by this flooding depending on the presence of currently flood-prone land on-site.

NSF Anacostia inundated by a Category 1 storm in 2100 will be greater than the area inundated by a Category 2 storm today.[6]

> ***With such regular flooding, affected areas could become unusable within the next 35 years.***

Sea level rise also changes the depth of flooding that the northern NSF Anacostia section of JBAB can expect with major storms. Whereas most of the inundation caused by a Category 1 storm today is five feet or less deep, a Category 1 storm in 2100 in the intermediate scenario causes more than 25 percent of NSF Anacostia to flood to a depth of five to 10 feet. However, even in 2100, Bolling AFB will be unaffected by flooding during a Category 1 storm.

For the mid-Atlantic region, a Category 4 storm in the highest scenario represents the worst case for future storm surge inundation. A Category 4 storm today exposes 30 percent of Bolling AFB and almost 90 percent of NSF Anacostia to flooding. In 2100 in the highest scenario, 75 percent of Bolling AFB and over 95 percent of NSF Anacostia flood during storm surge. At both sites, more than half of the flooded areas are under more than five feet of water.

Washington Navy Yard

TIDAL FLOODING AND LAND LOSS

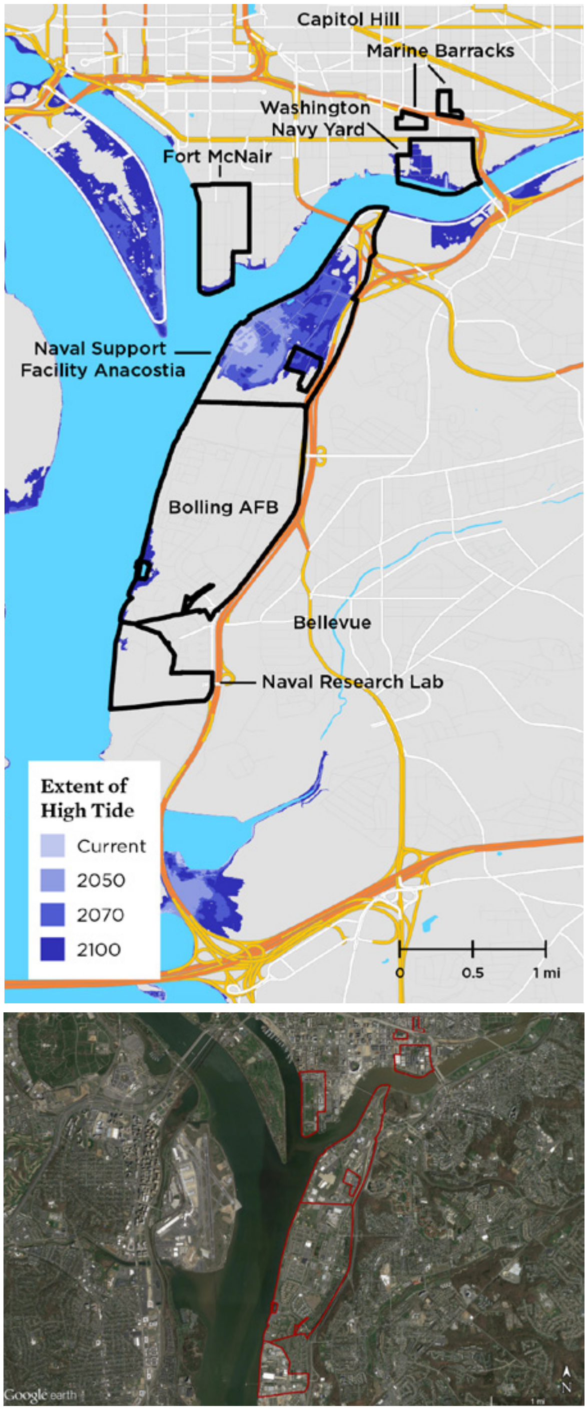
Washington Navy Yard is not directly affected by the routine high tide flooding that impacts the Washington, DC, area an average of about 40 times per year. As sea level rises, however, the base will experience increasingly frequent and extensive inundation during routine high tides. In the intermediate scenario, Washington Navy Yard experiences flooding of limited extent even in 2100. In the highest scenario, however, about 30 percent of the installation's land area becomes part of the tidal zone and an additional 10 percent experiences flooding during extra-high tides by the end of the century.

THE CHANGING THREAT OF HURRICANES

Category 1 hurricanes are the most likely type to affect this area. Just above 10 percent of Washington Navy Yard is exposed to storm surge resulting from a Category 1 storm today. Most of that storm surge flooding is five to 10 feet deep. In the intermediate scenario, the extent of exposure increases by 5 percent by 2050. By 2100, 45 percent of the base is exposed to storm surge from a Category 1 storm, greater than the area exposed to flooding during a Category 2 storm today.

A Category 4 storm hitting in 2100 in the highest scenario is the worst-case scenario for the area. In this case, more than 75 percent of Washington Navy Yard is exposed to storm surge. About 65 percent of the base experiences flooding more than five feet deep, and flooding is deepest along the shore of the Anacostia River. Even in this worst-case scenario,

FIGURE 3. JBAB Is Expected to Lose Currently Utilized Land



The projected reach of future daily high tides, shown in the top panel, encompasses currently utilized land; the Naval Support Facility Anacostia (home to the National Defense University and US Coast Guard headquarters) is particularly affected. The highest scenario is mapped here.

SOURCE: GOOGLE EARTH.

the northeastern corner of Washington Navy Yard is unaffected by flooding.

Mobilizing on the Front Lines of Sea Level Rise

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). JBAB recognizes it has a flood risk problem and inadequate protection and is working to mitigate these risks, including by prioritizing storm water management strategies to reduce flood hazards (NCPC 2014). For its part, the Washington Navy Yard is working with the Army Corps of Engineers on a vulnerability study (Underwood 2016).

> ***The gap between the military's current sea level rise preparedness and the threats outlined by this analysis is large and growing.***

But here and across coastal installations there is still far to go: the gap between the military's current sea level rise preparedness and the threats outlined by this analysis 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, including JBAB and the Washington Navy Yard, face all of these risks.

This analysis provides snapshots of potential future exposure to flooding at JBAB and Washington Navy Yard. For the military to take additional action on the front line of sea level rise, however, it 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 planning efforts and to detailed mapping that includes future conditions; support planning partnerships with surrounding communities; and allocate resources for preparedness projects, on- and off-site, many of which will stretch over decades.

Military bases and personnel protect the country from external threats. 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.

ENDNOTES

1 *The intermediate sea level rise scenario assumes ice sheet loss that increases over time, while the highest scenario assumes rapid loss of ice sheets. The latter scenario is particularly useful for decisions involving an especially low tolerance for risk. These results are a small subset of the full analysis. For more information, the technical appendix, and downloadable maps, see www.ucsusa.org/MilitarySeasRising.*

2 *UCS analyzed storm surge depth and exposure extent for each base using the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model, developed by the National Oceanic and Atmospheric Administration (NOAA), for storm events ranging in severity from Category 1 to Category 4, in addition to tidal floods. Both storm surge and flooding during extra-high tides can be significantly exacerbated by rainfall and wave action, neither of which was included in this study.*

3 *This analysis involved consultation with JBAB. However, here and at other installations, 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.*

5 *Nor'easters are more common in the region and known to generate damaging storm surge. As SLOSH models only hurricanes, we did not include lesser storms, such as nor'easters, in this analysis. Increases in surge extent and depth should be expected with these storms as well.*

6 *It is important to note that while the JBAB partial levee is technically decertified, it would provide some protection above that shown in the models.*

4 *The watershed that contributes flooding affecting JBAB and the Washington Navy Yard originates in Bladensburg, Maryland. This watershed area is highly urbanized and quickly generates large volumes of storm runoff resulting from rain. This modeling does not account for rainfall.*

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FIND THE FULL ANALYSIS AND METHODOLOGY ONLINE: **www.ucsusa.org/MilitarySeasRising**

The Union of Concerned Scientists puts rigorous, independent science to work to solve our planet's most pressing problems. Joining with citizens across the country, we combine technical analysis and effective advocacy to create innovative, practical solutions for a healthy, safe, and sustainable future.

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Exposure to Coastal Flooding at the US Naval Academy (USNA), Maryland

HIGHLIGHTS

With seas rising at an accelerating rate, coastal military installations are increasingly exposed to storm surge and tidal flooding. The Union of Concerned Scientists (UCS) conducted analyses of this changing exposure for 18 installations along the East and Gulf coasts. Analysis for the US Naval Academy (USNA) found that in the second half of this century, in the absence of preventive measures, the academy can expect more frequent and extensive tidal flooding, loss of currently utilized land, and substantial increases in the extent and severity of storm-driven flooding to which it is exposed.

