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Storm of the Century Every Two Years

Mark Fischetti

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

In Brief

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- 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.

ADDITIONAL IMAGES AND ILLUSTRATIONS


[EAST COAST] Sea-


[NEW YORK CITY]


[LOWER

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MANHATTAN] Flood Damage: Local Fixes Can Lessen Loss

Thomas Abdallah has seen a lot of water in his 26 years of work for New York City's transit system. In December 1992 a nor'easter storm killed the subway's power, forcing rescue crews to evacuate passengers from flooding tunnels. In August 2007 a five-inch deluge that meteorologists called an “extreme climate event” shut down the system again. So did Hurricane Irene in August 2011. Then came Hurricane Sandy.

As Sandy's storm surge began to flood downtown Manhattan last October, dozens of New York City transit workers scrambled in the wind and rain to place plywood sheets and sandbags across subway entrances. But the oncoming water pushed right through the feeble barricades, pouring down stairwells until underground stations filled chest deep, in turn filling seven long train tunnels running under the rivers between the boroughs. Huge pumps in more than 300 man-made caverns deep below the city's subway line, which can push out 18 million gallons of water a day, couldn't possibly keep up.

After the deluge, Abdallah, who is the transit system's chief environmental engineer, assessed the damage with his colleagues. Saltwater had corroded electrical equipment throughout the subway system. Much of it had to be replaced. The transit authority chair at the time, Joe Lhota (now running for mayor), testified before Congress that fully restoring the system would cost $5 billion. And that would just bring the subways back to their pre-Sandy condition; the money would do nothing to enhance protection against the next hurricane or against rising seas.

That status quo is becoming increasingly costly in money and lives. Experts predict that damaging storms will get more severe and more frequent. According to the latest estimates, the chance of widely destructive flooding in New York City will be one in two each year by the end of the century unless significant infrastructure 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

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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 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 what 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 push 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. Those 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 things work where Aerts comes from: he is a specialist in geographical risk management at the Institute for Environmental Studies in Amsterdam. In the Netherlands, top-down management is a key to building and maintaining the world's most extensive flood-protection system. When Aerts realized that New York City's politics precluded such an approach, he and the city agreed to work separately. He continues to develop his blueprint, aiming for the end of May, parallel to the NPCC's deadline for reporting to Bloomberg. He is concerned that planners may shrink from recommending expensive barriers in a time of tight budgets and from recommending retreat from the shore.

Even if state and local governments were to accept Aerts's plan, it has its complications. For one thing, engineers would still have to agree on the best places to install the massive structures. A barrier is basically a wall that has enormous gates within it. The gates normally stay open to allow ships to pass and to allow the daily mixing of tides and freshwater from rivers that keeps a bay's ecosystem alive. When a storm comes, the gates close to hold back the surge.

Malcolm Bowman of Stony Brook University floated a plan several years ago for three barriers that would primarily protect Manhattan, but engineers are now leaning toward a two-barrier plan proposed by the commercial Halcrow Group that includes a five-mile-long span that would close off all of New York City [*see box on page 63*]. Although such a mammoth "outer harbor gateway" might sound crazy, in 2010 a barrier three times longer began operating in St. Petersburg, Russia. That $6.9-billion barrier is a good model because the water depths and land elevations in St. Petersburg are similar to those in New York City, says Jonathan Goldstick, an engineer and vice president at Halcrow, a lead consultant for the St. Petersburg installation.

Because gates remain open, barriers do nothing to deflect sea-level rise, so other measures would be needed for that threat. Critics also contend the water that a barrier holds back would flow to either side, making flooding worse in adjacent communities. But Philip Orton, an ocean engineer at Stevens Institute of Technology, says most of the reflected water spreads out across the sea. Before Sandy struck, he and his colleagues were running a computer model that re-creates the storm surge from Cape Cod to Maryland from Hurricane Irene. Orton can simulate barriers in different places to see how the surge responds. Tests of Bowman's three-barrier

system showed that water alongside the gates would rise only an additional 5 to 7 percent. Orton is now adapting the model to Sandy's floodwaters.

Another concern is that barriers can become death traps. That's why Jacob is not a fan, even though they would have prevented Sandy from flooding his own house up the Hudson River from Manhattan. As barriers close off the bay around the city, the massive Hudson River, other rivers and heavy rainfall flowing into New York Bay would begin to fill it from behind the closed wall. Orton says the rate could be as high as three feet a day—but that is a lesser evil than an 11-foot surge. Most surges last only a matter of hours, so procedures would have to be in place to reopen the gates as soon as possible.

