JULY 2021

Focused adaptation

A strategic approach to climate adaptation in cities

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C40 is a network of nearly 100 mayors of the world's leading cities who are working to deliver the urgent action needed right now to confront the climate crisis and create a future where everyone, everywhere can thrive. Mayors of C40 cities are committed to using a science-based and people-focused approach to help the world limit global heating to 1.5 degrees Celsius and build healthy, equitable, and resilient communities. Through a Global Green New Deal, mayors are working alongside a broad coalition of representatives from labor, business, the youth climate movement, and civil society to go further and faster than ever before. The current chair of C40 is Eric Garcetti, mayor of Los Angeles, and three-term mayor of New York City Michael R. Bloomberg serves as president of the board. C40's work is made possible by our three strategic funders: Bloomberg Philanthropies, Children's Investment Fund Foundation (CIFF), and Realdania.

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This report draws on joint research carried out by C40 Cities and McKinsey Sustainability. This work is independent, reflects the views of the authors, and has not been commissioned by any business, government, or other institution.

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Acknowledgments

The authors wish to thank the following people for their contributions to this article:

Joyce Coffee, Climate Resilience Consulting; Edith de Guzman, University of California, Los Angeles; Hans de Moel, IVM Institute for Environmental Studies; Victoria Gonsior, Freetown City Council; Rebecca Ilunga, C40 Cities; Lykke Leonardsen, City of Copenhagen; Rob McDonald, The Nature Conservancy; David McLeod, City of Toronto; Pedro Ribero, C40 Cities; Kurt Shickman, Global Cool Cities Alliance; Felix van Veldhoven, Climate Adaptation Services; and Regina Vetter, C40 Cities.

From McKinsey & Company: Jihane Belghiti, Scott Blackburn, Yolande Daeninck, Holger Harreis, Andrew Jackson, Kristen Jennings, Mekala Krishnan, Linda Liu, Erwann Michel-Kerjan, Cait Murphy, Dickon Pinner, Hamid Samandari, Humayun Tai, and Jonathan Woetzel.

Contents

Executive summary

Cities are on the front lines of the growing physical risks associated with climate change.[1] Urban areas are home to dense concentrations of people and are often located in places of particular climate risk, such as on coastlines, floodplains, and islands. Moreover, the built environment associated with cities can exacerbate climate impact. Given existing emissions, some climate change is already locked in, making these risks unavoidable. To protect the lives and livelihoods of urban residents, cities must improve their resilience.

Previous research has shown the risks of inaction. Among the possible consequences: hundreds of millions of people could suffer lethal heat waves in India, floods in Vietnam's Ho Chi Minh City could result in losses of billions of dollars, and homes in Florida could lose $30 billion to $80 billion in value.[2] The imperative is to adapt—and to start now.

Cities are complex, characterized by a wide variety of natural features, economic endowments, social conditions, institutions, and built environments. They also face different climate risks and have varying levels of vulnerability. Some adaptation options that are effective in most cities may not be feasible in others, given soil conditions, topography, elevation, power composition, age of buildings, and other factors. This complexity means that city leaders have a dizzying array of options for adaptation, making it difficult to set priorities and choose a course of action.

This report, written by C40 Cities and McKinsey Sustainability, examines adaptations that city leaders can consider as a starting point. Our research has identified a set of 15 high-potential actions that can work for many types of cities, based on their risk-reduction potential, cost, feasibility, and stakeholder complexity.

Four of the actions build systemic resilience, meaning they strengthen cities of all profiles. The other 11 are hazard specific, meaning they target particular physical climate risks (Exhibit E1). Several of the solutions address both risk reduction and decarbonization. This list is not a definitive directory of actions that all cities should take, but we hope it is a useful guide to help leaders address the climate risks facing their cities.

The 15 high-potential actions range from infrastructure actions such as flood- and storm-resilience measures for buildings in coastal, flood-prone geographies to behavioral actions such as encouraging water conservation during droughts. Looking at these actions as a whole, leaders will notice that several themes emerge.

First, nature-based solutions—such as planting street trees, managing river catchment, using nature-based sustainable urban drainage solutions, and creating coastal nature-based barriers—are among the most attractive actions in terms of both their impact on reducing risks and their feasibility. Nature-based actions can build resilience across all five hazards addressed in this report; in three of the five hazards, nature-based actions are the most attractive options. In addition, they often have benefits beyond adaptation in areas such as decarbonization, health, and economic growth.[3]

Second, cities should invest in actions that increase resilience systemically, in addition to adapting to specific and immediate hazards. Systemic resilience includes increasing awareness of physical climate risks, incorporating risk assessment into city processes, optimizing emergency response, and enhancing financial and insurance programs. Within each of these four categories, all cities, regardless of risk profile, should consider the following categories of action: performing risk assessments, incorporating climate risk into planning, building early-warning systems, and increasing access to affordable hazard insurance.

Finally, this report is a call to action—focused action. Climate adaptation is one of many competing priorities, and urban resources are limited. In a study of climate funds raised by developed countries for developing countries from 2013 to 2018, the Organisation for Economic Co-operation and Development (OECD) found that in 2018, only 21 percent of funding went to climate adaptation and resilience.[4] By identifying the most effective and feasible actions, cities can focus on executing them well and build momentum to do more.

The effects of climate change are already measurable.[5] Furthermore, decarbonization efforts are not on track to meet the global consensus goal of limiting the rise in temperature to no more than 2 degrees Celsius—let alone the more ideal goal of 1.5 degrees Celsius.[6] This report provides critical guidance to help cities play an important role in making swifter, surer progress in adapting to climate change.

Exhibit E1

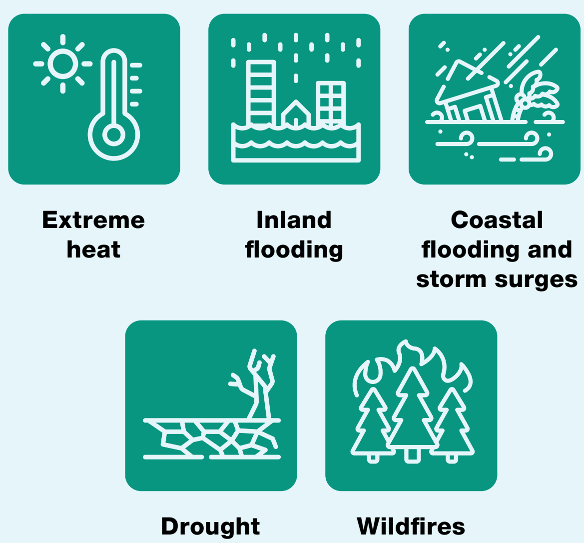
To be successful, city-adaption plans should include two types of actions.

Systemic-resilience actions

Actions that increase the adaptive capacity of a city, regardless of the hazard exposure(s) the city might face

Hazard-specific actions

Actions that reduce the impact of a specific hazard or enhance a city's ability to recover from that hazard



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1 Introduction

Why cities are at risk from climate change—and how adaptation can help

More than half of the world's people live in urban areas, and that figure is projected to rise to 68 percent by 2050.[7] Cities are vulnerable to climate-related risks because the built environment can exacerbate climate hazards, and climate hazards can put pressure on urban systems. Buildings and roads, for example, absorb and re-emit the sun's heat, causing what is known as the urban heat-island effect. Poorly planned infrastructure, such as paved-over streams, can interfere with water drainage.

Moreover, modern urban infrastructure and its operating systems are closely connected. A failure in one part of a network can affect another part, multiplying the damage. Flooded roads, for example, can damage links to public transport. Storm surges and extreme heat can lead to power outages that knock out technology systems critical to homes, hospitals, and industries. To build climate resilience, leaders need to understand these connections.

Cities are already experiencing debilitating natural disasters. In 2018, Cape Town, South Africa, almost ran out of water.[8] During a 2019 heat wave, Patna, Gaya, Bhagalpur, and other cities in eastern India experienced hundreds of fatalities and daytime outdoor work was banned.[9] In January 2020, flooding in Jakarta killed 66 people and displaced more than 36,000.[10]

A 2018 UN report found that from 1998 to 2017, climate-related and geophysical disasters caused 1.3 million fatalities and incurred $2.9 trillion in economic losses globally.[11] Climate-related disasters accounted for more than three-quarters of the damage.

The risk is that climate change could increase the severity and frequency of hazards such as extreme heat, coastal flooding, drought, wildfires, and tropical cyclones.[12] More than 90 percent of all urban areas are coastal; by 2050, more than 800 million urban residents will be affected by sea-level rise and coastal flooding.[13] In addition, 1.6 billion could be vulnerable to chronic extreme heat (up from 200 million today), and 650 million could face water scarcity.[14] These risks are why cities must invest in adaptation as well as mitigation.