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US Navy

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The USNA, one of five service academies in the country, trains students who go on to become officers in the Navy and the Marine Corps. Annapolis, the academy's location, is one of the East Coast cities that has seen a marked increase in the frequency of tidal flooding—on average, Annapolis now experiences roughly 50 floods a year. By 2050, the academy's flood-prone areas can expect to be underwater hundreds of times each year.

increase (Parris et al. 2012).[1] We modeled tidal flooding, permanent inundation, and storm surge from hurricanes.[2] The results below outline potential future flooding to which the academy could be exposed, assuming no new measures are taken to prevent or reduce flooding.[3] This analysis finds the following key results:

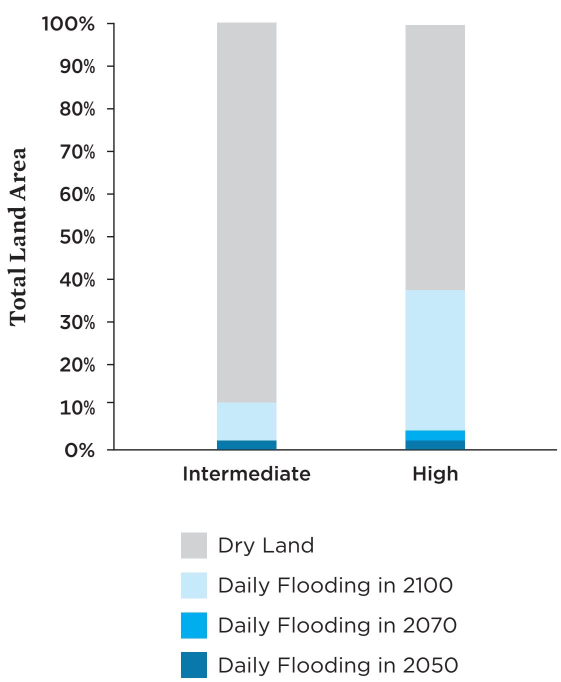
TIDAL FLOODING, PERMANENT INUNDATION, AND LAND LOSS

- **Flooding during extreme high tides will become more extensive.** Today, the Annapolis waterfront, including parts of the academy, is affected by flooding during extra-high tides roughly 50 times per year. In the highest scenario, almost 15 percent of the academy is flooded with this same frequency by 2070.
- **Certain locations could flood with each high tide.** The intermediate scenario shows the USNA experiencing roughly 400 tidal flooding events per year—on average, more than one per day—by 2050. By 2070, flood conditions begin to span several high tide cycles and flood-prone areas are underwater 85 percent of the time.
- **Sea level rise could claim currently utilized areas.** In both scenarios, currently flood-prone areas are underwater nearly constantly by 2070. In the intermediate scenario, with four feet of sea level rise, roughly 10 percent of the academy's land area is part of the tidal zone (flooding daily) by 2100. In the highest scenario, which projects 6.4 feet of rise, the area that floods with daily tides climbs above 35 percent by 2100.

STORM SURGE

- **Sea level rise exposes previously unaffected areas to storm surge.** In both the intermediate and highest scenarios, sea level rise increases the area exposed to flooding from Category 1 storms by nearly 30 percent by 2100.
- **Sea level rise exposes the academy to deeper, more severe flooding.** Today, most storm surge flooding from Category 2 storms is less than five feet deep. By 2100 in the intermediate scenario, Category 2 storms expose one-third of the academy to surge flooding five to 10 feet deep.

FIGURE 1. The USNA May Experience Significant Land Loss



As high tide reaches farther inland, significant land loss is possible at the USNA, particularly if the highest scenario proves true. Unlike some of the other installations analyzed, where inundation may affect undeveloped areas most heavily, the academy consists almost entirely of developed, utilized land.

Base Information

The USNA is located in Annapolis, Maryland, where the Severn River joins the Chesapeake Bay. It is situated within an East Coast sea level rise hot spot, where natural subsidence, low-lying topography, and changing ocean circulation patterns contribute to above-average rise (Sallenger, Doran, and Howd 2012). One of five service academies in the country, the USNA trains students who ultimately become officers in the Navy and the marine corps (DOD 2016).

US Naval Academy

Branch:	Navy
Established:	1845
Size (Acres):	338
Midshipmen:	4,400
Faculty:	580

SOURCE: DOD 2016.

Historic Exposure to Storm Surge and Flood Hazards

Since 1876, 15 hurricanes have passed within 150 nautical miles of the academy (NOAA n.d.). Hurricanes are relatively rare in the Chesapeake Bay area; the Navy has estimated that there is a 20 percent chance of a tropical cyclone and a 3 percent chance of a hurricane passing within 75 nautical miles of Annapolis in any given year (Kato, Handlers, and Brand 2000). However, storm surge from Hurricane Isabel, a Category 1 storm passing nearby in 2003, caused unprecedented flooding that rendered half of the academy's classroom unusable (NOAA 2004).

To mitigate damage from coastal flooding, the USNA has installed five seawalls (Marine Technologies n.d.).

Future (Projected) Exposure to Storm Surge and Flood Hazards

SEA LEVEL RISE

The intermediate scenario projects that the USNA will experience 4 feet of sea level rise and the highest scenario projects nearly 6.5 feet of rise by 2100. This rise will drive the high tide line inland and lead to increased exposure to different types of coastal flooding.

TIDAL FLOODING AND LAND LOSS

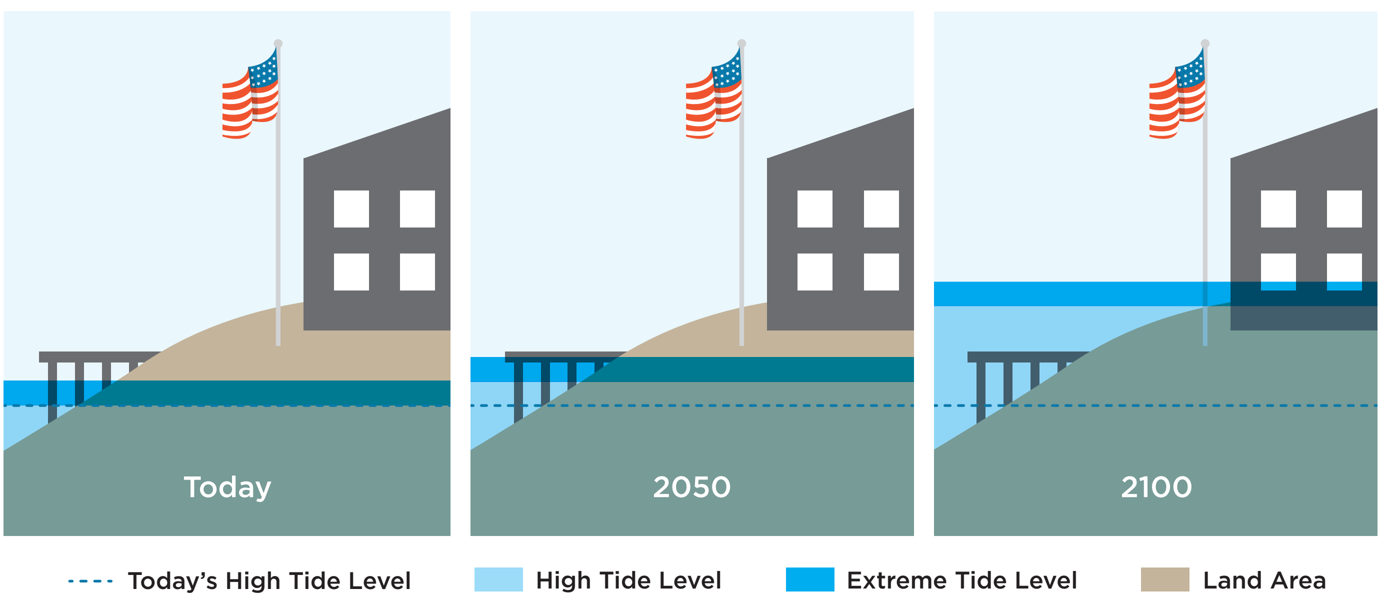
Currently, the Annapolis waterfront and parts of the academy experience flooding during extra-high tides associated with a full or new moon roughly 50 times per year. The intermediate scenario projects that, by 2050, areas currently affected by occasional tidal flooding will experience about 400 tidal floods per year—in other words, they would flood daily on average. This land can thus become unusable within the next 35 years.

TABLE 1. USNA Projected Sea Level Rise (Feet) in Two Scenarios

Year	Intermediate	Highest
2050	1.2	1.8
2070	2.1	3.3
2100	4.0	6.4

In the intermediate scenario, ice sheet loss increases gradually in the coming decades; in the highest scenario, more rapid loss of ice sheets occurs. The latter scenario is included in this analysis to help inform decisions involving an especially 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 (DeConto and Pollard 2016; Trusel et al. 2015; Chen et al. 2013; Rignot et al. 2011). Values shown are local projections that include unique regional dynamics such as land subsidence (see www.ucsusa.org/MilitarySeasRising).

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.

TABLE 2. Annapolis Area Tidal Flooding Frequency

	Intermediate		Highest	
Year	Events per Year	% of Year	Events per Year	% of Year
2012	50 ± 13	1	50 ± 13	1
2050	403 ± 34	42	291 ± 15	74
2070	177 ± 22	85	12 ± 5	97
2100	2 ± 2	98	1 ± 1	100

Projected sea level rise will lead to constant or near-constant flooding around USNA. Shown here are flood events in low-lying, flood-prone areas projected by the intermediate and highest scenarios. Events per year are reported as the average over a five-year period with one standard deviation. Percent of year is reported simply as the average over a five-year period. As flood conditions begin to span multiple high tide cycles, the number of distinct flood events gradually drops toward one, while the duration of flooding increases until it is constant.