Huge barriers have proved effective in several places around the world. But one lesson the Dutch learned the hard way would have to be incorporated into any New York plan. They started building barriers in the 1950s and recently began to reengineer them at great cost to account for sea-level rise. New York would have to design barriers that can be raised over time—five feet in the ensuing 90 years, then more in the next century.

Likewise, new building codes to direct flood-proofing measures would have to take into account ongoing sea-level rise. Any adaptation plan should be even broader than that, says Sergej Mahnovski, director of the city's Office of Long-Term Planning and Sustainability. It should address all aspects of climate change, including longer heat waves and higher humidity that could seriously stress the electric grid, as well as stronger winds.

The main objection to barriers is cost. Yet the investment could pay off handsomely. Paul Kirshen, professor of environmental research and engineering at the University of New Hampshire, says every $1 spent in protection measures can prevent $4 in repairs after a storm, based on smaller-scale measures already implemented in various Northeast municipalities. Sandy cost New York City $19 billion in losses, according to Bloomberg. That's just one storm.

“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.”

Each city will have to assess its own unique threats and potential solutions. Because sea level in Norfolk, Va., the third-largest port on the East Coast, has risen 14 inches since the 1930s, its downtown area floods often. Miami might face the worst case. It is exposed to many more hurricanes than the Northeast, and unlike New York City almost all of it is at sea level. Moreover, the city is built on porous carbonate. When the sea lifts, the carbonate absorbs water, which rises up through the streets, flooding the city from the inside out. “How do you defend

against that?" asks S. Jeffress Williams, a coastal marine geologist at the U.S. Geological Survey and the University of Hawaii. "I don't know." The city is expanding a pumping system that clears floodwater from rainstorms, but the system cannot pump the city out of a surge and would be useless for five feet of sea-level rise because the elevation of much of Miami is less than three feet.

Protecting the East Coast

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Barriers and seawalls might protect certain cities, but what can be done for the hundreds of miles of Jersey, Carolina or Florida beachfronts between them? Conventional measures such as man-made wetlands are inadequate. Wetlands that can absorb minor surges do not grow well along sloped shorelines exposed to open seas—and they offer no protection against sea-level rise. Swimming in muck doesn't thrill anyone, either. Piling up sand as an endless dune or a deep, rising beach is the only engineering option; however, "it's not clear there is enough quality sand" out on the continental shelf, Williams says.

Sand that has the right grain size to hold a beach against waves, much less storms, occurs in discrete deposits on the ocean floor, built up over thousands of years. Ships pump the sand onto barges, which drop it on the shore, where workers spread it with trucks. This "beach nourishment" requires vast quantities of sand and money, and it's a losing game. As routine tides and storms relentlessly wash away beach sand, it fans out across the seafloor in thin layers that cannot be harvested.

Over time a higher ocean will wash away even more sand. "Could beach nourishment keep up with sea-level rise and surge for a few decades? Probably," says Robert Young, a geologist at Western Carolina University and an expert in beach nourishment. "Could we do it for 100 years? I don't think so."

For now, the U.S. Army Corps of Engineers, which mines and bulldozes much of the sand in question, will continue to replenish beaches every five to 10 years, according to Kathleen White, a senior environmental engineer there. Each episode can cost $1.5 million to $10 million per mile; New Jersey is at the high end. White says the corps is looking across a larger span of ocean for quality deposits, but she cannot say what it might find. Of course, the farther from shore the sand is, the more it costs to retrieve.

The entire pursuit is dubious in the long term, however. Beaches and barrier islands—which are wearing thin along the East Coast—are meant to slowly migrate landward, as very high tides or surges push sand from the ocean side toward the land side. The migration allows the beachfront to remain high and robust—nature's own storm protection. "The only reason for beach nourishment is to keep a beach line in place," Young says. The best way to preserve a beachfront is to let it move. Protective seawalls make matters worse over time. They stop the sand from migrating and reflect

wave energy, so it scours away even more sand. “Erosion doesn't destroy beaches,” Young says. “Seawalls and roads do, by getting in the way of natural beach relocation.”

End the Perversion

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Allowing migration means people along the shore have to get out of the way. But perverse incentives encourage them to remain in high-risk areas.

Disaster recovery funds are one culprit. As long as Congress keeps authorizing them, people will keep rebuilding. The National Flood Insurance Program is another because the federal government subsidizes it. Individuals and businesses in flood zones do not pay anywhere near the full premiums. If they did, Aerts notes, “people would say, ‘Oh, that is too high,’ and they wouldn't build there.”

