

Norfolk: A case study in sea-level rise

A Virginia city that owes its livelihood to the sea is in danger of being engulfed by it.

Norfolk, Virginia, is on the front lines of climate change. With the highest rate of sea-level rise on the US East Coast, 4.5 mm per year, it has been ranked by the Organisation for Economic Co-operation and Development as 10th among the world's port cities whose assets are at risk from rising seas. According to the US Army Corps of Engineers, New Orleans is the only US city in more danger.

Rising sea level is a problem for the entire low-lying region situated at the mouth of the Chesapeake Bay. Known as Hampton Roads, the region, which boasts 2 million inhabitants, comprises 7 major municipalities and 10 smaller ones. "You can't go five minutes without crossing water or having water on your left or right," says Emily Steinhilber, assistant director for coastal resilience research at Old Dominion University (ODU).

Flooding of roads from exceptionally high tides causes ODU to cancel classes several times each year. Storm surges have washed the covering off an area landfill, causing the contents to spill into the Elizabeth River, which flows past ODU and Naval Station Norfolk, the world's largest naval base, and eventually drain into the Chesapeake.

The number of hours each year in Norfolk when waters reached a foot or more above what's considered the inundation level rose from just over 100 in 1992 to a peak of around 275 in 2009, according to data compiled by ODU oceanographer Tal Ezer. Both were El Niño years, when higher tides generally occur along the East Coast. Last year, a strong El Niño year, there were about 240 hours of flood conditions.

Sea level in Norfolk has risen 46 cm in the past 100 years. About 20 cm of that is attributable to the global rise in sea level. The remainder comes from land subsidence from various causes, chiefly groundwater withdrawal. "I think our



SKIP STILES

TIDES IN NORFOLK, VIRGINIA, are especially high during autumn full moons, as in this October 2013 photo of flooding along the Lafayette River.

water table in some places is like 60 meters below when John Smith showed up," says Skip Stiles, executive director of Wetlands Watch, a Norfolk environmental nonprofit group; Smith was the 17th-century founder of England's nearby Jamestown colony.

Subsidence in the area has two other principal causes. The land continues to sink as it readjusts to distortions in Earth's crust created by the continental ice sheets 10 000 years ago. (See "The puzzle of global sea-level rise" by Bruce Douglas and Richard Peltier, *PHYSICS TODAY*, March 2002, page 35.) And a bolide—an extremely bright meteor—that slammed into the southern end of the Chesapeake Bay about 35 million years ago produced an 85-km-diameter crater into which the surrounding land continues to slowly slide. Larry Atkinson, an oceanographer at ODU, says that one-two punch probably accounts for about one-third of the total subsidence.

In addition to the effects of subsidence, the slowing of the Gulf Stream that began in the mid 1990s has had a noticeable effect on sea level by moving the current, which flows well above mean sea level, closer to the Virginia coast, notes Stiles.

J. Pat Rios, the US Navy's director of

facilities and environmental for the mid-Atlantic region, says that a further 61 cm rise in sea level is expected by 2050. Today, unusually high tides and a moderate storm surge will sometimes necessitate shutting off the electric and steam lines that run under the naval base's piers. By midcentury, he says, the same combination of events will flood most piers.

Norfolk is increasingly subject to nuisance flooding that occurs after heavy rains and when tides are exceptionally high, particularly in the fall. Water doesn't drain well from many streets because century-old stormwater outfalls are submerged even at low tides. "You have a thunderstorm and suddenly everybody in Norfolk is modifying how they get from point A to point B because they know certain streets they won't be able to drive on," says Ann Phillips, a retired rear admiral and Norfolk resident who consults for ODU's office of research. "In some places, it gets up to feet deep, and things are completely impassible."

A pilot project

Eighteen federal agencies have facilities in the area, and 40% of the regional economy is dependent on the presence of the military. With the naval base, nearby

Norfolk Naval Shipyard, and Naval Air Station Oceana in Virginia Beach, the navy has the biggest footprint. But Langley Air Force Base, NASA's adjacent Langley Research Center, and the Department of Energy's Thomas Jefferson National Accelerator Facility are also located nearby. The US Army operates a special forces training facility that is being expanded. "There's not a lot of places where you can move this stuff," Atkinson notes.

In June 2014 the cities and federal agencies formed the Hampton Roads Sea Level Rise Preparedness and Resilience Intergovernmental Planning Pilot Project. Its goal is to formalize cooperation among state, federal, and local governments and the private sector to adapt to sea-level rise in the region. Next month the pilot project is due to release recommendations for a framework for cooperation; specific actions to address the problem will come next.

The pilot project is being coordinated by ODU, which had already recruited physicists, oceanographers, economists, and others to form a multidisciplinary team. Michelle Covi, an assistant professor in the Virginia Sea Grant's Climate Adaptation and Resilience Program at ODU, says, "We were finding that it was difficult for the federal entities, particularly the [Department of Defense] entities, to share information across lines with the local planning bodies for preparing for flooding and sea-level rise."