As sea level rises, flooding that occurs during high tide lasts longer. In Annapolis, the difference between high and low tide is small enough that flood conditions are expected to eventually exist even at low tide. By 2050 in the highest scenario, the number of individual flood events will increase but also, and more significantly, the duration of flood conditions in low-lying areas will increase. By 2070, that flooding is essentially constant and the land in question is permanently inundated. Both scenarios project that the academy can expect flood-prone areas to be nearly constantly under water by 2070. Given the highest scenario's projection of 6.4 feet of sea level rise by the end of the century, roughly 40 percent of the academy's land area would flood daily.

THE CHANGING THREAT OF HURRICANES

Category 1 hurricanes are the most likely type to affect the USNA.[4] Today, a Category 1 hurricane exposes roughly 20 percent of the academy's area to storm surge flooding. In 2070 in both scenarios, the area inundated by a Category 1 storm is equivalent to the area inundated by a Category 2 storm today. And in 2100 in both scenarios, a Category 1 storm exposes an additional 30 percent of academy area to storm surge.

Sea level rise also increases the depth of flooding the academy can expect with major storms. Category 1 storms today cause relatively shallow flooding at the academy: most is five feet or less deep. In the highest scenario, however, more than half the flooding resulting from a Category 1 storm in 2100 is five to 10 feet deep.

For the mid-Atlantic region, the worst-case scenario considered in this analysis is a Category 4 storm occurring in the highest scenario in 2100. Today, a Category 4 storm exposes 50 percent of the academy to flooding, and more than 40 percent of the base could be covered by flood waters greater than five feet deep. By 2100 in the highest scenario, a Category 4 storm exposes almost 60 percent of the academy to flooding. Almost half of its area could experience flooding 10 or more feet deep, and roughly 20 percent would see depths of 20 or more feet.

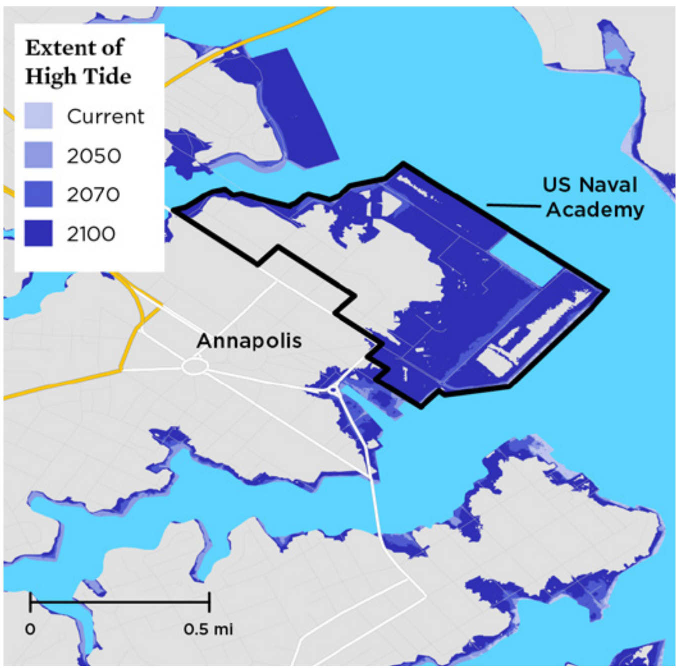
Given the highest scenario, roughly 40 percent of the academy's land area would flood daily.

Mobilizing on the Front Lines of Sea Level Rise

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). Recognizing the threat of increased flooding, the USNA has multiple flood hazard mitigation measures in place and in process. Academy staff have been repairing its seawalls and installing necessary backflow preventers within its storm water system. Door dams designed to protect academic buildings and other structures from flooding have also been installed (Kenson 2016). The USNA is currently working on a flood mitigation design informed by the Army Corps of Engineers' analysis (Kenson 2016).

But here and across US coastal installations there is still far to go: the gap between the military's current sea level rise preparedness and the threats outlined by this analysis 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, including the Academy, face all of these risks.

FIGURE 3. The USNA Is Expected to Lose Currently Utilized Land



The projected reach of future daily high tides, shown in the top panel, covers currently utilized land at the academy, shown on the bottom. The highest scenario is mapped here.

SOURCE: GOOGLE EARTH.

This analysis provides snapshots of potential future exposure to flooding at the USNA. For the academy to take action on the front line of sea level rise, however, it 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 planning efforts and to detailed mapping that includes future conditions; support planning partnerships with surrounding communities; and allocate resources for preparedness projects, on- and off-site, many of which will stretch over decades.

Military bases and personnel protect the country from external threats. 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.

ENDNOTES

1 *The intermediate sea level rise scenario assumes ice sheet loss that increases over time, while the highest scenario assumes rapid loss of ice sheets. The latter scenario is particularly useful for decisions involving an especially low tolerance for risk. These results are a small subset of the full analysis. For more information, the technical appendix, and downloadable maps, see www.ucsusa.org/MilitarySeasRising.*

2 *UCS analyzed storm surge depth and exposure extent for each base using the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model, developed by the National Oceanic and Atmospheric Administration (NOAA), for storm events ranging in severity from Category 1 to Category 4, in addition to tidal floods. Both storm surge and flooding during extra-high tides can be significantly exacerbated by rainfall and wave action, neither of which we included in this study.*

3 *This analysis involved consultation with the USNA. However, 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.*

4 *Nor'easters are common in the region and generate damaging storm surge. As SLOSH models only hurricanes, we did not include lesser storms, such as nor'easters, in this analysis. Increases in surge extent and depth should be expected with these storms as well.*

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Union of Concerned Scientists

FIND THE FULL ANALYSIS AND METHODOLOGY ONLINE: www.ucsusa.org/MilitarySeasRising

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The US Military on the Front Lines of Rising Seas

Exposure to Coastal Flooding at US Coast Guard Station Sandy Hook, New Jersey

HIGHLIGHTS

Highlight: With seas rising at an accelerating rate, coastal military installations are increasingly exposed to storm surge and tidal flooding. The Union of Concerned Scientists (UCS) conducted analyses of this changing exposure for 18 military installations on the East and Gulf coasts. Analysis for US Coast Guard (USCG) Station Sandy Hook found that in the second half of this century, in the absence of preventive measures, the installation can expect more frequent and extensive tidal flooding, loss of currently utilized land, and substantial increases in the extent and severity of storm-driven flooding to which it is exposed.

The US Armed Forces depend on safe and functional bases, such as USCG Station Sandy Hook, New Jersey, to carry out their stated mission: to provide the military forces needed to deter war and to protect the security of the country. A roughly three-foot increase in sea level would threaten 128 coastal Department of Defense (DOD) installations in the United States and the livelihoods of the people—both military personnel and civilians—who depend on them (NAS 2011). In the area of Sandy Hook, seas are projected to rise between four and 6.4 feet by the end of this century.

To enable decision makers to better understand the sea level rise threat, and where and when it could become acute, UCS has performed a new analysis of 18 East and Gulf Coast military installations, including USCG Station Sandy Hook. These sites were selected 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.

UCS projected exposure to coastal flooding in the years 2050, 2070, and 2100 using the National Climate Assessment's midrange or "intermediate-high" scenario (referred to here as "intermediate") and, in light of the low tolerance for risk in some of the military's decisions, a "highest" scenario based on a more rapid rate of increase (Parris et al. 2012).[1] We modeled tidal flooding, permanent inundation, and storm surge from hurricanes.[2] The results below outline potential future flooding to which USCG Station Sandy Hook could be exposed, assuming no new measures are taken to prevent or reduce flooding.[3] This analysis finds the following key results:

Andrew Leahey/Creative Commons (Flickr)

WILL RESCUE STATION NEED RESCUING?

USCG Sandy Hook, one of the oldest and most famous life-saving stations in the country, is located on the tip of a barrier spit (which is much like a barrier island, but connected at one end to the mainland). As sea level rises, USCG Sandy Hook's exposure to flooding from both high tides and storm surge is growing.

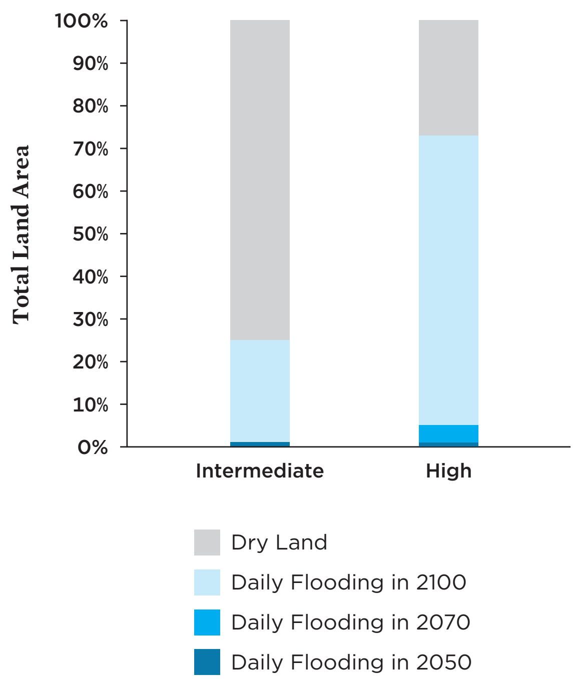
TIDAL FLOODING AND LAND LOSS

- **Areas currently affected by occasional tidal flooding could flood daily**. Certain low-lying areas of USCG Station Sandy Hook and the surrounding region are already affected by flooding during high tides more than 30 times per year on average. In the intermediate scenario, this flooding occurs more than 550 times per year by 2070—an average of more than once each day.
- **Flooding during extreme high tides will become more extensive**. Today, the station sees only small areas affected by flooding during extreme tides. But in the highest scenario, these tides encompass over half of the base and inundate access roads more than 30 times per year by 2070.
- **Extensive land loss at USCG Station Sandy Hook is possible**. Some parts of USCG Station Sandy Hook are projected to flood with such frequency by 2100 that they would effectively be part of the tidal zone as opposed to dry, usable land. Indeed, in the highest scenario, nearly three-quarters of the station's land area floods with daily high tides.

