HOBOKEN, N.J.: Sandy’s storm surge flooded downtown and cut off power.

STATEN ISLAND: At least 17 residents drowned despite protective levees.
CLIMATE SCIENCE

STORM OF THE CENTURY*
*EVERY TWO YEARS

New York City and the entire U.S. East Coast could face frequent destruction unless the region takes drastic action.

By Mark Fischetti Maps by XNR Productions
In Brief

The chances of severe flooding in New York City will be as high as one in two each year by 2100, in part because the U.S. East Coast is a hotspot for sea-level rise.

Experts may be reluctant to recommend the ultimate protection measures for New York City: building massive barriers that would cost billions of dollars and moving communities out of the lowest-lying areas.

The primary way to protect long coastlines between cities is to pile sand along beaches every five to 10 years, but it is unclear whether enough quality sand deposits exist offshore.

Ending federal subsidies for flood insurance, so that beachfront residents must pay the full cost, might encourage people to move out of vulnerable areas.
States Underwater
Centuries from now, sea level could rise by six meters (19 feet), as polar ice sheets melt extensively. Yet even a one-meter rise, now predicted by 2080, would inundate a lot of coastal property.

Area Submerged from Sea-Level Rise
- 1-meter rise
- 6-meter rise

Percent of city below 1-meter elevation
- New Orleans: 91%
- Miami: 18%
- Tampa: 15%
- Norfolk: 9%
- Jacksonville: 7%
- New York: 7%
- Boston: 3%

Most Vulnerable Cities
The municipalities called out on this map have large populations, are exposed to the ocean and include substantial areas that are at extremely low elevations, making them the most prone to disaster.

Subsidence Hurts
Since North American glaciers began retreating 20,000 years ago, the eastern U.S. has been sinking as the crust adjusts to the unloading. The shore from New York City to North Carolina will continue to subside by one millimeter (0.04 inch) or more a year, helping the ocean invade.

Local Sinking
Norfolk, Va., and Virginia Beach are subsiding even faster than certain hotspot cities because the sediment underneath them continues to slump into the impact crater that formed Chesapeake Bay 35 million years ago.

Hotspot for Flooding
Sea-level rise varies worldwide. It is particularly aggressive along the mid-Atlantic Coast from Massachusetts to North Carolina, according to tidal gauges in place for decades. By 2100 the ocean along that region could rise 12 to 24 centimeters (4.7 to 9.4 inches) above and beyond the average global increase.

Accelerated Sea-Level Rise at Select Tidal Gauges, 1970–2009
- More than 5 mm/yr
- 4–5 mm/yr
- 3–4 mm/yr
- 2–3 mm/yr
- 1–2 mm/yr
- less than 1 mm/yr


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ture changes are made. Each decade from now until then, the "average" flood will become worse and worse. Billions of dollars in repairs will become commonplace.

New York City is not alone in facing a watery future. The U.S. East Coast—one of the wealthiest and most densely populated regions in the world—is a hotspot for sea-level rise. Melting Arctic ice is changing Atlantic Ocean currents in a way that raises water along the coast. At the same time, the land is subsiding. In 2012 Asbury Sallenger of the U.S. Geological Survey reported that for the prior 60 years, sea level from Cape Cod outside Boston to Cape Hatteras in North Carolina had risen three to four times faster than the global average. Using the data, Sallenger (who died in February) confirmed models by colleagues indicating that by 2100 the mid-Atlantic region would experience 4.7 to 9.4 inches of sea-level rise above and beyond the average global increase, which itself is expected to be several feet at least.

Sandy's damage has focused the minds of scientists, politicians and the public on the vulnerability of coastal areas to storm surges and sea-level rise. Experts are debating which actions could best protect the Eastern seaboard, especially as millions more people flock there. Turning the entire coastline into a fortress is prohibitively expensive and would ultimately be a losing proposition for many sandy coastlines. Yet the alternative—moving people away from the water—would be a political tinderbox and cause social and economic disruption.