Federal subsidies create “a moral hazard,” Young maintains. “It's a totally false economy. It's bad fiscal policy, and it's bad federal policy—if we believe we should be adapting to climate change. I'm not suggesting we abandon the coast,” he adds. “But it has to pay for itself.”

After decades, Congress has just begun to change the program. Less subsidized premiums will be slowly phased in. A homeowner at the highest point in a floodplain might pay $800 a year, for example, but someone near the lowest point might pay $25,000. Gradually, people might opt to abandon the most expensive—and vulnerable—land.

It is still unclear if flood insurance subsidies will disappear entirely, and wealthy people could still choose to build in low-lying areas at their own financial risk, forcing municipalities to try to provide some form of public safety during storms. As an alternative, cities and states could buy out residents whose properties repeatedly flood. New York governor Andrew Cuomo said he would use $400 million of his state's federal disaster relief to offer such buyouts. Cas Holloway, deputy mayor for operations in New York City, says Sandy ruined about 500 homes there, and another 500 might have to be demolished.

If done over, say, 50 years, buyouts could clear the most vulnerable neighborhoods, leaving the land as a natural buffer.

Retreat or Swim

top

Buyouts epitomize the ultimate solution to storm protection: retreat from the shore. But retreat is a tough sell. When Kirshen surveyed people who live in the low-lying East Boston community, they uniformly said they would not leave, even after recurrent flooding. They said the ocean is part of their identity. Rosenzweig, the Columbia climate scientist (who co-chairs the NPCC), adds that no adaptation plan can succeed “without taking the voices of neighborhoods into account.”

Moving people is also politically unpopular. “Are we thinking about categorical retreat from the sea?” asks New York City deputy mayor Holloway rhetorically. “Absolutely not.”

Yet retreat is under way elsewhere. The people and houses of Billingsgate Island off Cape Cod and of Hog Island off Virginia were moved to the mainland long ago. After a March 7 nor'easter ruined more than a dozen homes on Plum Island north of Boston, Massachusetts officials reiterated the state's policy of not allowing seawalls, saying that in the lowest-lying areas, moving homes to higher ground is the best option.

Jacob thinks that retreat in unavoidable and that discounting it is a form of risk denial. Policies need to be put in place to encourage people to move, he says. The Nature Conservancy, for example, is encouraging New York and other states to establish land trusts that can buy out a community, help it relocate, and allow the land to become a park or revert to a natural landscape.

The U.S.'s census of New York City, however, shows that even more people were living in low-lying areas in 2010 than in 2000. That trend is particularly befuddling, Jacob notes, because unlike Miami, much of New York City does lie well above sea level. With grim irony, he points out that “the city has a lot of cemeteries on high ground. We could switch the living and the dead, and probably the dead wouldn't mind.” To him, that morbid plan might be a lesser evil than beachside residents drowning in a future storm.

Do leaders of cities and suburbs all along the coastal U.S. have the political will to do what's right for the long term? Or will they postpone the tough decisions and let nature force the consequences on residents later, at considerably more expense and suffering?

MORE TO EXPLORE

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NY-NJ Outer Harbor Gateway. Presentation by Dennis V. Padron and Graeme Forsyth. March 31, 2009. Available as a PDF at http://bit.ly/XHwUSJ

Climate Change Adaptation in New York City: Building a Risk Management Response. New York City Panel on Climate Change in *Annals of the New York Academy of Sciences*, Vol. 1196; May 2010.

Hotspot of Accelerated Sea-Level Rise on the Atlantic Coast of North America. Asbury H. Sallenger, Jr., et al. in *Nature Climate Change*, Vol. 2, pages 884–888; December 2012.

SCIENTIFIC AMERICAN ONLINE

For a full explanation of why sea level could rise by five feet in New York City by 2100, see ScientificAmerican.com/jun2013/fischetti

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EAST COAST

Sea-Level Rise: A Global Hotspot

Rising seas could drown a significant portion of the U.S.'s valuable and highly populated East Coast, including famous cities. The latest estimates indicate that global sea level could rise by at least one meter (3.3 feet) by 2080 (*red*), as warmer seas expand and glaciers melt. Yet the effect is not uniform around the world. The coast from Massachusetts to North Carolina is a hotspot; sea level there has risen three to four times faster than the global average over the past 40 years, in part because of changes in Atlantic Ocean currents caused by melting ice in the Arctic (*map at far right*). Furthermore, the land under most of the coast is sinking, making the sea relatively higher still (*green line*). Certain municipalities such as Atlantic City are subsiding even faster because they are rapidly extracting groundwater that helps to prop up land.

States Underwater

Centuries from now, sea level could rise by six meters (19.7 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.