The government installations can't be made resilient to sea-level rise without



SIGN NEAR THE USS WISCONSIN at the Nauticus science center in Norfolk, Virginia. During tidal surges, a barrier is raised to seal the flood wall.

taking into account the communities that surround them. Says Rios, "I could make this [naval] base an island, but it's not particularly useful." The base depends on the surrounding communities for its electricity, communications, and workforce.

Phillips, who chairs the pilot project's infrastructure working group, points to flooding that occurs around yet another naval installation, the Joint Expeditionary Base Little Creek-Fort Story, and in adjacent watershed areas of Norfolk and Virginia Beach. "The efforts of any one of the three taken independently will negatively impact the other two if not

done in a collaborative way," she notes. "If one side dams off their piece of the Pretty Lake-Little Creek inlet, the other two will suffer."

In January deputy secretary of defense Robert Work issued a directive on climate change resilience that delineated responsibilities within the Department of Defense for providing resources to assess and manage climate change impacts. The bureaucratically dense missive did not allocate funding or even address specific concerns. Yet Phillips calls it "a significant step forward" that indicates a willingness at the DOD's



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highest levels to start to implement climate adaptation and resilience measures.

Due to the naval presence and the heavy commercial vessel traffic, Hampton Roads is not suited for the sort of giant surge barriers that have been built in the Netherlands and in London. What's more, Norfolk is surrounded on three sides by water: the Chesapeake Bay to the north and the Elizabeth River to the west and south.

Responses to the threat of rising seas will combine dozens of small-scale projects—none available off-the-shelf—each tailored to a specific neighborhood or even to individual parcels of property. “It’s actually sort of tougher stuff to deal with because no one size fits all solutions,” Stiles says. “You have to work neighborhood by neighborhood, community to community to figure out how you’re going to approach it.”

Rios says that piers built recently at the naval station are several feet higher than piers built earlier. But he notes, “I don’t want to offer that we built them exclusively for sea-level rise. We built them to satisfy our mission, and when we can, we build them to accommodate the local phenomenon we’re seeing.” A new barracks was built with an underground retention pond and other features to help abate stormwater. “We’re working features into projects as they come up,” he says.

Sea-level rise and storm surges have eroded beaches used for training troops at the Oceana and joint expeditionary bases, Rios says, and more than \$10 million has been spent to replenish sand.

A mix of hard and green

The North Atlantic Coast Comprehensive Study, released last summer by the US Army Corps of Engineers, listed a half-dozen structural measures that could be employed in Hampton Roads. They ranged from building berms and levees to elevating roads and light-rail track beds to double as levees. The elevation idea is a two-edged sword, however; erecting new barriers could block water flows on one side and create new drainage problems.

Options for countering erosion include hard structures such as seawalls along shores exposed to wind and waves and greener “living shorelines” that stabilize and restore habitat on more sheltered creek banks. Living shorelines can also be created behind hard structures, the corps study notes.



US NAVY

A STORM SURGE SLAMS THE BREAKWATER at Naval Station Norfolk. Rising sea levels will increase the frequency of flooding in the surrounding region.

Also cited by the corps are nearly a dozen nonstructural measures that could be implemented. They include revising and standardizing building codes, elevating houses or buying out homeowners in vulnerable areas, expanding wetlands to store additional stormwater, and relocating utilities and other critical infrastructure.

In February Norfolk city officials signed an agreement for a corps study that will make specific recommendations to address flooding. The \$3 million effort is scheduled for completion in 2019.

The navy, Norfolk, and Virginia Beach, with the help of a grant from the DOD’s Office of Economic Adjustment, are conducting a separate assessment of sea-level rise in the area. Rios says that the study, expected to be completed next year, will focus on mutual investments the three parties can make to ensure the longevity of the base and the communities.

Some adaptation is already taking place. One hospital in a particularly flood-prone downtown area has moved its heating and cooling equipment and backup power generators out of the basement. After repeated flooding events, the Langley air base relocated basement offices and modified some hangars to improve drainage.

The Hampton Roads Sanitation District and the consulting firm CH2M are planning a \$1 billion sustainable water-recycling project that will pump potable treated wastewater into the depleted aquifer. The goal is to provide a sustainable source of groundwater, slow the rate of land subsidence, and inhibit saltwater

intrusion. It will also significantly reduce surface-water discharges into Chesapeake Bay tributaries and will thereby reduce nitrogen pollution. This summer the project partners will pilot two process concepts and several emerging technologies for mainstream wastewater treatment and nitrogen removal.