Adaptation is particularly important for protecting vulnerable populations, such as low-income communities, people with disabilities, children, some minority groups, women, and the elderly. Members of these groups may be at higher risk for climate-related damage. For example, continued rapid urbanization and, in some geographies, the emergence of climate risks outside of cities are leading to increased populations in informal settlements.[15] These areas often lack the resources and adaptive capacity to withstand major events, such as floods or extreme heat.[16]

The Global Commission on Adaptation estimates that climate change could push an additional 100 million people in developing countries below the poverty line by 2030.[17]

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Exhibit 1

Climate change could directly increase the severity and frequency of natural hazards.

Extreme heat	1.5°–5.0°	Range of expected average local temperature increase by 2050, relative to today (°C)[1]
Inland flooding	4x	Increase in some regions, in likelihood of extreme precipitation events (defined as a once-in-a-50-year event) compared with the period 1950–81[1]
Coastal flooding and storm surges	12–60 inches	Range of expected sea-level rise by 2100, which will lead to significantly more coastal flooding[2]
Drought	~66%	Percentage of world population that could be under water-stressed conditions by 2025 without substantive mitigation and adaptation actions[3]
Wildfires	2x–6x	Estimated increase in the annual area burned by wildfires in the western United States by 2050[4]

[1] Our Climate Risk and Response research estimates the inherent risk from climate change without adaptation and mitigation to size the potential impact and highlight the case for action. Our estimates use the Representative Concentration Pathway (RCP) 8.5 scenario of greenhouse-gas concentration because the higher-emission scenario it portrays enables us to assess physical risk in the absence of further decarbonization. *McKinsey Climate Risk and Response report.*
[2] *Coastal flooding, climate change, and your health: What you can do to prepare*, Centers for Disease Control and Prevention, November 2017, cdc.gov.
[3] *The future we don't want: How climate change could impact the world's greatest cities*, C40 Cities, February 2018, c40.org.
[4] *Fourth National Climate Assessment*, U.S. Global Change Research Program, 2018, nca2018.globalchange.gov.

What to do: The role of adaptation

Climate risk directly affects people (livability, health, workability), assets (hospitals, homes, businesses), and services (energy, food supply). To respond to these risks, cities need to build comprehensive strategies for climate adaptation and mitigation.[18]

Designing and implementing an adaptation agenda requires a variety of capabilities. Cities must have the technical expertise to assess the hazards, prioritize the risks, and quantify the costs and the potential for risk reduction. They must also understand the extent of their jurisdictional powers and the connections among the health, energy, food, water, drainage, sanitation, security, and transportation systems.

For example, cities may not have direct authority over privately owned water or electric utilities or transportation companies. They will therefore need to coordinate with partners, within and beyond government, to build resilience. (Two previous C40 Cities reports explored these topics.)[19]

In building an adaptation agenda, cities need to not only anticipate the multifaceted, decentralized, and unequal consequences of physical climate hazards but also choose among hundreds of possible actions. To manage this complexity, cities should concentrate on actions that play to their strengths—in terms of resources, physical features and assets, and jurisdictional control—while offering a high return in terms of risk reduction.

Identifying such high-impact adaptations can be daunting, given the steadily developing nature of the climate threat and many cities' lack of capacity. At the same time, it is also important to remember the possible upsides: adaptation can bring wider benefits that can complement other priorities, such as improvements to infrastructure, equity, and public health.[20] In this report, we present a starting list of adaptation actions for cities to consider.

Scope of report

This report has two parts: "How cities can adapt: Recommended priority actions" and "The pathway to successful implementation."

Part 1 considers both systemic-resilience and hazard-specific actions. Systemic-resilience actions reduce risks and increase adaptive capacity. Hazard-specific actions reduce the impact of a particular problem or enhance a city's ability to recover from it.

For both types of action, we describe high-potential approaches that could work in most cities. Local conditions differ in many ways—in topography, soil type, access to water, jurisdiction, and finances, to name a few—and climate-change risks manifest in different ways. Therefore, local knowledge is critical in determining priorities.

The actions considered in this analysis were chosen on the basis of three main sources: C40 Cities and McKinsey analysis, consultations with city leaders and adaptation experts, and an extensive literature review.

After compiling the list of actions, we divided them into categories—first into systemic versus hazard-specific, and then into subcategories for each (Exhibit 2). For each action, we assessed both its potential to reduce risk and its feasibility—that is, the financial and institutional resources required to take a given action, together with the level of stakeholder complexity. To evaluate these factors, we conducted analyses that were both quantitative (such as cost-benefit ratios for past projects) and qualitative (expert evaluation of stakeholder complexity required for implementation).

For example, we looked at cost-benefit analyses published in case studies and peer-reviewed research. The US Federal Emergency Management Agency (FEMA) evaluated $3.5 billion in mitigation grants disbursed from 1993 to 2003. It found an average cost-benefit ratio of 1:4 for flood, earthquake, and wind-hardening grants.[21] We also collected quantitative case examples, including one about actions to reduce flood risk in Rotterdam.[22] In this study, the authors measured the expected annual damage to residential buildings across a variety of damage-reducing actions, such as implementing warning systems (which reduced damage by 16 percent), wetproofing buildings (40 percent), and elevating buildings (83 percent when elevated 50 centimeters). We then worked with adaptation experts and city experts to use these findings to score each action on a scale of 1 to 5, with 5 being the most promising (see Appendix 1 for more detail on the methodology).

To examine how cities might differ in their adaptation approaches, we grouped them into typologies with similar characteristics, including financial capacity, institutional power, and the built environment (see Appendix 2). High-potential actions are primarily the same across typologies. This finding strengthened our belief that most cities should consider a similar set of high-impact actions as part of their adaptation plans.

Part 2 of the report describes, in broad terms, how cities can implement these actions. We recommend that cities begin by defining the hazards most relevant to their circumstances and by understanding the risks these hazards pose to people and assets. On that basis, cities can then conduct detailed analyses of the risk-reduction impact, costs, and feasibility of different actions. Principles such as governance and monitoring are part of any city planning process and are a crucial component of every action listed.

This report is intended as a starting point to help cities develop an agenda for adaptation. Leaders will need to go deeper, addressing issues such as social-equity implications and accounting for costs and benefits. Critically, our assessment did not consider vulnerability, defined as the likelihood and magnitude of actual harm from a specific hazard and related to the local context; a city therefore needs to understand its own vulnerabilities when designing an adaptation agenda.

Exhibit 2

A city's adaptation plan should consider the following high-impact actions.

Four high-potential systemic-resilience actions

- **Risk assessment: hazard maps, impact assessment, and spatial analysis**
- **Incorporating climate risk into urban planning**
- **Early-warning systems and protocols**
- **Climate insurance provision and alignment**

High-potential actions for each of five hazard types

(leaf) Nature-based solution

Extreme heat	Inland flooding	Coastal flooding and storm surges	Drought	Wildfires
(leaf) Street trees	(leaf) River-catchment management	(leaf) Coastal nature-based barriers	Water-conservation behavior programs	Development planning
Cool surfaces	(leaf) Nature-based sustainable urban drainage solutions (SUDS)	Coastal artificial barriers	Water-system efficiency	Preventive forestry management
		Flood- and storm-resilient buildings		

2 can adapt

High-potential actions

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A successful city-adaptation plan includes both systemic-resilience and hazard-specific actions. This report focuses on helping cities determine which will be most effective, given their circumstances; it can be seen as an element in their climate-action-planning (CAP) process.

Systemic-resilience actions

Actions that build systemic resilience fall into four categories. In the following discussion, we define the categories and identify the high-potential action for each. Intergovernmental coordination plays a crucial role in many of these actions, which can present a challenge for cities with high stakeholder complexity.

Increasing awareness

To start, cities need to understand their own risk profiles. Then they can work to educate their citizens on the risks and on what can be done to improve resilience.

Risk assessment: Hazard maps, impact assessment, and spatial analysis. Solving any problem starts with understanding it. Risk assessments play a key role in helping cities understand their distinctive challenges; location-specific hazard maps, part of the risk-assessment process, are an essential component of CAPs. These maps can help cities make informed adaptation decisions by identifying the potential risks associated with specific hazards, such as extreme heat or flooding, over a given timeframe and within a certain geographic area. A city may also choose to model multiple scenarios, forecast over a period of time. Hazard maps should identify who and what is at risk, where, and to what extent. Quezon City in the Philippines, for example, has compiled a City Risk Atlas that provides a comprehensive analysis of flood risk down to the neighborhood level.[23] Cities can work with partners such as academic institutions or specialized researchers when creating hazard maps.