STORM SURGE

- **Sea level rise exposes previously unaffected areas of USCG Station Sandy Hook to storm surge flooding**. In the intermediate scenario, the area exposed to storm surge flooding during a Category 1 storm in 2100 is equivalent to the area exposed to flooding by a Category 2 storm today.
- **Sea level rise exposes USCG Station Sandy Hook to deeper, more severe flooding**. By 2100 in the intermediate scenario, the area inundated by five feet or more of seawater during Category 1 storm surges increases from roughly 30 percent of the station today to roughly 80 percent.

FIGURE 1. USCG Station Sandy Hook May Experience Major Land Loss



As high tide reaches farther inland, extensive land loss is possible at USCG Station Sandy Hook. Affected land may include developed and undeveloped areas and even wetlands that reside above the current high tide mark. The station is projected to see substantial loss of currently developed and utilized areas, particularly in the highest scenario.

Base Information

USCG Station Sandy Hook is situated within an East Coast hotspot, where natural subsidence, low-lying topography, and changing ocean circulation patterns contribute to above-average sea level rise (Sallenger, Doran, and Howd 2012). It is located at the northern tip of Sandy Hook, a barrier beach peninsula at the northern end of the New Jersey shore (NYHP 2016). The entire Sandy Hook peninsula, which is just one mile wide at its widest, is part of the National Park Service's Gateway Recreational Area.

Built in 1848, USCG Station Sandy Hook is one of the oldest and most famous life-saving stations in the country. The station became part of the Coast Guard in 1950 (USCG n.d). Today, USCG Station Sandy Hook houses response boats, Coast Guard cutters, and other life-saving vessels (USCG 2014). The station performs search and rescue operations and is responsible for law enforcement, environmental protection, and coastal security for regional waterways.

USCG Station Sandy Hook is an integral part of the regional economy, to which it contributes approximately 1,000 jobs, $67 million in labor income, and $83.5 million in gross

USCG Station Sandy Hook

Branch:	Coast Guard
Established:	1848
Size (Acres):	220
Active Duty:	70
Reserve:	50

SOURCE: USDHS AND USCG 2014.

domestic product (Lahr 2013). Seventy active duty and 50 reserve personnel are assigned to the station (USCG 2014).

Historic Exposure to Storm Surge and Flood Hazards

USCG Station Sandy Hook is highly exposed to storm surge today. A Category 1 hurricane exposes nearly 90 percent of the station to flooding related to storm surge. During Category 2 and stronger hurricanes, the entire station is exposed to flooding. Defenses including jetties, seawalls, and beach nourishment are used to protect the area (Monmouth County 2014).

There have been 22 hurricanes passing within 150 nautical miles of Sandy Hook since 1858 (NOAA n.d.), including Donna (1960), Felix (1995), Irene (2011), and Sandy (2012). Ten of these storms passed within 75 miles of the station.

Severe coastal flooding at Sandy Hook begins to occur when water levels reach 8.7 feet above the level of low tide. Hurricane Sandy set a new record in tide height at Sandy Hook, with water levels reaching 13.3 feet above the low tide line and waves that likely crested at 12 to 24 feet along the oceanfront. Hurricane Sandy caused $50 million in damage to the Coast Guard facilities (Sherman 2014). USCG vessels had to be relocated until facilities could be restored, affecting base mission and time-critical deployments (USDHS and USCG 2014). The Coast Guard also abandoned a number of housing units at the station that were damaged by Sandy, displacing about 30 families (Sherman 2014).

Future (Projected) Exposure to Storm Surge and Flood Hazards

SEA LEVEL RISE

The intermediate scenario projects that the Sandy Hook area will experience four feet of sea level rise and the highest scenario projects about 6.5 feet of rise by 2100. This rise will drive the high tide line inland and lead to increased exposure to different types of coastal flooding.

TIDAL FLOODING AND LAND LOSS

As sea level rises, routine tidal flooding is expected to become both more extensive and more frequent. Today, USCG Station Sandy Hook experiences very little flooding during extra-high tides. The intermediate scenario projects that, by 2100, extra-high tides could flood well over 60 percent of the station. In the highest scenario, roughly this same extent of flooding occurs by 2070.

UCS projections indicate that the frequency of tidal flooding at USCG Station Sandy Hook will increase steeply, jumping from an average of roughly 33 events per year today to roughly 260 events per year by 2050 in the intermediate scenario. In the highest scenario, low-lying locations experience roughly 680 events per year by 2070. With the highest scenario, flood-prone areas throughout the region could experience flooding with each of the two daily high tides and be underwater more than 40 percent of the time.

TABLE 1. USCG Station Sandy Hook: Projected Sea Level Rise (Feet) in Two Scenarios

Year	Intermediate	Highest
2050	1.2	1.8
2070	2.1	3.3
2100	4.0	6.4

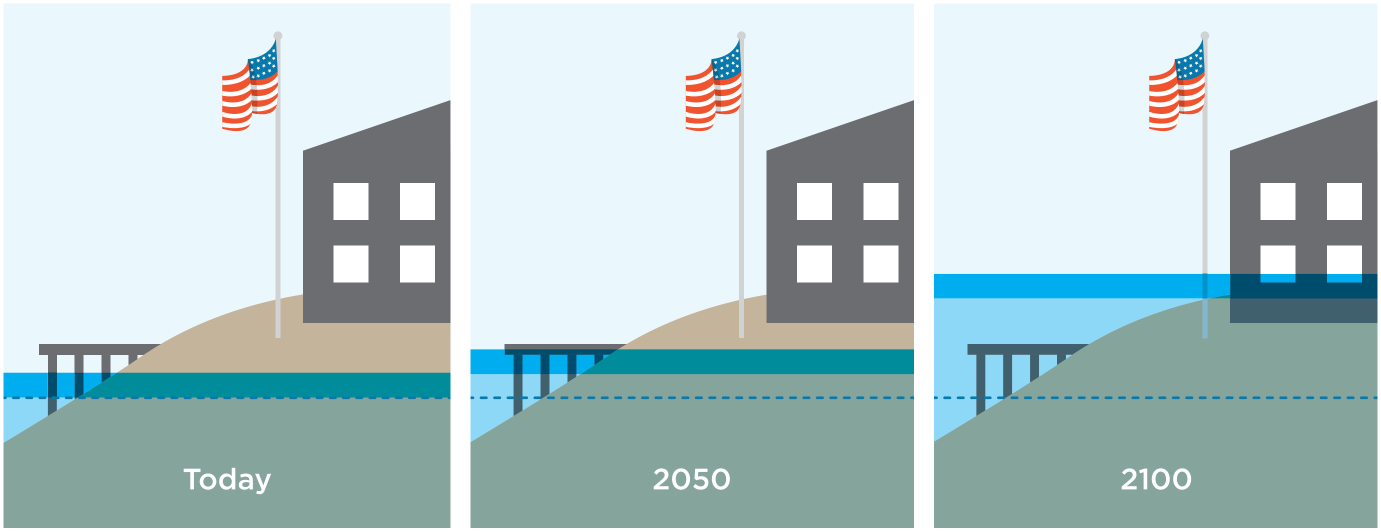
In the intermediate scenario, ice sheet loss increases gradually in the coming decades; in the highest scenario, more rapid loss of ice sheets occurs. The latter scenario is included in this analysis to help inform decisions involving an especially low tolerance for risk. Moreover, recent studies suggest that ice sheet loss is accelerating and that future dynamics and instability could contribute significantly to sea level rise this century (DeConto and Pollard 2016; Trusel et al. 2015; Chen et al. 2013; Rignot et al. 2011). Values shown are local projections that include unique regional dynamics such as land subsidence (see www.ucsusa.org/MilitarySeasRising).

As sea level rises, the flooding that occurs in low-lying areas during high tides lasts longer. In the highest scenario, flood events in this area will begin to span many high tide cycles during the last quarter of this century. As a result, the number of individual flood events will decrease but the duration of flood conditions will increase until flooding is essentially constant and land that was once above the high tide line is permanently inundated. At Sandy Hook, the difference between high and low tide is small enough that flood conditions in some areas will eventually exist even at low tide. Indeed, in the highest scenario, USCG Station Sandy Hook's flood-prone areas are underwater about 90 percent of the year by 2100. Moreover, nearly three-quarters of the installation's land area would become part of the tidal zone by the end of the century, flooded by daily high tides (see Figure 3, p. 5).

THE CHANGING THREAT OF HURRICANES

Category 1 hurricanes are the most likely type to affect this area.[4] Today, Category 1 storms expose about 90 percent of the station's area to flooding related to storm surge. In the intermediate scenario, that percentage rises just slightly by 2050 but rises to nearly 100 percent by 2100. In both the intermediate and highest scenarios, the area flooded by a Category 1 storm in 2100 is equivalent to the area flooded by a Category 2 storm today.

