

But for new pipes, Ghandehari suggests a much lower-tech solution: put utility lines in tunnels that human workers can walk through. “The rule of thumb is that you need to have access for inspection,” he says. “Cities of the future should consider how to deal with providing access to the urban lifeline.”

In the meantime, New York has some difficult decisions ahead as it recovers from Sandy. “The hard thing is going to be where to rebuild, and where not to rebuild,” Barone says.

It might be best to leave some neighbourhoods uninhabited so that they can take the brunt of future floods. “We had built on barrier islands,” Barone says. “Where an entire neighbourhood has been destroyed, do you rebuild it? Or do you do something else?”

It’s a cruel calculus, but for the shoreline just north of New York City that was hit by hurricane Irene last year, Sandy’s aftermath is all too familiar.

“In two years, most parts of the region have been touched by natural disaster,” Barone says. “We can’t assume this will be every 10 or 20 or 50 years any more, like we used to. We are going to have another one.” ■

Additional reporting by Michael Marshall

No trains today: South Ferry subway station in Manhattan’s financial district was inundated

Protecting New York City from the next big storm

AS THE full extent of the devastation wreaked by superstorm Sandy sinks in, the question for the future is how to protect the New York metropolitan area when a similar disaster strikes again.

Embryonic plans exist, both to erect massive flood barriers and for “soft” engineering schemes that would redesign waterfronts to incorporate wetlands, oyster beds and other natural features that could slow storm surges. The hope is that Sandy will provide the will – so far lacking – to turn these plans into reality. “It’s not just a wake-up call, it’s a wake-up scream,” says Cynthia Rosenzweig of Columbia University.

Years of work and tough decisions lie ahead. Flood defences don’t come cheap and in a region with more than 2400 kilometres of coastline that is home to 20 million people, it isn’t possible to protect everything. For instance, little can be done to shield the low-lying beachfronts on Long Island and Jersey Shore, which Sandy ravaged.

There’s also a philosophical gulf to be bridged between civil engineers, who want to hold back the waves with concrete and steel, and those who favour more natural solutions.

One thing is clear: the threat is only going to get worse. Sandy’s storm surge peaked at about 3.5 metres above average sea level in lower Manhattan. New York City officials currently assume that a 2.6-metre flood will happen once a century, and a 3.3-metre flood once every 500 years. The New York City Panel on Climate Change, co-chaired by Rosenzweig, has estimated that, by 2100, rising sea levels could bring 100-year floods every 25 years (*Climatic Change*, doi.org/fdq5g8). Factor in changes to storm patterns expected with climate change and they could strike every three to 20 years (*Nature Climate Change*, doi.org/jnm).

Barriers with gates that can be closed when a surge is brewing are the obvious solution. It’s a tried and tested technology, used extensively in the Netherlands to protect low-lying areas from North Sea storms.

A team led by Malcolm Bowman of Stony Brook University’s Storm Surge Research Group has studied the protection that could be offered by a system of three flood barriers (see map, right). To the south of Manhattan, these would be built across the Verrazano Narrows, between Brooklyn and Staten Island, and the Arthur Kill, between Staten Island and New Jersey. To the north-east, another barrier would block rising waters in Long Island Sound from surging down the East River.

Simulations using a “juiced up” version of hurricane Floyd, which hit the region in 1999, indicate that the barriers would protect large areas from flood waters, says Brian Colle, a member of the Stony Brook team. Though Sandy’s surge was much bigger, in principle barriers could be engineered to hold back such floods.

The big problem with these barriers, however, is that they would leave densely populated areas – especially parts of Brooklyn and Queens – at the mercy of a storm surging into Jamaica Bay. In fact, those districts would be hit even harder if these barriers were built. Philip Orton of the Stevens Institute of Technology in Hoboken, New Jersey, studied what would have happened if the three barriers were in place when tropical storm Irene hit in 2011. His simulations showed that they would have diverted the water, increasing flood levels by 5 per cent in Jamaica Bay.

Any solution that protects Manhattan at the expense of poorer neighbourhoods is likely to be unacceptable – especially after the residents of Sandy-devastated Staten Island complained of being the “forgotten borough” as the city focused on restoring normality to Manhattan.