The risk-reduction value of hazard maps is well established. The US Association of State Floodplain Managers estimated in 2013 that updated national hazard maps have guided policies that saved more than $1 billion a year in flood damages.[24] To be effective, hazard maps must be updated regularly and incorporated into decision making.[25] Developing a comprehensive risk assessment to inform climate-action planning requires access to a large body of climate, spatial, and infrastructure data, and to systems for analyzing these data.

Incorporating risk

These processes include development planning, investment business cases, and maintenance plans for critical systems.

Incorporating climate risk into urban planning. Cities need to account specifically for climate change in their approaches to urban planning, decision making, and standards. This scope includes building redundant and diversified critical systems, integrating climate risk into utility-budgeting processes (in cities where this is a municipal responsibility), and developing systems for rating the resilience of infrastructure. Accounting for risk in existing systems can enable a city to encourage the private sector to invest in resilience. Rebates can provide incentives for homeowners and others to invest in physical adaptations such as flood- and fireproofing. Incorporating risk in urban planning can also have a high ROI. An analysis of $3.5 billion in FEMA hazard-mitigation grants from 1993 to 2003 found that the risk-reduction benefits outweighed the costs by a factor of four.[26]

One low-cost way to incorporate physical climate risk into urban planning is to limit building in risk-prone areas such as floodplains; this approach can reduce future damage and save lives. Well-considered zoning rules can also foster social equity. In rapidly urbanizing areas, low-income households and informal settlements are more likely to be located in high-risk and exposed areas.[27] Buyouts and resettlements may be necessary in some circumstances; these can have significant implications for community disruption and equity. Planning and zoning measures, when done in an inclusive manner, provide an opportunity to address such inequities.

While zoning and urban planning are not inherently expensive—studies have shown the benefits in terms of risk reduction can be as much as eight times the cost[28]—they are complex in terms of stakeholder management. To shape development, cities need to be able to make trade-offs, enforce restrictions, and collaborate with landowners and developers.

One example of incorporating resilience into planning: the Canadian city of Toronto is developing a “climate lens” to inform its decision making. Once fully implemented, this lens will ensure that all proposed projects and initiatives requiring budget approval are assessed in advance for their effect on greenhouse-gas (GHG) emissions and climate resilience.

In rapidly urbanizing areas, low-income households and informal settlements are more likely to be located in high-risk and exposed areas.

Optimizing response

Given the likelihood that climate events will increase in both number and severity, cities need to be ready. Fast and effective responses save time, money, and lives.

Early-warning systems and protocols alert city leaders and residents that extreme weather events may be on the way so that they can prepare for them. Such warnings are critical for protecting people and assets, and they can take a variety of forms, from digital messaging and broadcasts to putting signs on the backs of rickshaws, as the Indian city of Ahmedabad does.[29] According to the Global Commission on Adaptation, even a single day's notice can reduce damage from natural disasters by 30 percent.[30] Investing $800 million in early-warning systems in developing countries could avoid losses of $3 billion to $16 billion per year.[31] Significant investments are already being made: from 2015 to 2019, the World Bank and its partners spent more than $200 million on the Climate Risk Early Warning Systems Initiative,[32] and the United Nations Development Program is doing something similar, mainly in Africa and Asia.[33]

City governments can integrate these emergency protocols into planning and operations while ensuring that their most vulnerable residents are protected. Hong Kong has developed an information service and mobile app to provide early-warning and family-location services to protect older people from heat stress.[34] When Hurricane Mitch bore down on Honduras in 1998, no one died in the city of La Masica, largely because the city's disaster agency had an early-warning service and an emergency-management system that monitored the situation.[35]

Enhancing financing programs

Finance is a critical part of creating climate resilience; not only can it be used to create incentives to improve mitigation and adaptation policies, but it can also help cities bounce back faster after disasters.

Climate insurance that is appropriately priced and widely available can help people and cities to absorb the financial impact of climate change. Insurance does not reduce the risk of climate damage, but it can help victims to bounce back faster by reducing financial shocks. Insurance can also signal risk levels to individuals and businesses. Charging higher rates to build on flood-prone land, for example, can reduce the incentive to develop there. According to German insurer Munich Re, insurance companies have paid more than $1.5 trillion in natural-disaster claims since 1980.[36]

Current premium levels and insurer-capitalization levels may need to be reconsidered to account for shifting risks. Moreover, increased risk levels and inefficient pricing may price low-income households out of flood insurance and other needed policies. Cities often have a limited role in supporting increased adoption of natural-disaster insurance, but they can bring their influence to bear by educating citizens, promoting accessibility, and building public–private partnerships to create standards and business models.

Hazard-specific actions

These actions are designed to reduce the damage caused by a specific hazard or enhance a city's ability to rebuild after a disaster.

Local conditions will play a role in the choices cities make. For example, to increase resilience to heat, cities in arid climates need to assess water availability when considering nature-based solutions. A city's density also matters; some simply don't have the land to build sizable parks and may need to opt for microparks and tree planting.

To a large extent, financial and institutional capacity and stakeholder complexity will determine which actions are feasible. Cities with strong institutional capacity have a wider range of choices. For example, effective source-water management requires cities to have jurisdiction over the access and use of source water. Those with limited institutional powers will find it more difficult to act.

In what follows, we describe specific hazards—heat, inland flooding, coastal flooding and storm surges, drought, and wildfires—and then detail the two highest-potential actions for each.

Insurance does not reduce the risk of climate damage, but it can help victims to bounce back faster by reducing financial shocks.

Public–private partnerships such as Flood Re, a temporary flood-insurance program in the United Kingdom, can support homeowners by reducing financial risk and insurance costs. Flood Re wrote 150,000 policies in 2018. Of these, four out of five households saw more than a 50 percent price reduction in flood insurance compared with 2017.[1] Premiums are based on tax bands, with financial support available for those who need it. The long-term goal is to transition Flood Re to a fully private program once premiums are appropriately priced to reflect risk.

Public entities can support efficient and affordable climate-insurance programs if there is close collaboration between city and national governments. If used strategically, insurance can motivate both cities and people to invest in resilience actions that decrease climate risks and therefore insurance premiums. However, it may be less useful for smaller cities and those with limited financial resources.

1 *Annual report and financial statements,* Flood Re, 2018, floodre.co.uk.

Heat

Figure 1

These high-potential actions reduce extreme heat.

Street trees

Planting trees and local species reduces heat at street level

Cool surface treatments

Solar-reflective 'cool' pavements mitigate urban heat-island effects

Cool surface treatments

'Cool' roofs reduce conduction of heat into the building, convection of heat into the outside air, and thermal radiation of heat into the atmosphere

Today, more than 350 major cities experience average summertime temperature highs of 35 degrees Celsius or more. By 2050, that number could expand to 970 cities—home to 1.6 billion people.[37] Climate change is increasing the likelihood of extreme heat waves, typically defined as wet-bulb temperatures above 35 degrees Celsius—which can be fatal even for healthy people who are resting in the shade.[38] A recent McKinsey analysis of projected physical-climate risk found that as soon as 2030, 160 million to 200 million people could face a higher risk of suffering a lethal heat wave in any given year.[39] There are also real economic costs. According to the *Lancet*, a medical journal, 302 billion work hours were lost globally due to extreme heat in 2019.[40]

Extreme heat is not only a threat for cities where high temperatures are common. It can also affect more temperate places, which may not be prepared for very hot days and will suffer as a result; extreme heat in such places can cause outcomes for individuals that range from discomfort to death.[41] Heat is particularly difficult for those with less financial resources because they are less able to cool their housing with fans or air conditioners, and they often work outdoors.

Two high-potential actions are planting street trees and installing cool surface treatments.

Street trees and other small green environments reduce air and surface temperatures. Larger green spaces such as parks have a similar impact, but they are more costly to build and maintain. Planting street trees is a more feasible way to mitigate urban heat islands in many dense, land-scarce cities.

In 2016, for example, the city of Medellín, Colombia, launched the Corredores Verdes (Green Corridors) project to create a network of greenery across the city. Over three years, the city planted 8,800 trees and palms, helping to reduce the average city temperature by 2 degrees Celsius.[42] Similarly, in 2017, Barcelona kicked off the Master Plan for Barcelona's Trees to minimize the urban-heat-island effect by increasing the tree canopy from 5 percent to 30 percent by 2037.[43]

In addition to improving urban aesthetics, planting street trees can help reduce peak summer temperatures[44] and reduce surface heat by up to 15 degrees Celsius.[45] Street trees often don't cost much to plant, but they require upkeep. Even so, one study found $1.50 to $3.00 in risk reduction for every dollar spent.[46]

Local climate and soil conditions and development density are important considerations. For example, street trees might not be the best option for cities in arid climates.