This dilemma is being played out in New York City, where scientists and engineers are scrambling to present protection options to Mayor Michael R. Bloomberg by the end of May. They were expected to recommend steps to repel minor flooding, but it is not clear that they would be willing to recommend the only sure way to protect against an 11-foot surge like Sandy's: massive flood barriers that would cost $10 billion to $20 billion. It is also unclear whether they would recommend an end to federal subsidies for flood insurance and the evacuation of low-lying land, even though these steps are the ultimate long-term solutions to the sea-level rise that the latest climate science predicts.

The choices are even more stark for the long stretches of coastlines between cities—along New Jersey, Maryland, the Carolinas, Florida. The U.S. would have to build a wall 16 feet high—
to handle storm surge on top of sea-level rise—along every inch of the East Coast. Even if the money for such work were found, the millions of people who live in beachside communities would never stand for it because it would block their ocean view and access. The only politically viable option is to continually pile sand along beaches, even though higher and higher seas will erode more and more of it away—a Sisyphean postponing of the inevitable retreat from the shore.

In interviews with dozens of experts, it is clear that extreme measures needed to harden the East Coast would take decades to complete, cost hundreds of billions of dollars and disrupt many lives, but they are necessary evils.

**DEFENDING NEW YORK CITY**

Since Hurricane Sandy struck, all eyes have turned toward New York City to see how best to defend against rising water. The metropolis ranks in the top 10 port cities most exposed to flooding worldwide and has more than $2 trillion of coastal property at risk—first or second on the planet. When Cynthia Rosenzweig, a climate scientist at Columbia University, attended a global...
Helping the Hudson
Sandy's surge raised the Hudson River all the way to Albany, around 240 kilometers north (not shown). Barriers would protect that entire corridor.

Backfill Problem
Barrier gates could close for only a day or so because heavy hurricane runoff from many large rivers would fill the bay from the inside, causing a different flood.

Winners and Losers
An East River barrier would help seal off all five boroughs but could raise floodwater immediately to the east.

Green Solution
Restoring tattered wetlands in Jamaica Bay, a process that has begun, could cut down storm surge for southern Brooklyn and Queens.

Barrier Protection
An eight-kilometer-long “outer gateway” barrier designed by Halcrow Group would close to stop a storm surge. Four pairs of swinging gates would usually remain open so that ships could pass, and five retractable sluices would allow the daily mixing of tides and freshwater needed to keep the bays alive. Levees on either side would stop flooding from water that reflected off the barrier. The design could also support a highway to speed traffic around the city.

Walk Away?
More than 100 homes in the Rockaways, one of the lowest neighborhoods, were destroyed by Sandy's surge or subsequent fires—perhaps a place for permanent retreat.
environment meeting after Sandy occurred, city officials from around the world told her they were looking to New York to lead.

Scientists and engineers are scrambling because Sandy and new science have washed out the basic assumptions that the city had made. In 2009 a report by the New York City Panel on Climate Change (NPCC) stated that the city should plan for at least two feet of sea-level rise by 2100, based on conventional climate models. But in 2012 new information from various global sources showed that Antarctica and Greenland are melting quicker than models predicted. According to various scientists call the rapid ice melt scenario, global sea level will rise four feet by the 2080s, notes Klaus Jacob, a research scientist at Columbia’s Lamont-Doherty Earth Observatory. In New York City, by 2100 “it will be five feet, plus or minus one foot,” Jacob says flatly.

The NPCC report also did not focus much on storm surges. Sandy’s surge topped out at about 11 feet above average sea level at the lower tip of Manhattan. But here’s the rub: Flood maps just updated in January by the Federal Emergency Management Agency indicate that an eight-foot surge would cause widespread, destructive flooding. So if sea level rises by five feet by 2100, a surge of only three feet is needed to inflict considerable damage.