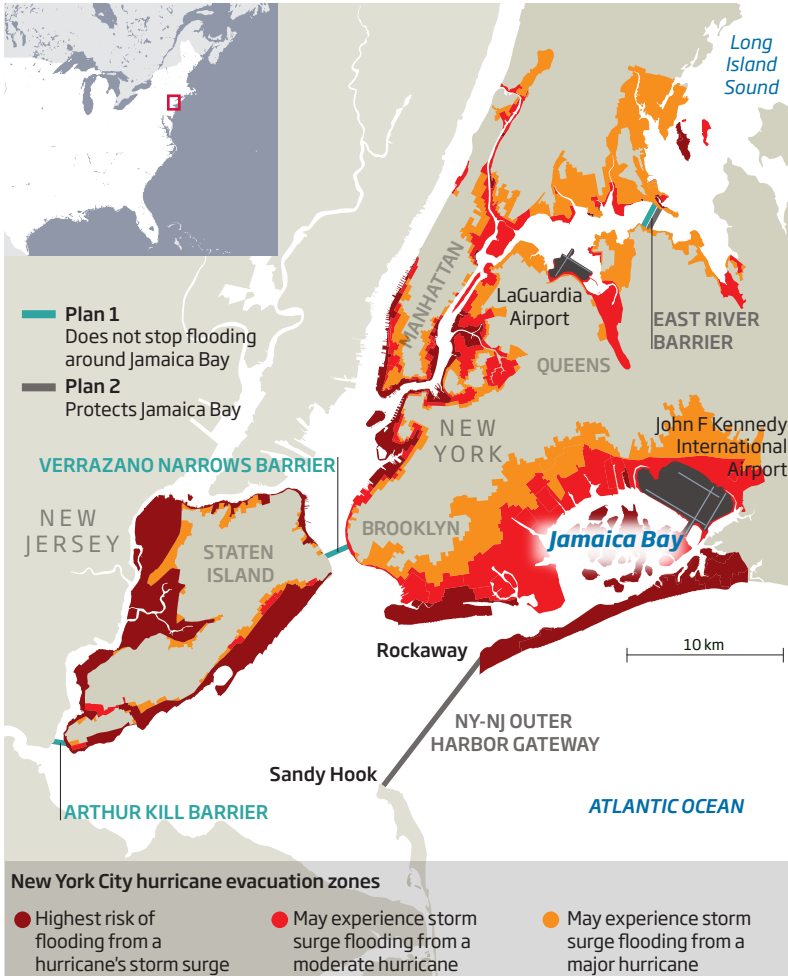
So the preferred plan is to keep the northern barrier, and replace the two southern ones with a much larger, single barrier across the entrance to the New York-New Jersey harbour, with gates to allow ships through.

Preliminary estimates from engineering firm Halcrow suggest that



Flood barrier future

Preliminary plans exist to erect barriers to protect the New York metropolitan area from hurricane-induced floods, with some offering more protection than others



"Big events require big engineering. I don't see any other way"

the outer barrier could be built for \$5.9 billion – including bolstering the low-lying peninsulas of Rockaway and Sandy Hook to ensure that surges don't simply flow around it. The East River barrier could cost another \$5 billion, says Bowman. Those are huge sums – but with losses from Sandy estimated at \$50 billion it may be money well spent.

Nevertheless, some experts warn against rushing into plans to build massive barriers, which would fundamentally change the region's environment. "We've learned in the past several decades that you harm fisheries if you block estuaries," says Orton. "You reduce the flushing. Therefore the amount of pollution in the system is going to grow." Such

concerns explain the enthusiasm in some quarters for soft engineering solutions, including the construction of new wetlands and oyster beds, which can help to slow storm surges.

The region's architects have turned these ideas into conceptual designs. In 2009, a team led by Guy Nordenson of Princeton University completed a study called "On the Water: Palisade Bay", which envisaged adding an archipelago of islands and reefs to the region, plus an extended waterfront including tidal marshes, piers and parks. Five teams of architects, engineers and landscape designers then refined the plans, which were exhibited in 2010 at New York's Museum of Modern Art. Lower

Manhattan, for instance, would fringe its familiar skyscrapers with salt marsh, and extend the island's southern tip into a field of rectangular islands. Streets would get porous surfaces and some would be equipped with subterranean channels that would drain storm surge water back out to sea.

The designs are stunning but do not come with cost estimates or storm-surge modelling to show what they might achieve. "I see them as dream exercises," says Benjamin Orlove of Columbia University, who studies environmental decision-making.

While wetlands can obstruct a storm surge, much depends on the local geography and the nature of the storm. A common rule of thumb is that a wetland extending 14.5 kilometres out to sea will reduce the height of a storm surge by a metre. But if a storm moves slowly and winds drive at the coast for an extended period of time, these benefits can vanish.

None of the experts contacted by *New Scientist* believes the architects' plans would protect against a major storm. "Big events require big engineering. I don't see any other way," says John Mutter of Columbia University, who studies vulnerability to natural disasters.

Still, artificial wetlands and other soft engineering approaches could improve resilience against smaller storms, and be part of a comprehensive approach to flood protection. "We need to look to the Dutch," says Rosenzweig. "They have the barriers, but they realise that hard engineering is not going to save them completely." For instance, in the Netherlands, agricultural land is used to soak up excess water in floods.

Political leaders seem divided on how to proceed. While New York state governor Andrew Cuomo has said that officials need to approach flood protection with an open mind in the light of Sandy's devastation, New York City mayor Michael Bloomberg remains sceptical about flood barriers.

Meanwhile, feasibility studies alone will take years and cost tens of millions of dollars. There will be no easy solutions, Rosenzweig warns. "We need to be very smart. But then New Yorkers are smart." Peter Aldhous ■