Moreover, cities will have to consider local economic realities and the potential severity of heat. Urban areas facing extreme and potentially lethal heat risks with low air-conditioner penetration or potential energy-grid vulnerabilities might instead establish cooling centers where people can take refuge during heat waves.

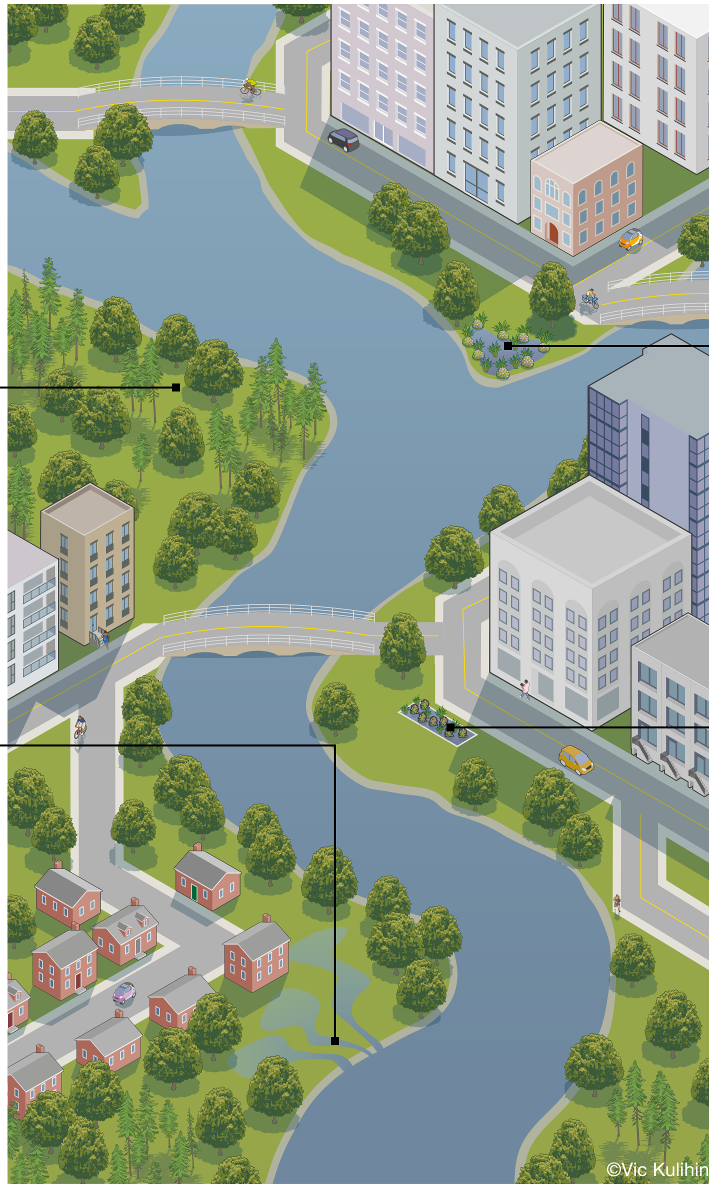
Cool surface treatments, such as applying white paint to roofs, walls, and pavements, can help reduce urban heat islands by adapting surfaces to reflect sunlight and absorb less heat. A 2014 study found that widespread implementation of cool roofs could reduce maximum daytime temperatures by up to 1.8 degrees Celsius in American cities such as Washington, DC.[47] Cool pavements can have even greater effects.[48] When Tokyo used thermal-barrier coating as part of road maintenance and construction, it reduced surface temperatures by at most 8 degrees Celsius compared with regular asphalt pavements.[49] Cool surface treatments will not have the same effects everywhere, and leaders must consider the shape and structure of their cities' roofs and pavements to assess the feasibility of installation.

Several cities have implemented cool-roof plans in recent years. When the Mercamadrid fish market in Madrid, Spain, installed a waterproof, solar-reflective roof with a white painted coating, temperatures inside the building fell by 7 degrees Celsius. In Seoul, the city government installed light-painted cool roofs on energy-poor homes in an effort to reduce rooftop temperatures by 10 degrees Celsius and indoor temperatures by 2–3 degrees Celsius.[50] Since 2017, Ahmedabad has installed 3,000 cool roofs in low-income homes as part of its heat-action plan.[51] Such efforts can be cost-effective. Cool roofs in California provide a net savings in energy costs of about 50 cents per square foot compared with traditional roofing materials.[52]

Inland flooding

Figure 2

These high-potential actions reduce inland flooding.



Inland flooding has two sources—rivers and extreme precipitation. Both can overwhelm urban drainage systems and cause other infrastructure damage.[53] By 2030, riverine flooding could affect 132 million people—compared with 65 million people today—and cause $535 billion in urban property each year.[54]

The best way to manage inland and urban flooding depends on a city's unique conditions. Cities with clay soil, for example, may not want to rely on solutions that increase infiltration into the ground. Topography also plays a role. Hilly cities, for instance, should account for their increased risk for landslides in choosing solutions.

Adapting critical infrastructure, such as energy and public transportation, can significantly reduce the impact of inland flooding. But the effort will require significant institutional power and stakeholder-management skills.

To reduce the risks of inland and associated urban flooding, two actions emerge as broadly applicable: river-catchment management and nature-based sustainable urban drainage solutions (SUDS).

River-catchment management refers to an approach that looks at the watershed as a whole—upstream, downstream, and the entire urban water cycle. It also promotes the development of natural ecosystems and river flow. It includes river-basin plans, infiltrating and retaining water in upper catchment, renaturalization of water bodies, and buffer protections—actions with significant potential to reduce risk. For example, reforestation with indigenous trees and shrubs along river embankments can reduce the runoff entering rivers, thereby alleviating the risk of flooding downstream.

Another option is to focus on downstream river management through strategies such as improving drainage along river banks. Still in the design phase, the eThekwini Transformative River Management Programme near Durban, South Africa, aims to manage the 7,400 kilometers of rivers and streams in the municipality to improve water quality and stem flooding.[55]

Catchment management involves many stakeholders, including scientists, policy makers, planners, nongovernmental organizations (NGOs), and residents. Given the effectiveness of catchment management in reducing flood risk, its potential for risk reduction is likely to outweigh the costs for many cities exposed to this hazard.

Nature-based sustainable urban drainage solutions (SUDS) use natural resources, such as soil, rocks, and slopes, to optimize water absorption and infiltration and reduce the use of concrete. Mimicking natural water-drainage systems, SUDS reduce the risk of inland flooding while also improving water quality. When Ramsey County in Minnesota built a range of SUDS solutions in 2014, including rain gardens, underground infiltration trenches, underground storage, and infiltration systems, stormwater runoff was nearly eliminated. And the cost was an estimated 20 percent lower than the comparable human-made engineering solutions.[56]

Copenhagen's Cloudburst Management Plan, which is designed to protect the city against floodwaters, found that SUDS-oriented solutions (known as the "blue-green approach") worked just as well as traditional solutions and cost half as much.[57] The city also experienced additional benefits in the form of improved health and a more pleasant urban environment.