Lowest of the Low

New Orleans, much of which is below sea level, is the most vulnerable of all major U.S. coastal cities. A single meter of sea-level rise would swamp more than 90 percent of it unless levees and other barriers are improved.

Sifting Sand

The only practical way to protect hundreds of kilometers of shoreline between cities is to pump sand from offshore deposits onto beaches every five to 10 years to replace what tides wear away. It is unclear, however, if enough quality deposits exist to last more than a few decades.

See next box for details

Continent rising
Continent sinking

Boston
Mass.
New York
Conn.
R.I.
New York
Pennsylvania
New Jersey
Baltimore
Maryland
Washington, D.C.
Delaware
Virginia
Chesapeake Bay Impact Crater
Norfolk
Virginia Beach
North Carolina
South Carolina
Georgia
Florida
Alabama
Mississippi
Louisiana
New Orleans
Jacksonville
Tampa
Miami
Wilmington
Charleston
Fort Pulaski
Fernandina Beach
Fort Myers
Naples

Boston
Mass.
Providence
Conn.
Newport
Woods Hole
New London
R.I.
Nantucket
N.Y.
Bridgeport
Montauk
New York (Battery)
Sandy Hook
Philadelphia
Pennsylvania
New Jersey
Maryland
Baltimore
Annapolis
Atlantic City
Cape May
Washington, D.C.
Lewes
Delaware
Solomon's Island
Chesapeake Bay
Virginia
Hampton Roads
Kiptopeke Beach
Norfolk
Virginia Beach

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

NEW YORK CITY

Storm Surge: Block It or Abandon Shore

Storm surge and sea-level rise threaten New York City. Hurricane Sandy's 3.4-meter (11-foot) surge was the highest to hit the city's metropolitan area. Like most cities, New York bases protection plans on maps from the Federal Emergency Management Agency, which show where flooding most likely will occur if a one-in-100-year storm hits. FEMA updated New York's flood zones in January, but Sandy's surge flowed farther inland in many areas (*key below*). Two massive barriers could hold back surges, but residents might have to abandon the lowest-lying communities, which already flood regularly, as seas relentlessly rise.

Flood Levels

A sea-level rise of 1.4 meters (4.5 feet), projected for 2100, would fall within some of the FEMA flood zones (*green* and *brown*) but would overrun them in other places (*blue* and *purple*). Sandy's storm surge covered all the FEMA area (*brown* and *red*) and much of the 1.4-meter area (*brown* and *purple*) but also moved farther inland than both boundaries in many places (*pink*).

Hurricane Sandy surge (3.4 meters)

Sea-level rise by 2100 (1.4 meters)

FEMA 100-year flood zone

NORTH

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.

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.

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.

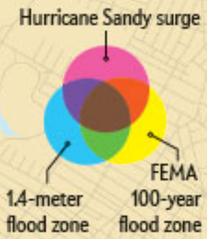
Levee
Sluice
Levee
Road
Tunnel
Navigation channel
Gate barriers (*shown closed*)

Long Island Sound
Hudson River
Harlem River
Bronx River
Hutchinson River
BRONX
Eastchester Bay
East River
Little Neck Bay
Flushing Bay
MANHATTAN
Passaic River
Hackensack River
Newark Bay
Upper New York Bay
BROOKLYN
QUEENS
The Narrows
Jamaica Bay
STATEN ISLAND
Arthur Kill
Rockaway Inlet
Lower New York Bay
Breezy Point
Raritan River
Raritan Bay
Sandy Hook Point
Sandy Hook Bay

LOWER MANHATTAN

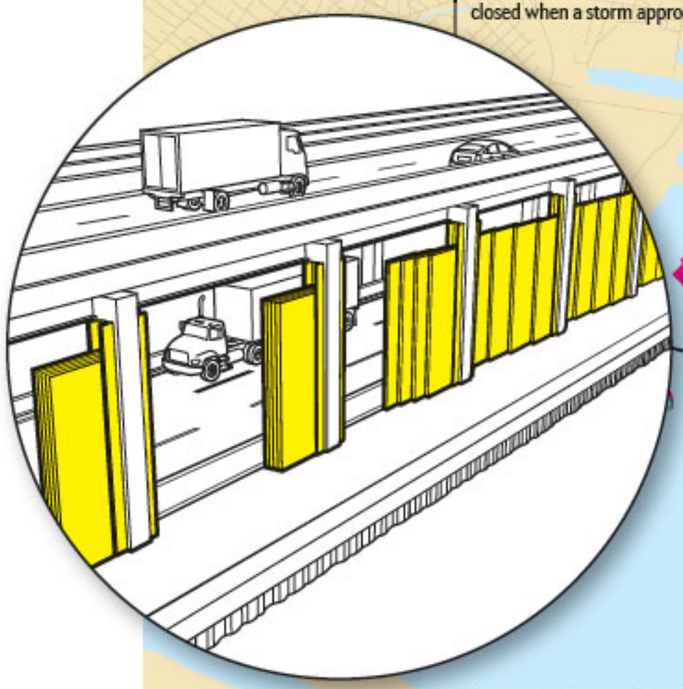
Flood Damage: Local Fixes Can Lessen Loss