A Dutch dialog

For the most part, regional governments are still trying to figure out what to do. Dale Morris, senior economist at the Netherlands Embassy in Washington, DC, organized a workshop in Norfolk last summer that brought together local officials with flood control experts from the Netherlands and elsewhere. “They very clearly need in Hampton Roads a regional entity that works at county level or higher to coordinate their resiliency focus,” Morris says. “Norfolk and Virginia Beach don’t collaborate enough. But they share a border that has flooding problems.”

For several low-lying Norfolk neighborhoods, the so-called Dutch dialog workshop produced potential solutions, such as creating new wetlands, swales, rain gardens, and arroyos to soak up rainwater. Morris says that recurrent flooding is happening in areas that old maps show were once marshy, and that some of that marsh could be restored to hold and absorb water. “Do it right and you can put some plants there to do some water quality improvement,” he says.

Some levees or walls will be needed to protect high-value areas, Morris says. An existing floodwall built in the 1970s

to protect downtown Norfolk needs to be built up to prevent overtopping (see photo, page 23).

A class project

With support from Virginia Sea Grant, the nonprofit Wetlands Watch helped organize a group of ODU and Hampton University engineering and architecture students who drafted a plan to make one low-lying neighborhood of 500 homes more resilient to flooding. They proposed that stormwater in the ironically named Chesterfield Heights area be drained into cisterns built beneath the roads and in basements—which would be sealed off from the rest of the home. The stormwater would be allowed to slowly percolate into the soil. Installation of one-way check valves on stormwater outfalls would keep backflow from creeks out of the neighborhood. A living shoreline on the creek would limit erosion from barge wakes.

In January the Department of Housing and Urban Development's National Disaster Resilience Competition awarded \$115 million to implement the students' plan. Though obviously pleased with that outcome, Stiles observes, "If it's \$115 million to implement this in a neighborhood of 500 houses, what do you do in a region with 2 million people in it?"

Morris cautions that the Chesterfield Heights project could cut off adjoining neighborhoods that would also benefit from flood controls. "Can you justify the costs of only doing Chesterfield Heights on a cost-benefit basis?" he asks. "The approach developed has the idea that you don't do this singularly in one neighborhood. We need to find a way to link up the region so that investments make more sense."

Stiles agrees. "If you do only one neighborhood without thought to the surrounding areas, infrastructure, transportation needs, access to hospitals, et cetera, you get safe islands," he says. But limited grant money meant larger designs had to be set aside.

"We have to have those larger plans in place and be opportunistic in funding pieces of the plan as money becomes available, and pray that there is enough time to do the job," Stiles says.

The Hampton Roads area might learn from mistakes the Dutch made with their gigantic Delta Works project, a system of dams, sluices, locks, levees, dikes, and storm-surge barriers erected around the

delta at the confluence of the Rhine, Meuse, and Scheldt rivers. Closing off the delta damaged the ecosystem and the fishing industry. "Now [the Dutch] are seeing they need to reopen some of the barriers to create a better-functioning ecosystem," Morris says.

No one is venturing an estimate for what it might cost to brace Norfolk and the rest of Hampton Roads against the rising sea. Nor has a source of funding been identified. With the exception of the Army Corps of Engineers, the military can't spend money on projects outside

their bases. And the corps budget is divvied up by Congress, where a majority of members have at least one water project in their district.

In the long term, a more Dutch-like approach, in which sea-level considerations are routinely taken into account in the construction of roads and other infrastructure, might help. But, says Morris, "in the US, because of the way transport money is allocated, it isn't easy to say that when you design a road, put this water feature in so it helps the neighborhood next door."

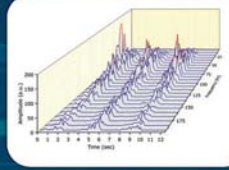
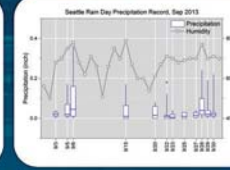
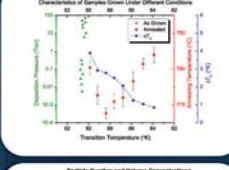
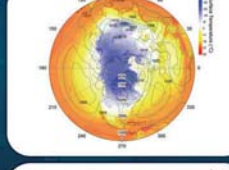
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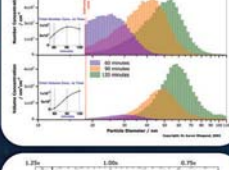
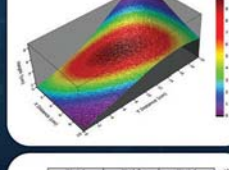
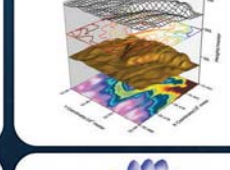
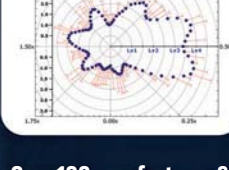
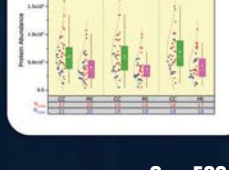
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