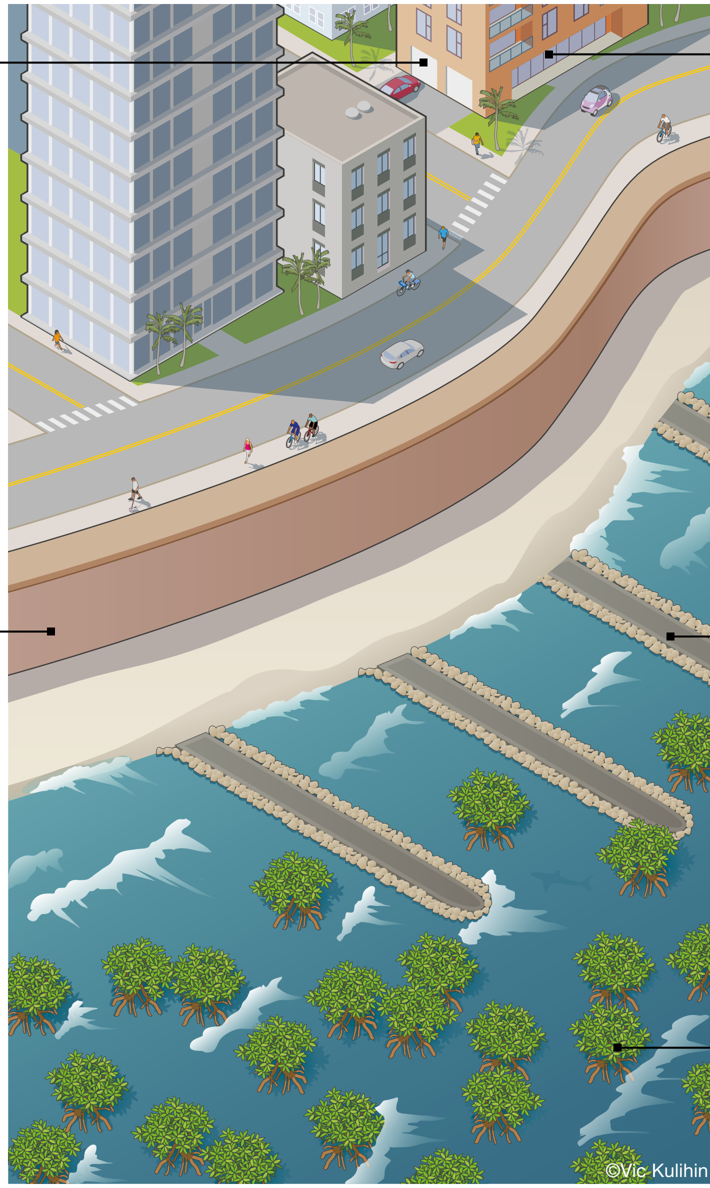
Bishan-Ang Mo Kio Park, a 62-hectare park in central Singapore, shows the possibilities of SUDS techniques. First opened in 1988, the park was defined by a 2.7-kilometer concrete canal that ran along its southern border. The canal often overflowed, flooding nearby roads. Beginning in 2009, Singapore "de-concretized," or renaturalized, the canal, converting it into a meandering, three-kilometer-long river. The river is not only more beautiful but also provides better drainage and water quality, reducing the risk of flooding.[58] Even the local wildlife approves. The new waterway has brought more biodiversity, including otters and a wide variety of birds.

While SUDS are promising, they are highly site-specific, and their success varies. Across 23 studies of bioretention systems, the effectiveness of SUDS in reducing stormwater runoff ranged from 5 percent to nearly 100 percent.[59] For SUDS solutions to work well, regular maintenance is required to maintain drainage and water quality.

Coastal flooding and storm surges

Figure 3

These high-potential actions mitigate coastal flooding and storm surges.



Investing in flood- and storm-resilient buildings

Building features such as dry-proofing and wet-proofing reduce flood damage; wet-proofing reduces interior damage by designing basements with flood openings and moving critical equipment such as boilers to upper floors

Investing in flood- and storm-resilient buildings

Elevated buildings are less likely to be damaged by flooding

Coastal artificial barriers

Seawalls, in addition to barriers such as floodgates, breakwaters, sandbags, and revetments, prevent flooding

Coastal artificial barriers

Groynes are human-made structures that interrupt waves, thereby reducing sediment erosion

Nature-based solutions

Mangroves restoration

By 2050, more than 800 million urban residents could be at risk from rising seas and storm surges in the 570 low-lying coastal cities that are at highest risk of sea-level rises of at least 0.5 meters.[60] Global economic costs from rising seas and inland flooding could amount to $1 trillion a year by 2050.[61]

In addition, major storms such as hurricanes, tornadoes, and high winds are becoming stronger and more frequent, damaging the urban landscape and infrastructure and carrying high costs. In 2017, hurricanes Harvey, Irma, and Maria caused a combined $265 billion in damage in just four weeks.[62]

The highest-priority actions to adapt to coastal flooding and storm surges are building barriers (both natural and artificial) and investing in flood- and storm-resilient buildings.

Coastal nature-based barriers such as wetlands and mangrove habitats restored to their natural physical, chemical, and biological characteristics can reduce the risks of large-scale flooding because the barriers store water, stabilize sediment, prevent erosion, and reduce wave height.[63]

In 2015, Colombo, the capital of Sri Lanka, launched a restoration of 2,000 hectares of wetlands as part of a World Bank–funded flood-control-management program that could benefit up to 2.5 million people.[64] Wetland restoration is not only relevant for tropical environments. During Hurricane Sandy, which hit the northeastern United States in 2012, existing wetlands helped prevent an estimated $625 million in property damage.[65] Indeed, US coastal wetlands provide storm protection worth an estimated $23.2 billion per year.[66]

Mangroves can reduce the height of nonstorm waves by 13 to 66 percent,[67] and mangrove restoration could reduce the impact of annual flooding on more than 18 million people.[68] Mangroves reduce flood risk by reducing wind and swell-wave energy as they move through roots and branches, thereby reducing height and energy of waves, and also by preventing erosion and thereby the rise of sea levels relative to land height. Finally, mangroves support a rich diversity of fish, animal, and plant life. Without mangroves, 39 percent more people would experience flooding every year, and flood damages would be some $82 billion higher.[69]

Local conditions dictate the selection of nature-based coastal-barriers solutions. Only cities with natural mangroves, for example, can undertake mangrove restoration. Beach-erosion solutions are relevant only for cities with an established beachfront.

Wetland restoration is highly affordable and does not require much investment in infrastructure, but ecological complexity makes it difficult.[70] There are many different types of wetlands, from high tidal zones to lagoons. Elements such as sediment and plants can be native and beneficial in one location but invasive in another. Getting restoration right requires detailed knowledge of coastal ecosystems.

Coastal artificial barriers such as floodgates, seawalls, breakwaters, sandbags, revetments, levees, and sea dikes can reduce the risks of coastal flooding and erosion by blocking tidal floods and storm surges. Artificial barriers have varying potential for risk reduction, but substantial impact has been demonstrated.[71] Research from the World Resources Institute found that every $1 spent on dike infrastructure in Bangladesh could save $123 in urban property damage.[72]

Installing floodgates and optimizing stormwater and sewage systems can be challenging, in part because they require significant policy making, engineering, and environmental-management knowledge and experience. In the Philippines, more than 6,300 people died in Typhoon Yolanda in 2013.[73] After Yolanda, the Department of Public Works and Highways announced the construction of a 27.3-kilometer barrier—dubbed the Great Wall of Leyte—at a cost of 9.6 billion Philippine pesos (approximately $198 million) to protect coastal communities from violent storm surges.[74] But many of the 10,000 residents tapped for relocation opposed the development, in part because they had concerns about the new housing.[75] This example highlights why city leaders who choose engineering solutions that have socioeconomic implications, such as relocation, must carefully consider the impact on citizens who are affected and ensure they are consulted, early and often.

Investing in flood- and storm-resilient buildings can significantly reduce the damage caused by storm surges and coastal flooding. This action involves developing flood- and storm-resilient building standards, including climate resilience in land-use planning, and incorporating solutions such as using reinforced concrete and installing impact-resistant windows, doors, and concrete masonry walls.

Retrofitting public infrastructure is expensive but can yield high returns. According to the US National Institute of Building Sciences, building retrofits related to wind can create $6 in value for every $1 spent.[76] The cost of implementing protective measures in New York's wastewater infrastructure is estimated at $315 million, but the cumulative risk avoided over 50 years is estimated to be worth $2.5 billion.[77]

Higher building standards can also bring a positive return on investment. An Australian study estimated that higher building standards in residential buildings could reduce risk by 50–80 percent in Brisbane, Sydney, and Melbourne,[78] at a cost of about 1 percent of house-replacement value.[79]