As seas rise, tides and surges will invade farther 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

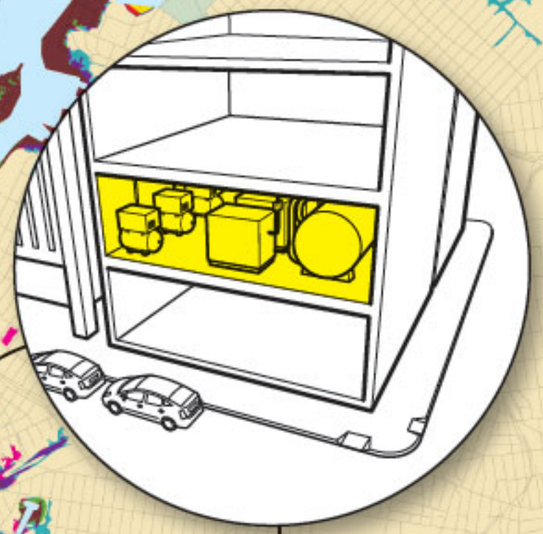
Runoff from downpours can overtop the curb and flow into subway air vents that lie flush in sidewalks. Surrounding a vent with a simple vertical frame can divert the flow.

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.

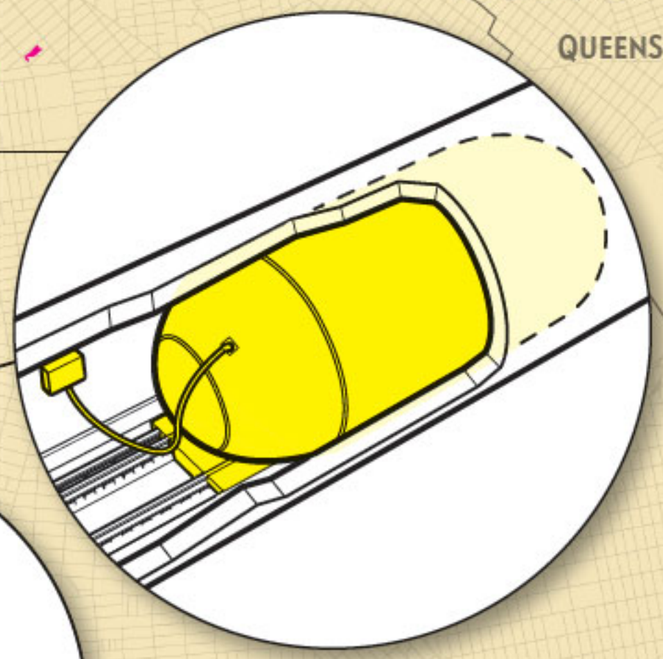


Elevate Mechanical Systems

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.

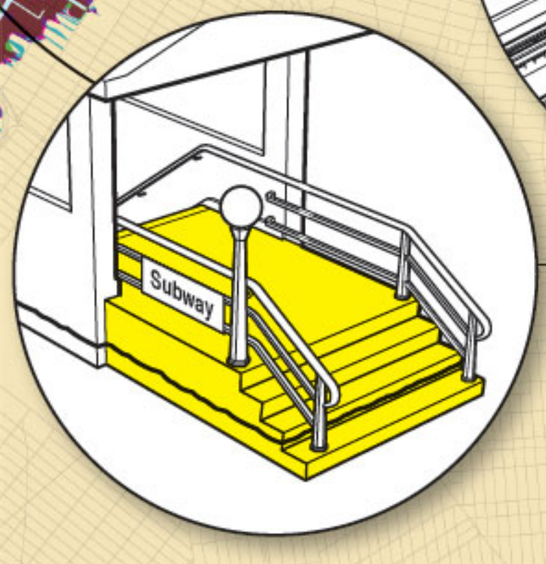
Flood-Proof Critical Infrastructure

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.

MANHATTAN
Hudson River
East River
Chelsea
West Village
SoHo
Tribeca
Financial District
Stuyvesant Town
East Village
Lower East Side
BROOKLYN
QUEENS