Union of Concerned Scientists

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.

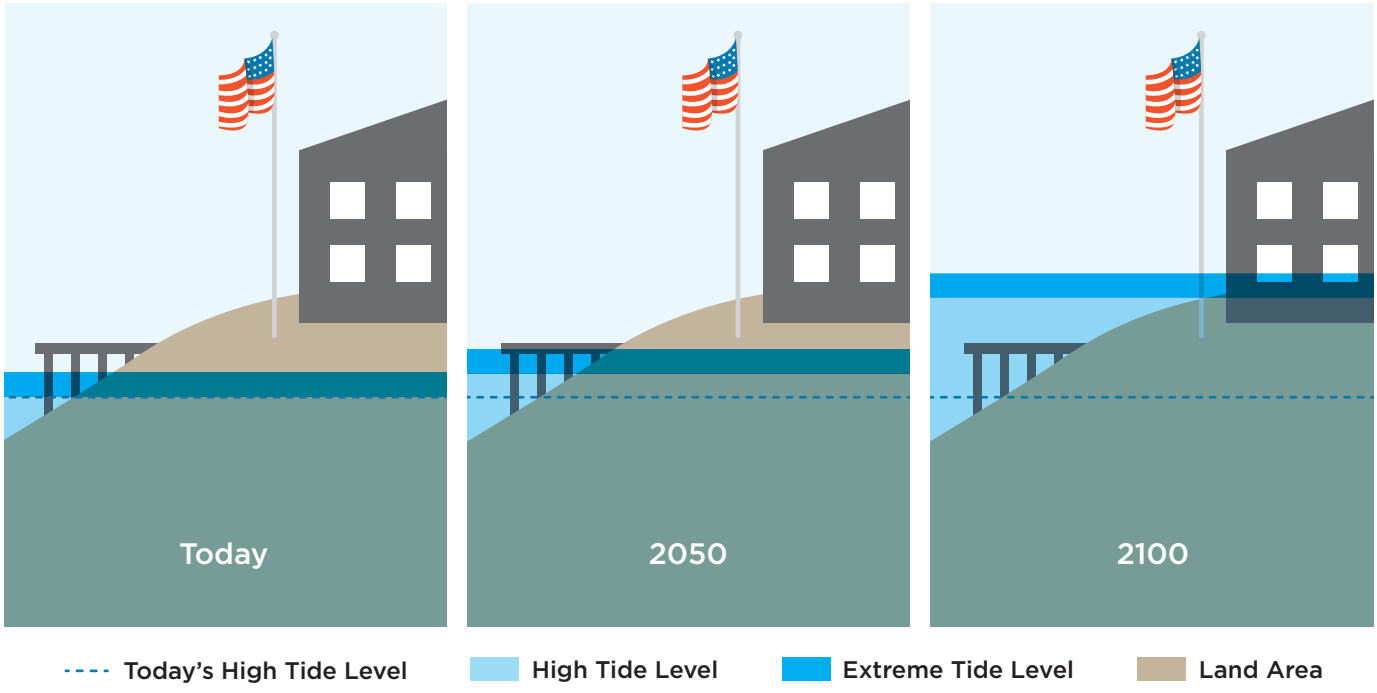
In the intermediate scenario, flood-prone areas throughout the region experience flooding twice daily on average and

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.

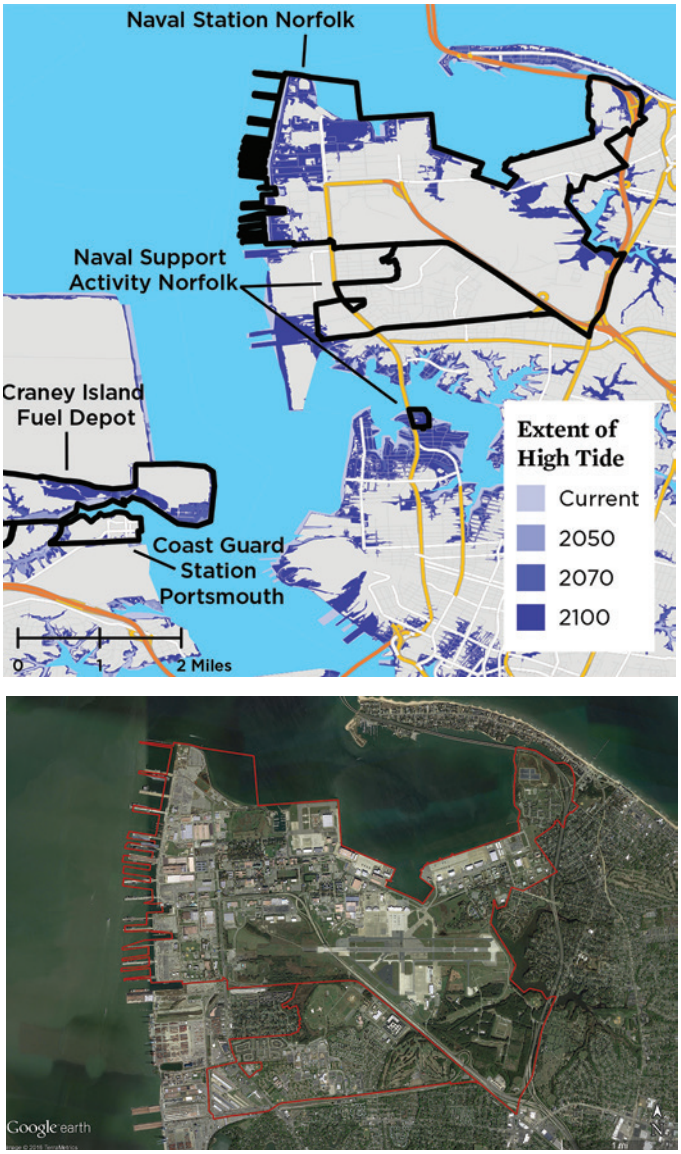
Today, most of the station (roughly 80 percent) is exposed to flooding less than 10 feet deep in a Category 4 storm. In the highest scenario, 55 percent of the station is exposed to flooding more than 10 feet deep by 2070. By 2100, 95 percent of the station experiences this depth of flooding.

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			
	Today	2050	2070	2100
Cat 1	11	19	35	78
Cat 2	62	83	94	100
Cat 3	98	99	100	100
Cat 4	100	100	100	100

	Highest: Percent of base exposed			
	Today	2050	2070	2100
Cat 1	11	27	66	99
Cat 2	62	90	99	100
Cat 3	98	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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