The NYC Resiliency Design Guidelines provide step-by-step instructions for going beyond building codes and standards. The guidelines incorporate both historical and projected climate data for use in the design of city facilities.[80] Using analysis of their vulnerability to flooding (based on FEMA maps), Austin, New York, and other cities have also developed guides to help residents retrofit their homes and buildings. Mandatory resilience standards, particularly for residential housing, has complicated social-equity implications, which should be considered before creating such policies.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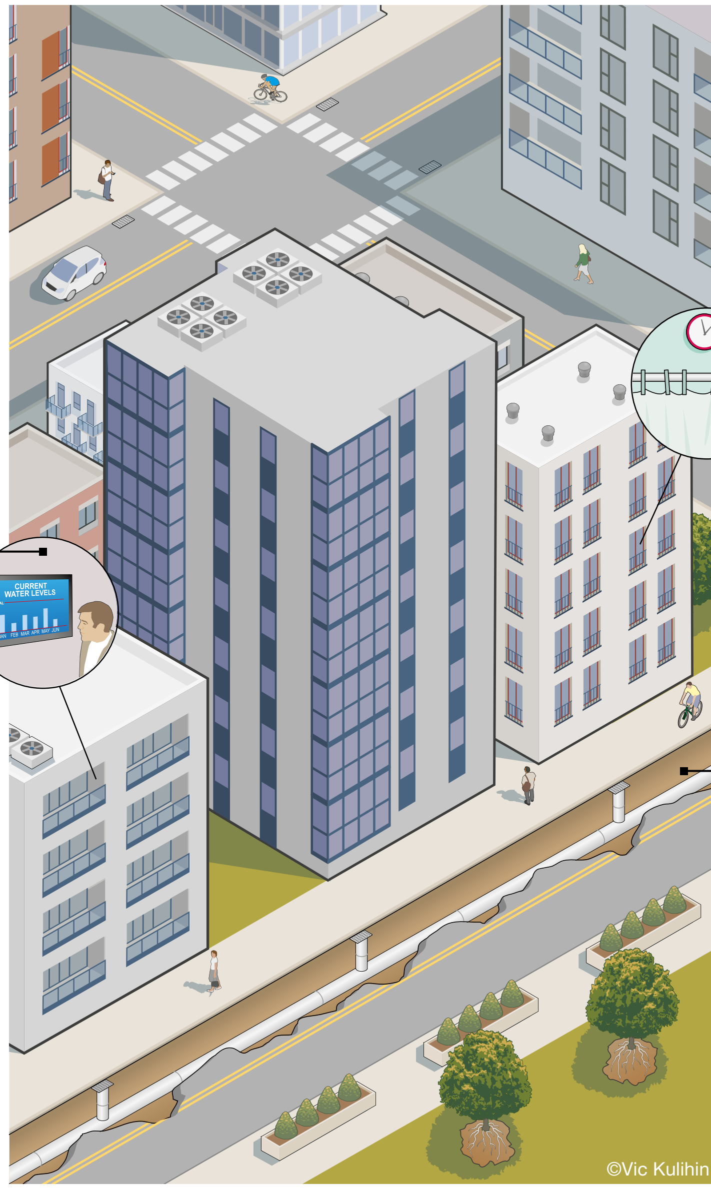
Drought

Figure 4

These high-potential actions address drought.



By 2050, 685 million people in more than 570 cities could face a 10 percent decline in availability of fresh water due to climate change. Some cities, such as Amman, Jordan; Cape Town, South Africa; and Melbourne, Australia, could experience much larger declines (30–49 percent), and Santiago, Chile, could face a decline of more than 50 percent.[81]

One limiting factor in adapting to drought is the level of authority cities have over land and water use. Some may have difficulty reducing groundwater usage if most of the withdrawal is going to private land outside the city limits. A city with significant authority over water management has access to more tools within its formal mandate. Cities with strong stakeholder-management capacity can consider adaptations that require the participation of a significant number of functions, such as water-demand management or upstream-river-water management.

Two key actions take priority in addressing diminishing water availability: behavioral-change programs related to water conservation and efficiency improvements.

Behavioral-change programs seek to educate people about their water usage and prompt them to reduce consumption. During the 2017–18 water crisis, Cape Town introduced a campaign to encourage residents to make behavioral changes and avoid "day zero," the day the city would run out of water.[82] The campaign communicated that day zero was a real possibility; sponsored positive activities, such as school competitions to lower water use; and used a series of nudges, such as promoting two-minute songs to sing in the shower, to prompt behavior change.[83] Cape Town successfully reduced water use by more than 50 percent from 2015 to 2018, with residential water usage declining significantly.[84]

Behavioral-change programs are generally low-cost because they require no new physical infrastructure, and they can have significant impact. One such program in the southern United States cost just 37 cents per 1,000 gallons saved.[85] These programs require a fair degree of stakeholder management because they need to be clearly defined, imaginatively devised, and well communicated to be effective. At least at first, directing these programs to people who consume the most water makes the most sense in terms of practicality and social equity.

Efficiency improvements. "Nonrevenue water"—water that is pumped but then lost or unaccounted for—is a major challenge for many cities.[86] The scale of nonrevenue water loss can be significant. In the United States, it is about 16 percent;[87] in other countries, it is much higher—35 to 60 percent in Turkey, for example, and 36 percent in South Africa.

System-efficiency improvements can help. One common tactic to address physical losses is conducting a full audit to identify weaknesses and leaks and then repairing them. Installing meters can help in addressing commercial losses. In 2016, the city of Seosan in South Korea devised an integrated approach to cut down on both kinds of nonrevenue water. The city focused on reducing water leakages and implementing smart meters that tracked customers' hourly water usage digitally. The project resulted in a 20 percent improvement in the ratio of water that is used and paid for, and reduced leaks by 190,000 cubic meters of water per year.[88]

Phnom Penh is another success story. In 1993, the capital of Cambodia estimated its rate of water loss was 72 percent. By 2020, loss was down to 9.8 percent due to an effective program of pipe replacement, leak repairs, water-meter installation, and other actions.[89] System-efficiency improvements tend to be of moderate cost and to pay for themselves.

Many cities have leaky underground water-supply systems. Replacement and repair of underground water-supply pipes is expensive, time-consuming, disruptive—and necessary. Cities may need to prioritize long-term concerted efforts to address underground water loss.

By 2050, 685 million people in more than 570 cities could face a 10 percent decline in availability of fresh water due to climate change.

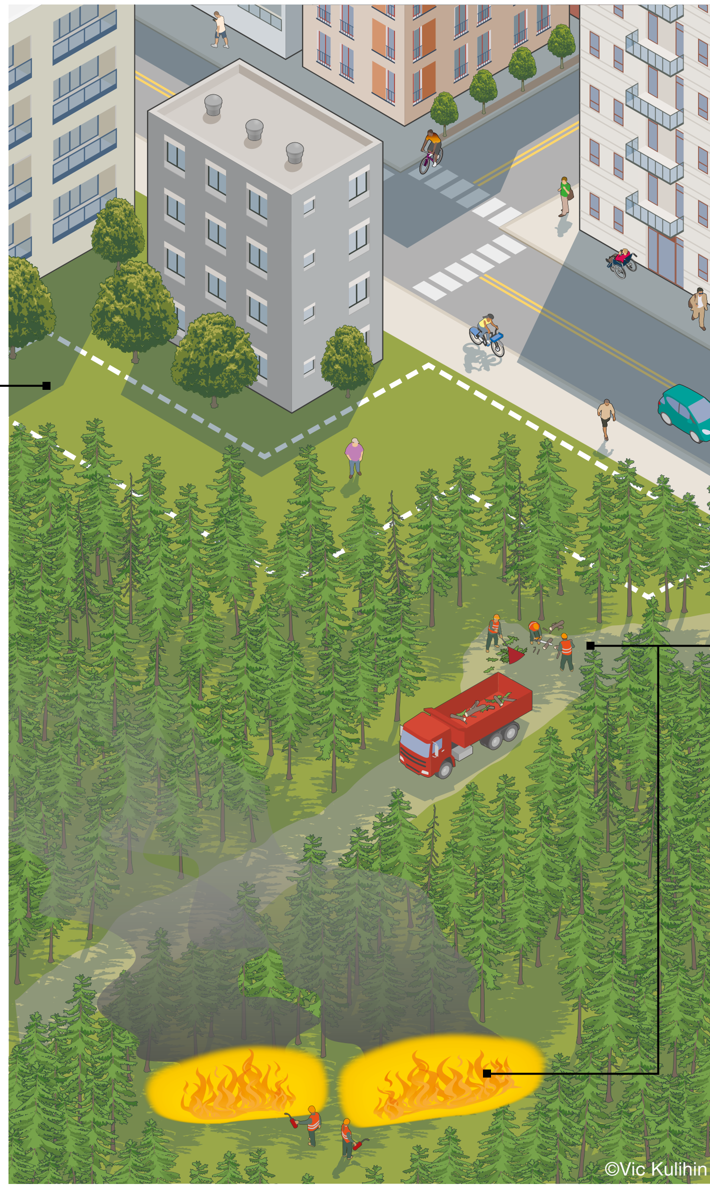
Wildfires

Figure 5

These high-potential actions reduce the severity of wildfires.

Development planning

Planning to reduce the building of homes and communities in wildfire-prone areas while creating ignition-resistant building codes for new developments reduces the impact of fire risk



Preventive forestry management

Fuel breaks such as cleared parts of forests or roads help to control, and possibly stop, the spread of wildfires

Prescribed and controlled burns consume organic material (eg, leaves and branches) in forests to intentionally reduce fuel for wildfires in a controlled manner

Many cities across the globe have been grappling with increasing numbers of wildfires and bushfires with each passing year. Paraguay declared a national emergency in October 2020 when more than 5,000 fires broke out and the capital city, Asunción, was enveloped by smoke.[90] Between June 2019 and March 2020, Australian bushfires destroyed more than 5,900 buildings and were linked with the deaths of at least 34 people.[91]

In the western United States, wildfires in 2020 were directly responsible for 43 deaths.[92]

Historically, municipalities have not held much of the responsibility for preventing and controlling wildfires. However, the impact of wildfires on urban air quality, services, infrastructures, and social disruption—combined with increasing wildfire frequency and severity—means that wildfire prevention is a priority for many cities.