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.

Sea level rise also increases the depth of flooding USCG Station Sandy Hook can expect with major storms. A Category 1 storm would cause 31 percent of the station to experience flooding five feet or more deep today; in the intermediate scenario, the same storm occurring in 2100 would cause such flooding over 78 percent of the station.

The worst case for Sandy Hook storm surge inundation considered in this analysis is a Category 4 storm occurring in the highest scenario. In that scenario, all of USCG Station Sandy Hook is exposed to flooding. And the flooding is deep. Today, a Category 4 storm exposes 53 percent of the base to flooding 20 or more feet deep. In the worst-case scenario,

TABLE 2. Current and Future Tidal Flooding Frequency at USCG Station Sandy Hook

	Intermediate		Highest	
Year	Events per Year	% of Year	Events per Year	% of Year
2012	33 ± 7	1	33 ± 7	1
2050	263 ± 24	7	471 ± 31	15
2070	562 ± 26	21	679 ± 34	41
2100	684 ± 33	52	254 ± 28	91

Projected sea level rise could lead to near-constant flooding of low-lying areas around USCG Station Sandy Hook. Shown here are flood events in flood-prone locations projected by the intermediate and highest scenarios. Events per year are reported as the average over a five-year period with one standard deviation. Percent of year is reported simply as the average over a five-year period. As flood conditions span multiple high tide cycles, the number of distinct flood events drops, but the duration of flooding increases until it is nearly constant. Installations will be affected by this flooding depending on the presence of low-lying land on-site.

FIGURE 3. The Reach of Future Daily High Tides at USCG Station Sandy Hook

The projected reach of future daily high tides, shown above, encompasses currently utilized land at USCG Station Sandy Hook, shown on the bottom. The highest scenario is mapped here.

SOURCE: GOOGLE EARTH.

75 percent of the station could experience such flood depths in 2050 and more than 95 percent of the station in 2100.

Mobilizing on the Front Lines of Sea Level Rise

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). After Hurricane Sandy, USCG Station Sandy Hook used disaster assistance funds to replace and repair damaged critical facilities to withstand a 500-year flood and to apply hurricane-resistant building codes (USCG 2014). Recognizing the threat of increased flooding at the USCG Station Sandy Hook, the coast guard is constructing new facilities above the 500-year flood plain where it considers this practical, as well as designing new structures for anticipated wave strength (Ingalsbe 2016).

But here and across US coastal installations, there is still far to go: the gap between the military's current sea level rise preparedness and the threats outlined by this analysis 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, including USCG Station Sandy Hook, face all of these risks.

This analysis provides snapshots of potential future exposure to flooding at USCG Station Sandy Hook. For the coast guard to take action on the front line of sea level rise, however, it 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 planning efforts and to detailed mapping that includes future conditions; support planning partnerships with surrounding communities; and allocate resources for preparedness projects, on- and off-site, many of which will stretch over decades.

Military bases and personnel protect the country from external threats. 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.

ENDNOTES

1 *The intermediate sea level rise scenario assumes ice sheet loss that increases over time, while the highest scenario assumes rapid loss of ice sheets. The latter scenario is particularly useful for decisions involving an especially low tolerance for risk. These results are a small subset of the full analysis. For more information, the technical appendix, and downloadable maps, see www.ucsusa.org/MilitarySeasRising.*

2 *UCS analyzed storm surge depth and exposure extent for each installation using the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model, developed by the National Oceanic and Atmospheric Administration (NOAA), for storm events ranging in severity from Category 1 to Category 5, in addition to tidal floods. Both storm surge and flooding during extra-high tides can be significantly exacerbated by rainfall and wave action, neither of which was included in this study.*

3 *This analysis involved consultation with contacts at multiple installations. However, in some instances, 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.*

4 *Nor'easters are more common in the region and known to generate damaging storm surge. As SLOSH models only hurricanes, we did not include lesser storms such as nor'easters in this analysis. Increases in surge extent and depth should be expected with these storms as well.*

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FACT SHEET

The US Military on the Front Lines of Rising Seas

Exposure to Coastal Flooding at Portsmouth Naval Shipyard, Maine

HIGHLIGHTS

With seas rising at an accelerating rate, coastal military installations are increasingly exposed to storm surge and tidal flooding. The Union of Concerned Scientists (UCS) conducted analyses of this changing exposure for 18 installations along the East and Gulf coasts. Analysis for Portsmouth Naval Shipyard (NS) found that in the second half of this century, in the absence of preventive measures, the installation can expect frequent and extensive tidal flooding, loss of currently utilized land, and substantial increases in the extent and severity of storm-driven flooding to which it is exposed.

The US Armed Forces depend on safe and functional bases, such as the Portsmouth NS, Maine, to carry out their stated mission: to provide the military forces needed to deter war and to protect the security of the country. A roughly three-foot increase in sea level would threaten 128 coastal Department of Defense (DOD) installations in the United States and the livelihoods of the people—both military personnel and civilians—who depend on them (NAS 2011). In the area of the Portsmouth NS, seas are projected to rise between 3.5 and 5.9 feet over the course of this century.

To enable decision makers to better understand the sea level rise threat, and where and when it could become acute, UCS has performed a new analysis of 18 East and Gulf Coast military installations, including Portsmouth Naval Shipyard. These sites were selected 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.

UCS projected exposure to coastal flooding in the years 2050, 2070, and 2100 using the National Climate Assessment's midrange, or "intermediate-high," scenario (referred to here as "intermediate") and, in light of the low tolerance for risk in some of the military's decisions, a "highest" scenario based on a more rapid rate of increase (Parris et al. 2012).[1] We modeled tidal flooding, permanent inundation, and storm surge from hurricanes.[2] The results below outline potential future flooding to which Portsmouth NS could be exposed, assuming no new measures are taken to prevent or reduce flooding.[3] This analysis finds the following key results.

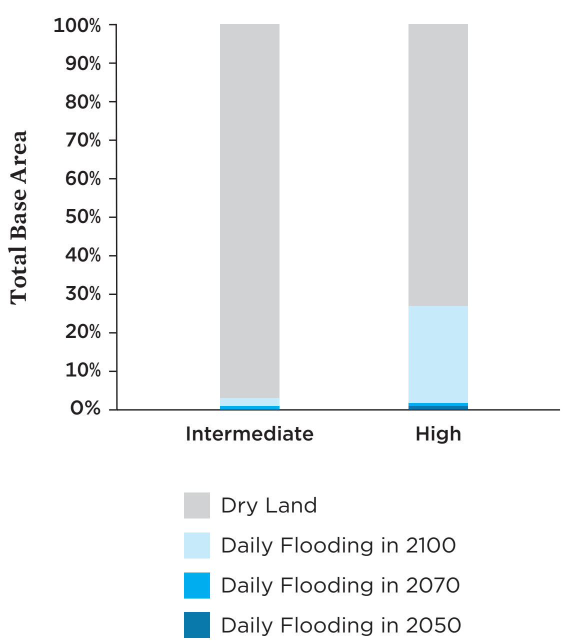
Selbe Lynn/Creative Commons (Flickr)

TWO IF BY SEA: TIDAL FLOODING THREATENS PORTSMOUTH NS
Portsmouth NS, which lies on the banks of the Piscataqua River, not far from the Atlantic Ocean, sees little tidal flooding today, even as low-lying areas of coastal New Hampshire and southern Maine have seen an increase in such flooding. Depending on the rate of sea level rise this century, however, extreme high tides could eventually bisect the shipyard.

TIDAL FLOODING AND LAND LOSS

- **Areas currently affected by occasional tidal flooding could flood daily.** By 2050, low-lying areas in this region could experience between 80 and 190 floods per year—compared to fewer than a dozen currently—depending on the scenario. By 2070, in the highest scenario, flood-prone areas throughout the region could on average experience flooding with each of the two daily high tides and be underwater more than 15 percent of the time.
- **Flooding during extreme high tides will become more extensive.** Today, Portsmouth NS itself sees little tidal flooding. By 2100, flooding during extreme tides could bisect the shipyard nearly a dozen times per year.
- **Sea level rise threatens to claim currently utilized areas.** How much of Portsmouth NS remains dry, usable land hinges on the trajectory of sea level rise through the end of the century and on the shipyard's adaptation measures. In the highest scenario, more than a quarter of the shipyard's land area, including places currently key to operations, would become part of the tidal zone.

FIGURE 1: Portsmouth NS Could Experience Land Loss



The pace of sea level rise matters greatly to Portsmouth NS. High tide would inundate 1 percent of its area by 2050, but 27 percent by the end of the century, given the faster rate of sea level rise assumed in the highest scenario. Inundated areas include some that are heavily utilized today. By contrast, given the moderate rate of rise assumed in the intermediate scenario, just 3 percent would shift to the tidal zone by late in this century.

STORM SURGE

- **Sea level rise exposes previously unaffected areas of Portsmouth NS to storm surge flooding.** By 2100 in the highest scenario, sea level rise will increase the area exposed to flooding by Category 1 and 2 storms by roughly 20 percent. By this time, the area exposed to flooding from a Category 1 storm is greater than the area exposed to flooding by a Category 2 storm today.
- **Sea level rise increases the exposure of Portsmouth NS to deeper, more severe flooding.** By 2100 in the intermediate scenario, roughly 25 percent of the base would be exposed to flood depths of five feet or more by a Category 1 storm, compared to just 8 percent today.