Of course, rapid climate change would raise the sea higher every decade until then. Jacob says the chance of what had been a one-in-100-year storm surge occurring in New York City will be one in 50 during any year in the 2020s, one in 15 during the 2050s and one in two by the 2080s. Scientists at the Massachusetts Institute of Technology say the chance of a one-in-100-year storm will be as great as one in three by 2100.

Despite the dire odds, none of the more than 20 scientists, engineers and city officials interviewed for this article would articulate a grand plan for protecting New York City against five feet of sea-level rise, plus an 11-foot surge, because that would require politically difficult choices. The lone exception is Jeroen Aerts, who served as an adviser to New York City’s Office of Long-Term Planning and Sustainability and Department of City Planning, until they parted ways after Hurricane Sandy.

To Aerts, the necessary plan is straightforward. Immediately start flood-proofing buildings, which would harden them against events like the five-inch deluge in 2007. Begin to retrofit subway, train and automobile tunnels so water cannot get in. Armor power plants, wastewater treatment facilities and other “critical infrastructure.” Meanwhile start the process of changing zoning laws to discourage construction in the lowest-lying areas. Add seawalls along the low edges of the city’s boroughs to fend off rising sea level. And start doing environmental and cost-benefit studies for enormous barriers that would be dropped into the bay to hold back surges. These studies take years, and construction would take years more, “so it will be 2030 before barriers would be in place,” Aerts explains. “In the meantime, you start implementing the ‘no regret’ steps,” such as raising subway entrances so floodwater cannot pour down the stairways onto the tracks.

Aerts was hoping New York would impose a regional plan such as the one he was developing, but in the aftermath of Sandy the groups he was advising told him that regional politics would make a centrally executed plan impossible. That is a far cry from how those things work where Aerts comes from: he is a specialist in geographical risk management at the Institute for Environmental

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**Flood Damage: Local Fixes Can Lessen Loss**

As seas rise, tides and surges will invade further into a coastal city, and even routine storms will cause more extensive flooding. Many street-level protection measures have been proposed for New York City and other municipalities; a variety of these proposals are shown here. Although quick implementation is tempting, experts warn that any mitigation measure should first meet standards and policies established in a region-wide protection plan, including a cost-benefit analysis for the short and long term. Otherwise, money could be wasted.

**Install Retractable Floodwalls**

If giant barriers are not built in the ocean outside a city to hold back a storm surge, high, retractable floodwalls could be installed between the pillars of a perimeter highway and closed when a storm approaches.

**Frame Sidewalk Vents**

Runoff from downpours can overtop the curb and flow into subway air vents that lie flush in sidewalks. Surrounding a vent with a simple vertical frame can divert the flow.

**Bulk Up Boardwalks**

Low-lying boardwalks and piers along the shore can be raised and fortified.

**Erect Reefs**

Artificial reefs or restored wetlands can break up waves and surges, reducing their energy.
Elevate Mechanical Systems
Power outages and fires in buildings can begin when basement boilers or electrical panels are hit by water. A flooded backup generator will not work. Raising critical mechanical systems aboveground and perhaps burying fuel tanks could reduce risk.

Flood-Proof Critical Infrastructure
Power plants, wastewater facilities and hospitals within a one-in-100-year flood zone are crucial during floods. Levees, flood doors, underground hatches, sealants at construction and pipe joints, and other steps can harden them against high water.

Deploy Tunnel Air Bags
Subway and road tunnels can trap many people if they flood quickly. Air bags made of incredibly strong but pliable fabric could inflate in minutes, keeping water out.

Raise Subway Entrances
Hurricane Sandy inundated New York’s subway system in part because seawater cascaded down stairwells. Adding a few steps up, before the steps that go down, can safeguard an entrance against high water.
The main objection to barriers is cost. Yet the investment could pay off handsomely. Studies of past disasters show that every $1 spent on protection measures can prevent $4 in repairs after a storm.