On the West Coast of the United States, for example, wildfire risk has an impact on urban housing and zoning decisions. As people move farther away from urban cores to find affordable homes, many build in the wildland-urban interface (WUI)—transition zones between buildings and wildland that are particularly vulnerable to fire.[93] From 1990 to 2010, the number of new houses in WUIs in the United States grew 41 percent, from 30.8 million to 43.4 million.[94]

Our analysis suggests that two types of actions have particularly high potential for cities as they seek to adapt to wildfires: development planning and preventive forestry management.

Development planning. In the context of wildfires, development planning is about limiting building in territory that is prone to wildfires. Since 1992, Santa Fe, New Mexico, has restricted new development in its "escarpment overlay district."[95] Initially, this effort was about preserving visual beauty, but after two big fires in 2000 and 2011, the city code made wildfire risk an explicit factor. Reducing development in vulnerable areas directly reduces wildfire risk; it also prevents developments from becoming fuel for fires.[96]

Development codes can also raise standards for those living near urban areas or in WUIs. In Australia, for example, certain areas are subject to the Bushfire Management Overlay, a zoning control that requires all new development to implement bushfire-protection measures during the permitting process. Measures include evacuation plans, management of vegetation, fire-resistant building design, and open-space requirements.[97]

Development planning has a high level of stakeholder-management complexity because changes in codes and zoning have an outsize impact on residents. In geographies facing housing shortages, development codes that reduce building density to reduce wildfire risk may be politically challenging. Northern California provides a good example of how difficult these trade-offs can be. Even after the 2017 Tubbs

Between June 2019 and March 2020, Australian bushfires destroyed more than 5,900 buildings and were linked with the deaths of at least 34 people.

Fire killed 22 people and destroyed more than 5,000 buildings, local planners loosened zoning requirements to allow a 237-unit affordable-housing development on a hillside that had been ravaged by the fire.[98] City planners must consider both vulnerability and equity when incorporating wildfire risks into development planning.

Preventive forestry management is critical in reducing the impact of wildfires and, in some cases, preventing them. It can include strategies such as prescribed burns, planting fire-resistant vegetation, chemical treatments, and fuel breaks. Forestry management is typically not a city responsibility, as forests and wilderness areas are often outside urban areas. That said, cities are often involved in regional issues, and in some jurisdictions, forestry managements does fall within the purview of municipal governments.

Various studies have shown that prescribed burns—carefully managed fires that are set under specified weather conditions to reduce fuel buildup and help restore natural habitats—can reduce fire-line intensity by 10–98 percent.[99] Moreover, in wildfire-prone areas, some plants and animals have evolved to rely on wildfires to thrive. Investment in forestry management can have a high return on investment when wildfires strike. In Colorado, $1 million in wildfire-mitigation efforts prevented the 2018 Buffalo Fire in Summit County from destroying buildings and infrastructure worth nearly $1 billion.[100]

Stakeholder complexity makes it difficult to execute controlled burns and clear vegetation. Fire services must navigate complicated land-ownership challenges and public concerns about air quality and safety.[101] Vegetation management, including clearance, requires close coordination with national and state governments and private owners to ensure safety. Finally, given that wildfires are both infrequent and unpredictable, many communities have been reluctant to invest in wildfire prevention until after disaster strikes.

Fuel breaks can also be difficult from a stakeholder-management perspective due to complex land-ownership structures. Before the Buffalo Fire, many Colorado homeowners opposed fuel breaks on the grounds that cutting down trees would diminish the beauty of the natural landscape.[102] When the fuel break stopped the Buffalo Fire from destroying homes, they changed their minds—even inviting forest rangers to work in their backyards.

3 The pathway to successful implementation

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Each city will have to make its own action plan to address its unique circumstances. That said, some fundamental ideas can be applied broadly. Here, we suggest four steps toward developing a climate-resilience plan and outline five principles that should inform it.

Step 1: Conduct a risk assessment

Cities should begin by identifying the hazards they face today and those that are likely to materialize in the coming decades. Then cities can assess the risks posed by each—to people (particularly the most vulnerable), assets, and services. Creating an inclusive process to solicit feedback and lay the foundation for equitable action is critical.

Step 2: Create a list of existing and potential adaptation actions

Keeping the local context in mind, cities should develop a provisional list of the most promising systemic and hazard-specific actions.

Step 3: Conduct benefit and feasibility analyses on each proposed action

Cities should consider local conditions such as climate, governance, and finance to determine how far and how fast they can go. This report has identified a set of actions that are likely to have high potential across many types of cities; nevertheless, cities must also evaluate their specific circumstances and prioritize actions accordingly. To build the case for action, cities can also identify climate-related actions with wider benefits, such as those that foster environmental improvement, economic development, or social equity. For example, flood-proofing public transport not only strengthens adaptation but also ensures more dependable access. Green solutions that improve air quality may also reduce air temperature.

Step 4: Create a cohesive plan

Once impact and feasibility analyses for each action have been completed, a city can consolidate this information and form a plan. Identifying changes that complement actions of other levels of government, such as national climate-adaptation plans, is also useful. When possible, actions should be incorporated into existing city processes, such as infrastructure-maintenance plans or budget-setting processes. For example, London has implemented SUDS solutions to restore streets and sidewalks.[103]

To be effective, these plans must be tailored to local conditions. But following five fundamental elements can help ensure that adaptation plans are constructive.

Element 1: Governance

To achieve success, a city must integrate its climate strategy into the full range of city activities by incorporating it into charters, agendas, decision-making processes, and more. In addition, the plan needs staff and institutional support to ensure accountability.

In New York City, for example, the Mayor's Office of Climate Resiliency (MOCR) leads climate-resilience efforts.[104] MOCR uses science-based analysis to inform adaptation policy and program development as well as capacity building for public agencies, businesses, and residents. The New York City Panel on Climate Change (NPCC) is responsible for synthesizing climate-change research to support adaptation and resilience-policy development.[105] This analysis is used to advise the Climate Change Adaptation Task Force (CCATF), a group of city departments and private infrastructure service providers that produces climate-resilience guidelines.[106] The CCATF meets at least twice a year to assess the implications of the NPCC's findings on the city's people, systems, and infrastructure. On that basis, it updates resilience strategies.

Another example comes from the capital of Bangladesh, where Dhaka South City Corporation regularly convenes the mayor and numerous public- and private-sector agencies to coordinate the city's master plan and to deal with issues regarding infrastructure development.[107]

Element 2: Strategic planning

To ensure that climate adaptation becomes a core part of their mission, cities should update their climate strategy and actions regularly. Lima, Peru, for example, has outlined plans to review its adaptation strategy every two years because of changes in both the physical and political climate.[108] The city will review the results of its monitoring and evaluation reports and make any modifications required by international and national regulatory frameworks.

Element 3: Monitoring and reporting

Once cities have decided which actions to pursue, they must define specific key performance indicators (KPIs), including implementation timing for each action, and put processes in place to monitor progress. Communication and transparency, both within government and to the public, are essential.

To ensure London is accountable to the public for the city's environmental strategy, the English capital has published its adaptation plans for 2018–23.[109] It also collects data on the outcomes of each action based on previously defined KPIs. For example, as part of its flooding adaptation, London tracks the number of properties affected by surface-water flooding.

Public-awareness campaigns can foster a culture of support for climate adaptation and build public trust. Without trust, communities may not support climate action.

Element 4: Capacity building and stakeholder management

Cities can build climate awareness and expertise by bringing in experts to provide training and knowledge programs to government employees, citizens, and even firms. Cities can also form partnerships with outside sources, such as academic institutions, to assist in strategy formulation, initiative development, and execution. Resilience transcends what the municipal government does. Engaging a broad set of stakeholders can help those stakeholders build their own individual and collective resilience. A common saying in disaster preparedness is, "The first responder is usually a neighbor." Community resilience is critical.

In Buenos Aires, Argentina, the Citizens Ready against Climatic Change program, which launched in 2017, raises awareness about climate change and the importance of being prepared for extreme climate events, with particular emphasis on heat waves and floods.[110] The program has put on a series of more than 200 workshops and also conducted mass communication campaigns.

Public-awareness campaigns can foster a culture of support for climate adaptation and build public trust. Without trust, communities may not support climate action. In order to mobilize citizens around proposed climate action, the city of Dakar in Senegal designed a three-part civic outreach approach in 2017: institutional support, including "green ambassadors" from the scientific and artistic community; mass communication in schools and media; and training.[111]

Element 5: Financing

Successful climate action depends on collaborations with different institutions and long-term, continuous funding. Public finance, in the form of annual budget allocations, is one source. Boston's budget for fiscal year 2020 includes climate investments such as restoring natural marshes to support its action plan.[112] The plan also allocates 10 percent of new capital funding to open space, infrastructure, and facilities projects that are climate resilient.

