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Flooding at a station in Koshigaya near Tokyo.

FLOODING

Water potential

Water is a necessity for any city, but too much of it can threaten lives and infrastructure. As climate change looms, new approaches can help to turn a threat into a resource.

BY JAMES M. GAINES

Water is vital, but as anyone who has felt the effects of flooding will attest, it is possible to have too much of a good thing. For many nations, flooding has always been a problem. Take the Netherlands, for instance: 26% of the country — and 21% of its population — is below sea level, and only a complex system of dykes, pumps and dams, constructed over hundreds of years, keep it dry. But in other countries, flooding is a more modern and growing concern — especially as absorbent rural land continues to be subsumed by the impermeable concrete of our rapidly expanding cities. Between 2008 and 2010, 62% of Chinese cities were flooded. And 39% of 351 cities in the country reported at least 3 serious floods in that time.

In 2012, the heaviest rainfall in more than 60 years killed 79 people in Beijing. Climate change is likely to make such events more common. According to researchers at the Massachusetts Institute of Technology in Cambridge and Princeton University in New Jersey, hurricanes of magnitudes previously seen only about once a century could hit land every 3–20 years by the end of the century[1]. And, in 2013, researchers estimated that the global financial impact of flooding in coastal cities would increase from US$6 billion per year in 2005 to $52 billion by 2050 (ref. 2).

The threat climate change poses isn't so much new as it is an amplification of existing flooding hazards; those already vulnerable will find themselves more at risk. And with cities' high population density and often coastal locations — three-quarters of large cities are found on the coast — they represent a great accumulation of risk. More than half of the world's population already lives in cities and towns, and with the global urban population set to reach 5 billion by 2030, a single flood has the potential to affect millions of people's lives.

How climate change is likely to affect the risks posed to cities by flooding is a question that researchers, developers and city officials around the world are working to understand. Faced with the certainty of some degree of change, a few cities are already developing infrastructure to allow them to control excess water — and potentially even turn it into a resource.

RISING TIDES

Kristina Hill, an urban designer at the University of California, Berkeley, is more familiar than most with the impact that flooding can have on an urban area. She worked in New Orleans as part of the Dutch Dialogues — a Dutch–American collaboration that brought together engineers, architects and designers after New Orleans was ravaged by hurricane-induced flooding in August 2005 to ensure that the city would be better prepared in the future.

Hill is applying what she learned in New Orleans to the San Francisco Bay Area. Many parts of California are experiencing a historic drought, but she believes that in the near future coastal cities such as San Francisco will have to deal with flooding, caused not by falling rain, but by rising tides.

Sea level in the Bay Area is projected to rise by around 1 metre by the end of the century. This has the potential to overwhelm defences and inundate beach-side areas, but Hill is concerned about another, subtler effect of sea-level rise — water bubbling up from underground.

"One of the things most people have forgotten, which the Dutch pointed out to me," she says, "is the groundwater connection to seawater rise."

Seawater is constantly seeping inland, deep underground. Because of its greater density, the salty water tends to push underneath freshwater aquifers. The effect of this is that, when sea levels rise, the level of the fresh groundwater also moves up.

This higher water table is likely to exacerbate flooding from heavy rains, Hill explains. Just as an already sodden sponge is less effective at mopping up liquid, so the ground loses some of its ability to soak up water from the surface. But even without a storm, if sea levels rise high enough, the fresh groundwater will be pushed to the point at which it begins to leak into underground structures, or up through the surface. "We'll end up with lots of flooding driven by groundwater," says Hill.

The effect that sea-level rise could have on groundwater in the Hawaiian city of Honolulu could more than double the amount of flooding that the city will experience owing to inundation from the sea alone, researchers have suggested[3]. And, in Miami, Florida, people have reported groundwater bubbling up through their gardens at high tide.

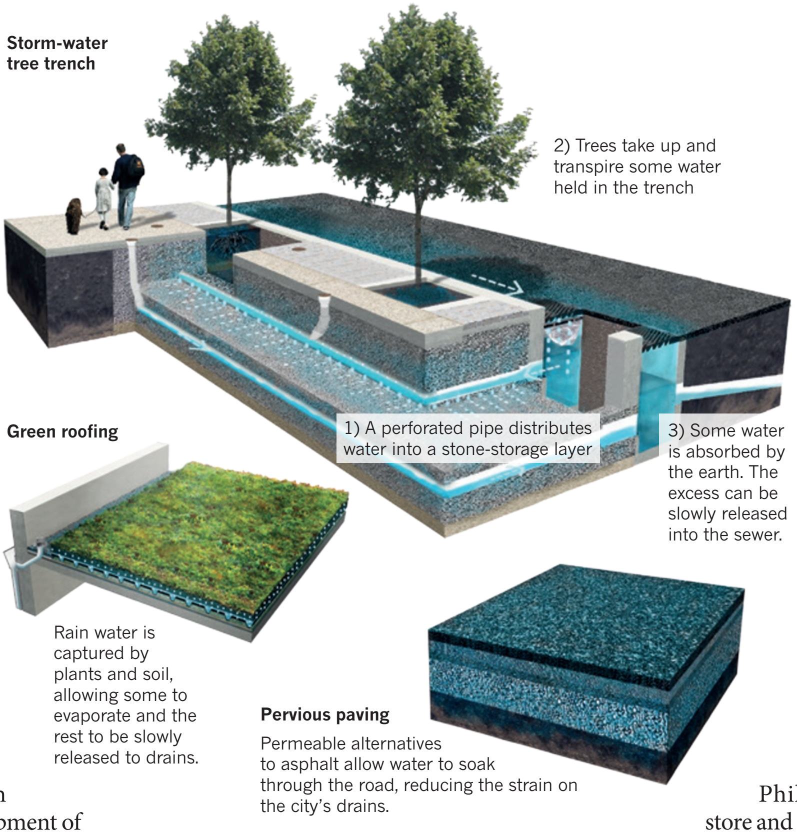
For Hill, the solution lies not in preventing sea-level rise, but in adapting to it. "We have to learn to live with our feet wet," she says. Waterproofing infrastructure such as the subterranean tunnels that carry essentials, including