Base Information

Portsmouth NS is located on Seavey Island in York County, Maine, near the town of Kittery. The shipyard lies on the banks of the Piscataqua River, across from Portsmouth, New Hampshire. It is one of only four naval shipyards in the country and the oldest continuously operated one. Portsmouth NS is responsible for repairing, overhauling, and modernizing the Navy's nuclear powered submarines (NAVSEA n.d.).

Portsmouth NS

Branch:	Navy
Established:	1800
Size (Acres):	281
Service Members:	200*
Civilians:	4500*
Docks:	3

*Approximately

SOURCE: DOD 2016.

New England has a long history of shipbuilding, and Portsmouth NS, which was established in 1800, has long been part of the region's maritime culture. Portsmouth NS is a high-density industrial area housing 376 buildings of which 116 are located in the Portsmouth NS Historic District and 50 listed on the National Register of Historic Places (NREL 2014).

Historic Exposure to Storm Surge and Flood Hazards

In the region surrounding Portsmouth NS, severe summer and winter storms are considered significant hazards (Kirshen et al. 2014; KEMA and YCEMA 2011). Indeed, the area is


US Navy

One of the country's four naval shipyards, Portsmouth NS specializes in maintaining the Navy's submarine fleet. Here, workers wrap up maintenance on the Los Angeles-class submarine USS San Juan (SSN 751) in August, 2011. This area of the shipyard is at risk of daily tidal inundation later this century.

no stranger to storm damages: A total of 48 tropical storms—including 18 hurricanes—have passed within 150 nautical miles of the shipyard since 1858 (NOAA n.d.). In August 1991, Hurricane Bob passed 13 nautical miles to the east of the coast. Residents within a quarter mile of the shore were ordered to evacuate, and, although the winds were less than hurricane force, an estimated 2.1 million businesses and homes lost power at some point during the storm (Handlers and Brand 2004). Ultimately, several million dollars worth of damage occurred in York and Cumberland counties (Cotterly 1996; Hidlay 1991).

In addition to acute damage from storms, tidal flooding is a growing problem in the region.

The highest water levels recorded locally occurred during the Blizzard of '78, when the combined height of the tide and storm surge, predicted to be 10.2 feet, reached 13.4 feet. This nor'easter and another that same winter inflicted major damage in York County (Colgan 1979). In 2007, the Patriots' Day storm caused an estimated $45 million of damage to public infrastructure, including $31.5 million to roads alone (Colgan and Merrill 2008).

In addition to acute damage from storms, tidal flooding is a growing problem in the region. Regular flooding of low-lying areas can damage homes and businesses and disrupt travel and has led local municipalities to take adaptive and educational action, including offering walking tours of flood-prone areas (Spanger-Siegfried, Fitzpatrick, and Dahl 2014; CPPD 2013).

Future (Projected) Exposure to Storm Surge and Flood Hazards

The intermediate scenario projects that Portsmouth NS will experience 3.5 feet of sea level rise locally and the highest scenario projects 5.9 feet of rise by 2100. This rise will lead to increased exposure to different types of coastal flooding.

TABLE 1: Portsmouth NS: Projected Sea Level Rise (Feet) in Two Scenarios

Year	Intermediate	Highest
2050	1.0	1.6
2070	1.8	3.0
2100	3.5	5.9

In the intermediate scenario, ice sheet loss increases gradually in the coming decades; in the highest scenario, more rapid loss of ice sheets occurs. The latter scenario is included in this analysis to help inform decisions involving an especially 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 (DeConto and Pollard 2016; Trusel et al. 2015; Chen et al. 2013; Rignot et al. 2011). Values shown are local projections that include unique regional dynamics such as land subsidence (see www.ucsusa.org/MilitarySeasRising).

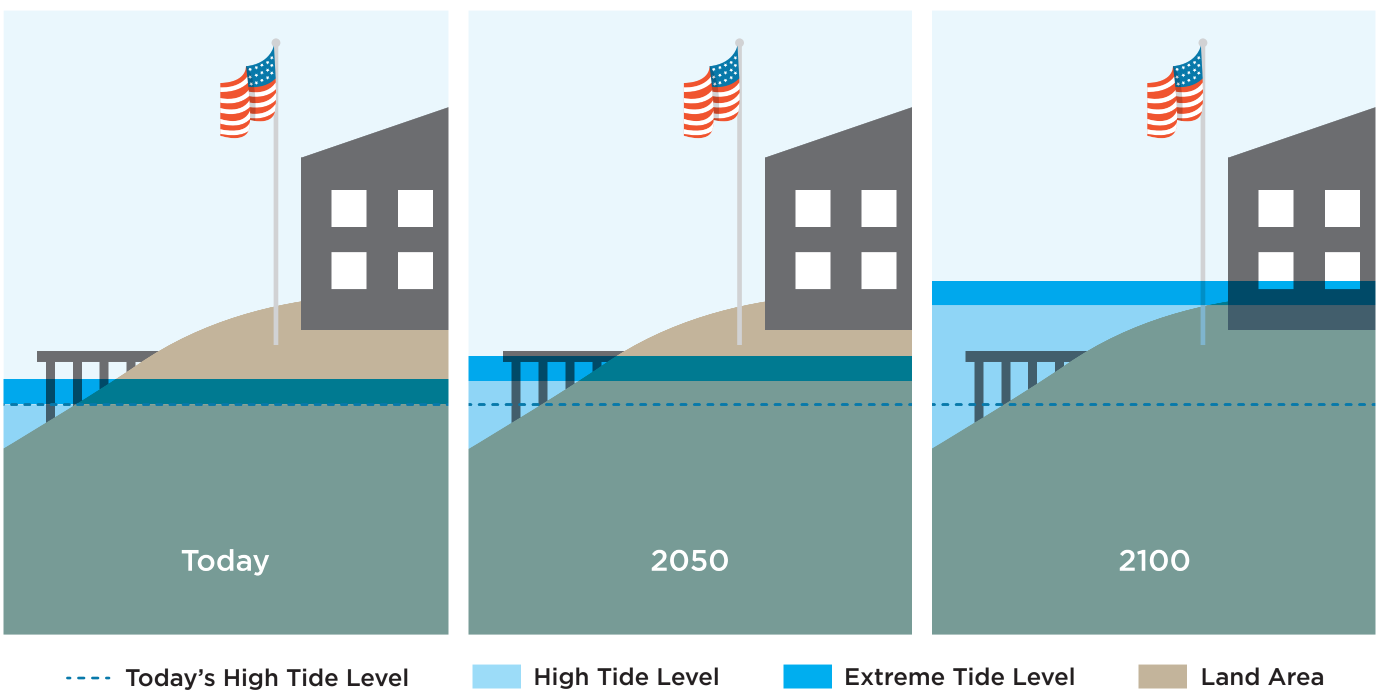
TIDAL FLOODING AND LAND LOSS

By 2050, nuisance tidal flooding could occur in low-lying locations on the surrounding seacoast on two of three days on average in the highest scenario. Without substantial adaptive measures, affected areas such as low-lying roadways and neighborhoods could become unusable land within the next 35 years. Though the affected area on Seavey Island itself could be limited to the immediate shoreline, the consequences of frequent flooding in the surrounding region—for example, damage to housing and travel delays affecting the shipyard's community of workers and its personnel housed off base—could affect the shipyard nonetheless.

As sea level rises further, periodic extreme tides would drive more extensive flooding, including at Portsmouth NS. In both the intermediate and highest scenarios, flooding during extra-high tides could bisect Seavey Island.

By 2100, more than 25 percent of the shipyard's currently dry land would fall below the high tide line in the highest scenario. The level of inundation is much lower in the intermediate scenario: by 2100, just 3 percent of the dry land area would be inundated.