PHILADELPHIA WATER

gas pipes, electrical lines and communications cables in many cities, is required to prevent the disruption of power and phone lines becoming a regular occurrence. Some infrastructure, Hill says, may need to be relocated away from low-lying ground entirely. But in the face of sea-level rise and ever more frequent storms, she is less than confident that everywhere will be able to cope. Some districts will be abandoned, at least temporarily, she says. "Cities like Miami, Honolulu, even parts of New York — Queens, Brooklyn, the Rockaways, Staten Island. There are definitely places that are not ready."

SPONGE CITIES

Conventional city drains can be overwhelmed by a sudden influx of storm water. In cities such as Philadelphia, technologies that allow the streets, pavements and roofs to soak up and store water and release it at a manageable rate are being used to reduce the burden on existing sewers.



CAPTURE AND CONTROL

An hour's drive from Berkeley, on the opposite side of San Francisco Bay, is Stanford University — one of the participants in ReNUWIt (Re-Inventing the Nation's Urban Water Infrastructure), a research group dedicated to the development of urban water management. Here, adaptation is the name of the game. Environmental engineer and director of the institute Richard Luthy is focused on how cities can control flooding, particularly that caused by storms.

Conventionally, cities have dealt with storm water by trying to get rid of it as fast as possible, says Luthy. "That means building these concrete channels and conduits that take the storm water to the bay or ocean as quick as we can," he says. If the rainfall is especially strong, however, the sudden volume of water can overwhelm these drainage systems and lead to flash flooding. Slowing down the flow of water through the system and diverting some away entirely can ease this problem — and possibly even turn troublesome storm water into a resource.

Luthy is working with the Californian cities of Sonoma and Los Angeles to improve their resilience to flooding by constructing storm-water reservoirs. Instead of immediately shunting water away down concrete waterways, these large basins will allow storm water to pool and collect.

As well as reducing storm-water-related damage, the reservoirs make it easier to harness the water as a resource. Vegetation planted in and around the reservoir purifies the water because the pollutants become trapped in the soil or the roots, and contaminants are taken up by tissues or even broken down into less harmful substances. The cleaner water can then be further purified and allowed to percolate into underground aquifers beneath the city, where it can serve as a drinking-water source during droughts. "We see storm water as an opportunity, not as a problem," said Luthy.

A number of cities are including plants and vegetation in water-management plans. Philadelphia's Green City, Clean Water programme, adopted in 2011, uses a variety of techniques to control storm water, including reservoirs like Luthy's. "There's dozens of technologies you can employ," said Chris Crockett, deputy commissioner of Philadelphia's water department.

One such tool is the tree trench: a deep ditch alongside the pavement, filled with absorbent fabrics, gravel and soil, and then planted with trees (see 'Sponge cities'). As well as adding a welcome dash of greenery to the urban environment (see page S56), the trench acts as an intermediary step between the storm drain and the sewer, using the same principles of slowing, capturing and purifying runoff to protect the city. The advantage, however, is that the tree trench can be installed in areas where a full-size reservoir could never fit, such as along busy streets.

Roads and streets are conventionally paved with materials such as asphalt or concrete, which are impervious to water and cause it to collect on the surface and flow into storm drains. But engineering can make a difference here too. Philadelphia is experimenting with pervious paving, which allows water to soak through a porous surface to stone reservoirs below, where it can be captured and stored.

Even the roofs of buildings can be used for flood-protection measures. Green roofs use plants and soil to capture and slow storm water, allowing much of it to evaporate before directing the filtered excess into the city's drainage system.

This drive towards newer, cleaner infrastructure to control flooding is not just a US phenomenon. Faced with drainage infrastructure that has not kept pace with rapid urbanization, the Chinese government approved the creation of 16 'sponge cities' in September 2015. These include parts of Chongqing, a city of nearly 10 million people. China hopes to use many of the same technologies being developed in California and Philadelphia, to quickly drain, store and recycle storm water.

Replacing and augmenting outdated sewerage systems and improving a city's resilience to flooding does not come cheap — China will spend about 400 million renminbi ($60 million) on each of its sponge cities per year for the next 3 years, and Philadelphia's programme will need about $2 billion to fund its entire 25-year programme. The price is worth it though, says Crockett. If sea levels rise and the city fails to adapt, it is predicted that annual flood losses could rise from $89 million in 2005 to more than $1 billion by 2050.

Through collaborations such as the C40 Cities Climate Leadership Group, a network of more than 80 cities around the world that together represent more than half a billion people, urban areas have led the way in taking steps to minimize and adapt to climate change. With half the population worldwide in the care of cities, how they adapt to a shifting climate will be crucial to future global health. As seas rise and weather patterns become more unstable, more cities may look to the experiments of Sonoma, Philadelphia and Chongqing for answers. ■

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