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



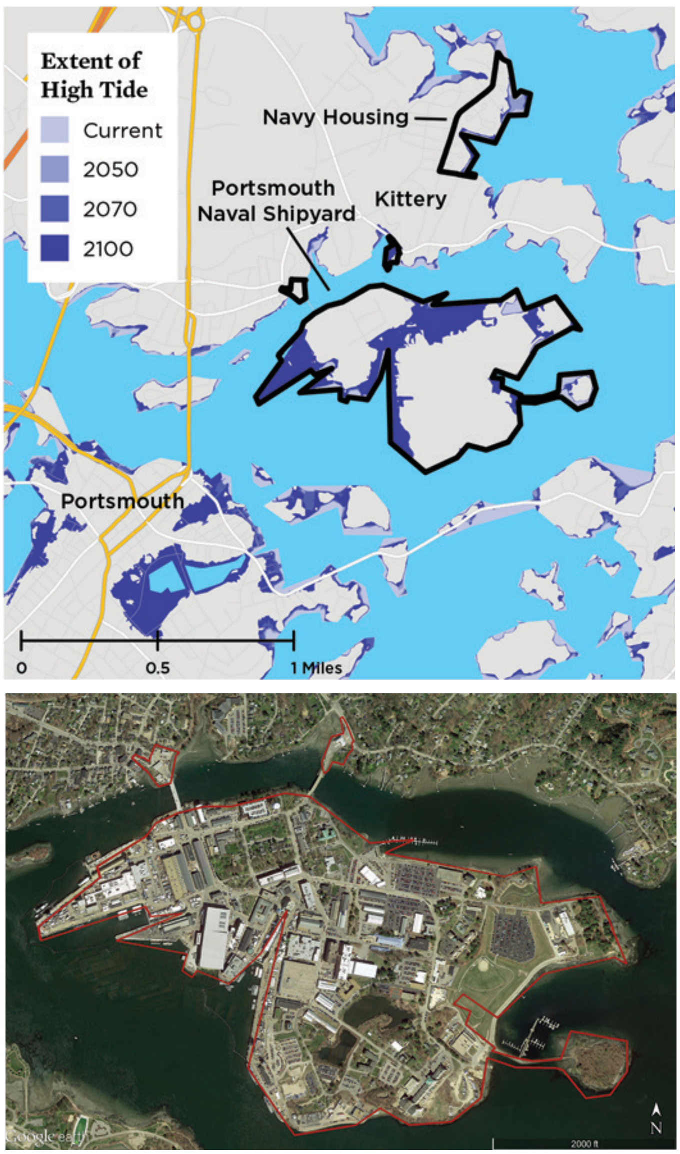
As sea level rises, extreme tides cause local flood conditions to occur more often, to a greater extent, and for longer time periods. And the daily high tide line can eventually begin to encompass new areas, shifting the tidal zone onto presently utilized land. In this analysis, land inundated by at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

THE CHANGING THREAT OF HURRICANES

Category 1 storms are the most likely type of hurricane to affect this area.[4] A Category 1 storm today exposes roughly 40 percent of Portsmouth NS to flooding related to storm surge. By 2070, the area exposed to flooding increases to 50 percent in the intermediate scenario and to 55 percent in the highest scenario. In the highest scenario, the area inundated by a Category 1 storm in 2100 is greater than the area inundated by a Category 2 storm today.

Sea level rise also changes the depth of flooding Portsmouth NS can expect with major storms. Whereas less than 10 percent of the inundation caused by a Category 1 storm today is more than five feet in depth, about 25 percent of the inundation would be five feet deep or more by 2100 in the intermediate scenario. In the highest scenario, nearly 40 percent of the shipyard is exposed to this degree of flooding.

FIGURE 3. Daily High Tides Will Reach Currently Utilized Land at Portsmouth NS



The reach of future daily high tides, shown on the top, is projected to encompass currently utilized land at the Portsmouth NS, shown on the bottom. The highest scenario is mapped here. By contrast, the intermediate scenario projects inundation of just 3 percent of this area.

SOURCE: GOOGLE EARTH.

> ***By 2100, more than 25 percent of the shipyard's currently dry land would fall below the high tide line in the highest scenario.***

The worst case for storm surge inundation of New England considered in this analysis is a Category 4 storm occurring in the highest scenario in 2100. Today, a Category 4 storm would expose 85 percent of Portsmouth NS to flooding. In the worst-case scenario, roughly 90 percent would be exposed to storm surge flooding, most of it over five feet deep. More than 25 percent of Portsmouth NS could experience flood depth of 20 feet or more.[5]

Mobilizing on the Front Lines of Sea Level Rise

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). Recognizing the threat of increased flooding, and that the most robust responses will be regional ones, the Portsmouth NS has, for example, sought opportunities to collaborate with regional stakeholders such as the Coastal Risk and Hazards Commission, the University of New Hampshire, the Shipyard Association, and state and local emergency managers (Crosby 2016).

But here and across US coastal installations there is far to go: the gap between the military's current sea level rise preparedness and the threats outlined by this analysis is large and

TABLE 2. Current and Future Tidal Flooding Frequency around Portsmouth NS

	Intermediate		Highest	
Year	Events per Year	% of Year	Events per Year	% of Year
2012	11 ± 6	0	11 ± 6	0
2050	82 ± 19	1	187 ± 26	4
2070	234 ± 31	5	558 ± 26	16
2100	647 ± 22	22	703 ± 1	43

Sea level rise is projected to cause coastal flood conditions in New Hampshire and southern Maine over significant portions of the year. Shown here are flood events in low-lying, flood-prone areas projected by the intermediate and highest scenarios. Events per year are reported as the average over a five-year period with one standard deviation. Percent of year is reported simply as the average over a five-year period. Installations will be affected by this flooding depending on the presence of low-lying land on-site.

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, including the shipyard, face all of these risks.

This analysis provides snapshots of potential future exposure to flooding at Portsmouth NS. For the shipyard to take action on the front line of sea level rise, however, it will need more detailed analysis and resources to implement solutions.

In one of the most visible signs of changes to come, extreme tides increasingly creep onto roads and into neighborhoods in the Seacoast region around Portsmouth NS, as in Hampton, NH, pictured here. With this trend, the Shipyard's lower-lying neighbors will be impacted by sea level rise decades before the installation itself, but with its large civilian workforce, this in turn can have implications for the Shipyard.

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 planning efforts and to detailed mapping that includes future conditions; support planning partnerships with surrounding communities; and allocate resources for preparedness projects, on- and off-site, many of which will stretch over decades.

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4 *Nor'easters are more common in the region and known to generate damaging storm surge. However, they could not be included in this analysis because of SLOSH model limitations. Increases in surge extent and depth should be expected with these storms as well.*

5 *By absorbing storm surge upstream, the Piscataqua River and Great Bay may exert a dampening effect on water levels not fully captured by this modeling. Conversely, heavy rainfall that often accompanies storms can exert an exacerbating effect on water levels, also not captured here.*

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The US Military on the Front Lines of Rising Seas:

Methodology and Key Caveats

The Union of Concerned Scientists' report "The US Military on the Front Lines of Rising Seas" assesses the potential exposure of coastal military installations to increased coastal flooding due to sea level rise. Specifically, we evaluated the effect of sea level rise on the severity and extent of storm surge inundation, the frequency and extent of tidal flooding, and the timing and extent of permanent inundation.

This document outlines the methods, tools, and data used.

Methodology

Storm Surge

The storm surge model: We have analyzed storm surge depth and extent using the SLOSH model, developed by the National Oceanic and Atmospheric Administration (NOAA), which is used to by the National Hurricane Center to issue storm surge alerts when a hurricane is approaching the coast and is routinely used by emergency managers. SLOSH forecasts were used, for example, as guidance by the New York City Emergency Management Department as Hurricane Sandy approached the city (NYC Emergency Management 2014).

NOAA has developed different composite storm surge predictions for each category of hurricane by running the SLOSH model several thousand times with hypothetical storms. We utilized a product of these composite runs known as the MOM, or the Maximum of the Maximum Envelopes of Water, which is considered a worst-case scenario for each particular storm category. The SLOSH model was chosen over other possible storm surge models such as ADCIRC because of its familiarity to emergency managers, its low computational cost, the ease of analysis for a wide range of storms, and its complete, consistent basin coverage of the East and Gulf coasts. Despite some studies finding that SLOSH may underperform in some situations due to its level of resolution and location-specific conditions (e.g. Kerr et al 2013), it is found to be adequate for our type of comparative analysis of various locations under similar storm conditions, i.e. storm categories (see key caveats, below).

The elevation data: Determining the extent and depth of inundation requires an elevation model. We obtained high-resolution elevation data primarily from the USGS 3DEP Program, which is regularly updated with the best available data. In most coastal locations, we have been able to obtain 1/9 arc-second data – approximately 3 m spatial resolution – derived from Lidar surveys. For Eglin Air Force Base, FL, we used data from both 3DEP and NOAA Digital Coast. We have interpolated the SLOSH results to the resolution of the elevation model. The vertical accuracy of the elevation data is typically less than 10 cm (USGS 2014).

The future scenarios: To assess the combined effects of sea level rise and storm surge, we have used locally specific sea level rise projections at three future time points – 2050, 2070, and 2100. These projections, provided by Climate Central (n.d.), are based on the widely utilized Intermediate-High and Highest global sea level rise projections developed for the 2013 National Climate Assessment (see Parris et al. 2012). We chose to use these projections rather than the Representative Concentration Pathways (RCPs) developed by the IPCC in its 5th Assessment Report (2014) based on input from a panel of military experts. The Highest scenario is recommended by the NCA for use when planning for areas that have a low risk tolerance.

To produce localized sea level rise projections, Climate Central first assessed the difference between the local rate of sea level rise at a set of tide gauges along the East and Gulf Coasts. Using the historical difference between the local and global rates of sea level rise, they developed a "local component" of sea level rise for each tide gauge. This local component does not quantitatively differentiate factors such as subsidence or groundwater withdrawal. Rather, all of these factors are lumped together to reflect the sum total of locally-relevant factors. For future projections, the local component for each tide gauge is held constant and used to adjust the global projection. The projections do not account for any changes in the rate of anthropogenic subsidence.

To assess the combined effect of sea level rise and storm surge, we have added the projected sea level rise linearly to the storm surge from the SLOSH model to define a future storm surge surface. For each surface, we performed a region group analysis and extracted only areas that were hydrologically connected to the ocean. This methodology is outlined in NOAA's Coastal Inundation Primer (2012).

For each of the time points (plus 2012 as a baseline for current conditions) and sea level rise projections, we evaluated surge for Category 1 to 5 storms for bases in the Gulf and East Coast up to Virginia, and Category 1 to 4 for bases north of (and including) Virginia, where Category 5 storms are extremely unlikely to occur.

The area statistics: Our analysis of the area of each base inundated at different depth intervals utilizes standard area statistics and other tools within ESRI's ArcGIS products. To determine base area overall, we have used the U.S. Census Bureau's latest spatial dataset of U.S. military installations. Note that the area of each base and the area inundated by storm surge may include natural bodies of water.

Tidal flooding

In addition to analyzing the combined effects of sea level rise and storm surge, we have analyzed how the frequency and extent of tidal flooding—often called minor coastal flooding or nuisance flooding—are affected by sea level rise in the years 2050, 2070 and 2100. As with our storm surge analysis, we utilized localized versions of both the Intermediate-High and Highest scenarios from the 2013 National Climate Assessment, provided by Climate Central (n.d.).

The method: To assess the frequency of tidal flooding today and in the future, we used NOAA's online Inundation Analysis tool. Tide gauges maintained by NOAA's National Ocean Service form the basis of our analysis. To be included in the analysis, a gauge must have a defined flooding threshold for minor coastal flooding defined by local Weather Forecast Offices (WFOs) and be available within the tool (NOAA Tides and Currents 2013). It is important to note that the results of the Inundation Analysis are tide gauge-specific and may have limited applicability to the surrounding areas. We have assessed the applicability of each tide gauge to the county containing the military base by evaluating the correlation between flood events--as determined by the Inundation Analysis tool--and the issuance of Coastal Flood Advisories by the National Weather Service for those flood events. And for Camp Lejeune, we could not confirm that the nearby Wrightsville Beach tide gauge reflects flooding in Onslow County, NC. For all other installations, the issuance of CFAs correlated well with the flood events identified through the Inundation Analysis. For more details on this method, see the Technical Appendix in Spanger-Siegfried, Fitzpatrick and Dahl 2014.

As reported by the Inundation Analysis tool, the errors associated with using tide gauge data to assess flood frequency include uncertainty in the tide gauge datum (approximately 1 to 5 cm) and tidal level measurements errors (1 to 2 cm).

Minor coastal flooding is typically associated with the issuance of a Coastal Flood Advisory, which alerts residents to minor, or nuisance, level flooding conditions that do not pose a serious risk to life and property (NWS 2009). For each military base, we have chosen the nearest available tide gauge with those properties. We have then calculated the average number of minor coastal floods annually using the five-year average for the 2009-2013 period. To assess future flood frequency, we effectively lowered the flooding threshold by subtracting the projected amount of sea level rise, then recalculated the annual average using the same 2009-2013 baseline. We report tidal flooding frequency as the mean for the 2009-2013 period and include error bars for +/- one standard deviation. For more detailed information, see the Technical Appendix in Spanger-Siegfried, Fitzpatrick and Dahl 2014.

It is important to note that the frequency of future tidal flooding applies only to the area currently affected by tidal flooding – the area shown in the lightest purple in our reports' maps. The areas that are currently exposed to tidal flooding tend to be limited and, in many cases, primarily wetlands. Our future tidal flooding frequency statistics apply to these areas. Our maps of the future extent of tidal flooding show the reach of extra-high tides as sea level rises. The newly exposed areas would experience tidal flooding with the same frequency as today. For example, if an area experiences 10 tidal floods per year today, the area mapped for 2100 would experience 10 tidal floods by that year.

In order to characterize the areas of each base that are currently exposed to tidal flooding, we visually assessed the overlap between wetland/marsh areas and areas that experience minor coastal flooding using the NOAA Sea Level Rise Viewer. We utilized this visual assessment to determine whether the areas exposed to tidal flooding are primarily wetlands or whether developed land is exposed as well.

To map the current and future extents of tidal flooding, we have again utilized the WFO-defined flooding threshold. For future extent, we have added the projected amount of sea level rise to that threshold and mapped the elevations that fall below the combined level. For each tidal flooding surface, we performed a region group analysis and extracted only areas that were hydrologically connected to the ocean. As with our storm surge analysis, we used standard area statistics tools within ESRI's ArcGIS products to determine the area of each base that would be inundated during a tidal flooding event. From this area, we have subtracted the area that is currently below the Mean Higher High Water (MHHW) level to ensure that the reported tidal flooding area does not include areas already below high tide today.

Permanent inundation

To assess the exposure of each base to permanent inundation, we have analyzed the changing extent of MHHW level as sea level rises. As with the other analyses for this report, we utilized localized versions of both the Intermediate-High and Highest scenarios from the 2013 National Climate Assessment, provided by Climate Central (n.d.).

The method: We obtained MHHW levels from tide gauge-specific pages within NOAA's Tides and Currents website. For each military base, we used the nearest available tide gauge maintained by the National Ocean Service. We performed a spatial analysis to create water surfaces for the present-day MHHW level at each base. We then added the projected amounts of sea level rise to the MHHW level and created a water surface for each sea level rise future. For each surface, we performed a region group analysis and extracted only areas that were hydrologically connected to the ocean. As with our other analyses, we used standard area statistics tools within ESRI's ArcGIS products to determine the area of each base that would be inundated at MHHW today and in the future. We have used the area inundated by MHHW today to determine the "currently dry land" area of each base by subtracting the MHHW area from the total base area. We report the future percentage of the base that would lie below the MHHW level as the percentage of the currently dry land area that would be inundated. In our products, we refer to this as the area that would be under water during high tide or the area that would become part of the tidal zone.

Uncertainty

This analysis is subject to a range of uncertainties. The elevation data we have used is primarily from Lidar and other high-resolution sources, but its vertical accuracy is only accurate to within about 10 cm (USGS 2014). The SLOSH MOMs are lower in resolution than the elevation data by an order of magnitude or more. Interpolating the SLOSH data as we have done may result in false precision. As higher-resolution SLOSH and elevation data become available, the areas we understand to be exposed to coastal flooding should be refined (NRC 2009).

As discuss below in the Key Caveats section, flooding simulated by SLOSH is limited only to that which is storm surge-induced. Sea level rise projections are highly dependent on the future trajectory of human emissions of heat-trapping gases as well as the Earth system response to those emissions. Both of those factors are uncertain, particularly in the latter half of the century. In addition, we assume that the effect of sea level rise on storm surge height will be linearly additive, while there is some evidence that this is not the case (e.g. ARCADIS 2013; Zhang et al. 2013). Our projections of tidal flooding frequency represent averages over a five-year period and thus incorporate some year-to-year variability.

We assume that tidal range and coastal morphology will not change substantially in the future, although there is evidence to suggest that this may not be the case (Flick, Murray, and Ewing 2003; FitzGerald et al. 2008; Lentz et al. 2016). Shoreline erosion, for example, and sea level rise can exacerbate one another. And beach nourishment projects and protective measures such as groins can have the unintended consequence of increasing coastal erosion in adjacent areas.

Key Caveats

It is important to highlight certain caveats of our analysis, mainly related to what it does and does not include, and our main objectives.

1. This study is not meant to be comprehensive. The military sites we analyzed are intended to provide snapshots of possible storm surge and sea level rise exposure and effects at points along the East and Gulf Coasts. They were chosen in consultation with military experts and do not include all existing bases on those areas.

2. The results of this study are intended to be illustrative of each military installation's potential exposure to flooding. Infrastructural planning and decision-making would require more detailed analysis.

3. This study does not address the probability of any particular category of storm hitting any particular stretch of coast. Nor does it address the return period of either major or minor coastal flooding. Planners at each military installation may want to consider conducting probability-based assessments of coastal flooding to better quantify risk.

4. The SLOSH model does not include rainfall-induced flooding or riverine flooding. It also does not include wave setup or run-up. We are aware that in many cases flooding is intensified by accompanying

precipitation due to the storm itself, but that is a separate, additional factor that we did not evaluate. Because of these factors, our results may underestimate the extent and severity of flooding at a given location.

5. Hurricanes are categorized on the Saffir-Simpson scale by wind speed, and storm surge levels are not tied directly or always proportionately to storm category. There are many factors that contribute to storm surge height, including storm size and angle of approach. The categories described in this report are based on thousands of simulations of hypothetical storms with wind speeds defined by the Saffir-Simpson scale. In this analysis, we use storm categories as a way of defining different strengths of storm independent of each hurricane's specific conditions. Therefore, it is important to note that not every storm of a given category will produce equal storm surge heights for a given location. It is also important to note that storms weaker than hurricane strength—e.g. nor'easters—often produce damaging levels of storm surge.

6. We are utilizing the SLOSH maximum of maximums, or MOMs, which represent a worst case scenario for a given storm category for every location within the SLOSH area. No one storm would be likely to produce the exact pattern of flooding depicted in each map.

7. We focus on "exposure" to storm surge rather than risk. A more technical definition of risk would include an assessment of probability, which we did not address.

8. We have assessed error on our tidal flooding frequency projections by capturing both the mean and standard deviation in the number of flood events over a 5-year period. However, the choice of a different 5-year baseline period (e.g. 2004-2008) could affect the future and projected frequency of tidal flooding. Aside from this, we have not quantitatively assessed uncertainty for this study.

9. The statistics for base area and storm surge area may include natural bodies of water. Moreover, we define "currently dry land area" as the area above the MHHW level. It is possible, however, that this area could contain natural bodies of water or wetlands that, in practice, are not usable, developable land.

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