Cities will need to be innovative in tapping into private resources and expertise, through public–private partnerships, green bonds, insurance, and other strategies. Bilbao, Spain, established a public–private partnership, based on share of land ownership, to fund resilience measures in the Zorrotzaurre district. Improvements included widening the canal, elevating the ground, and building green, open spaces. "Green bonds" are another promising option. In 2017, Miami voters supported the issuance of a $400 million general-obligation bond. The "Miami Forever" Bond was earmarked for resilience projects such as hardening drainage systems, raising roadways, and building a water-pumping station.[113] Ho Chi Minh City, Johannesburg, Paris, and other cities have also issued green bonds for climate-change mitigation and adaptation.[114]

As climate risks increase in both frequency and severity, city leaders must act. We hope that by identifying the most promising actions for climate adaptation, this report can help cities make significant progress.

Appendix 1: Methodology

The first step in creating this report was to build a list of adaptation actions. We started by compiling a long list of potential actions based on previous research by C40 Cities and McKinsey, then conducted a literature review to add to the list, eventually considering about 100 actions. Finally, we consulted both internal and external experts to refine the list and ensure that it was comprehensive.

We then evaluated each adaptation item based on its potential to reduce risk and its feasibility.

Risk reduction.

We defined risk-reduction impact as how much a given action could reduce risk in an urban setting. In assessing impact on risk reduction, we consulted hundreds of studies of the impact of each action, evaluating outcome measures and, where possible, comparing these outcome measures across actions. For example, we evaluated the impact of a variety of potential adaptation actions on street-level heat. To assess the impact of each action, we created a scoring system that rated each action, for each type of hazard, on a scale of 1 to 5, with 5 being the highest impact. We assigned scores based on the demonstrated impact of each action as evaluated in existing research. For example, street trees have a significant impact in reducing surrounding temperatures; on that basis, this action scored 4 for risk reduction.

Feasibility.

We defined an action's feasibility based on its financial requirements, infrastructure complexity, and stakeholder complexity. We analyzed both quantitative metrics, such as cost-impact ratios for past projects, and qualitative ones, such as number and type of stakeholders needed to execute. We used the same 1–5 scale, with 5 being the most feasible. Street trees, for example, are relatively easy to plant and maintain and do not need coordination across different sectors; this action therefore scored 4 on feasibility. It did not score 5 because in many cities, the nature of the built environment and ecological conditions preclude street trees as an effective adaptation lever. Building urban parks, on the other hand, requires significant stakeholder involvement and space. Maintenance costs can also be high. Its feasibility score is therefore lower (3).

We then determined the highest potential actions in each subcategory based on impact and feasibility scores. The higher an action scored, the higher it ranked in terms of priority.

Adaptation actions were evaluated by risk-reduction impact and categorized by hazard.

	Heat	Inland flooding	Drought	Wildfires	Coastal flooding and storm surges
5 *Highest rating*	Major reduction in ambient heat across urban environment (eg, through urban planning)	Very high reduction in the intensity of floods in urban environments (eg, sustainable drainage systems; river-catchment management)	Very high reduction in the intensity or frequency of drought (eg, improvements in water-system efficiency)	Reduction in the frequency of wildfires (eg, development planning)	Major reduction in the wind experienced in urban environments (eg, wind-resilient building standards)
4	Some reduction in ambient heat across urban environment (eg, cool envelope treatments)	Major reduction in the intensity of floods in urban environments (eg, blue infrastructure)	Major reduction in the intensity or frequency of drought (eg, sustainable agricultural practices)	Major improvement in limiting the spread of and damage from wildfires (eg, prescribed burns)	Some reduction in the wind experienced in urban environments
3	Major improvement in ability of large population to manage heat (eg, heat warning system)	Some reduction in the intensity of floods in urban environments (eg, canals)	Some reduction in the intensity or frequency of drought (eg, permeable paving)	Some improvement in limiting the spread and damage from wildfires (eg, vegetation management for critical infrastructure)	Major reduction in the damage potentially inflicted by wind (eg, nature-based wind reduction)
2	Some improvement in ability of large population to manage heat (eg, cooling centers)	Minor reduction in intensity of floods in cities (eg, geotextile tubes) or improvement in ability to recover (eg, flood-proof homes)	Minor reduction in the intensity or frequency of drought (eg, green or blue roofs)	Minor improvement in limiting the spread and damage from wildfires (eg, wildfire detection technology)	Some reduction in the damage potentially inflicted by wind (eg, smart grid technology)
1 *Lowest rating*	Minor improvement in individuals' or small groups' heat management (eg, maximum residential temperature ordinances)	Minor improvement in ability to recover from flood	Very minor reduction in the intensity or frequency of drought	Some improvement in ability to recover from wildfire damage	Some improvement in ability to recover from wind damage (eg, smart grid technology)

Action feasibility was measured and scored across three dimensions.

	Financial cost	Infrastructure complexity	Stakeholder complexity
5 *Highest rating*	Limited cost to execute (up-front and operating cost)	Does not require changes to infrastructure (eg, operational changes only)	Limited stakeholder groups required to execute Limited potentially negative effect on any stakeholder groups
4	Some cost to execute (up-front and operating cost)	Requires minor, nonstructural modifications to buildings or infrastructure	Low number of stakeholder groups required to execute; relatively easy to manage and get them on board Some potentially negative effects on select stakeholder groups
3	Moderate cost to execute (up-front and operating cost)	Requires adjusting the built environment (capital renovation of buildings or infrastructure)	Moderate number of stakeholder groups required to execute; moderate difficulty to manage and get them on board Some potentially negative effects on many stakeholder groups
2	High cost to execute (up-front and operating cost)	Requires major changes to the built environment (eg, some new buildings, underlying infrastructure)	Substantial number of stakeholder groups required to execute; substantial difficulty to manage and get them on board Some potentially negative effects on many stakeholder groups
1 *Lowest rating*	Very high cost to execute (up-front and operating cost)	Requires substantial, complex changes to the built environment (eg, widespread new buildings, underlying infrastructure)	Requires widespread coordination across major stakeholder groups to execute; difficult to get them on board Has significant and potentially inequitable impact on major stakeholder groups (eg, relocate large communities)

Appendix 2: City typologies

To ensure broad applicability across city types, we defined a range of city typologies using a combination of qualitative judgments and quantitative data. The goal was to group together cities that had similar capacity to adapt based on financial capacity, built-environment flexibility, and existing governance structures, and then evaluate whether a given action would apply to each of these types of cities.

Financial capacity: how much money is available to invest; we used GDP per capita as the indicator.

Built-environment flexibility: how much capacity a city has to build climate-resilient infrastructure and defenses as defined by:

— How fast the city's infrastructure stock is growing, using population growth rate as a proxy for infrastructure growth. Although this is an imperfect metric, faster-growing cities in many cases have a greater opportunity to shape the future of their built environment than cities that rely on existing stock.

— How much space is available to build new infrastructure, using city population density as a proxy.

— The relative likelihood of a city to invest in new infrastructure, based on the analysis of C40 Cities regional directors. In this assessment, regional directors determined how vulnerable a city's existing infrastructure is and thus how likely the city is to invest in new infrastructure. These categories included the following:

- High: more than 80 percent of the infrastructure is vulnerable; the city should invest in new infrastructure
- High to medium: 50 to 80 percent is vulnerable; the city should invest in new infrastructure
- Medium: 50 percent is vulnerable; the city can invest moderately in new infrastructure
- Medium to low: 20 to 50 percent is vulnerable; the city is less likely to invest in new infrastructure
- Low: less than 20 percent of infrastructure is vulnerable; the city is not likely to invest in new infrastructure

Governance: the extent to which a city can implement complex, multi-stakeholder actions, as defined by:

— The city's authority over urban planning and infrastructure, whether through direct ownership or regulatory and budget control

— The degree of public trust in government (defined at the national level).

We again used a 1 to 5 scale to score these capacities, with 5 being highest capacity. A city is grouped into its typology based on where it fits best, although not every criterion in a typology will fit every city. Vulnerability was not one of the criteria; city officials need to understand their own local vulnerabilities when designing an adaptation agenda.

	Income level	Built environment			Institutional power	
	GDP per capita	**Infrastructure vulnerability**	**Density**	**Population growth rate**	**City power**	**Trust in government**
Global centers	High	Low to medium low	Medium to high	Low to medium	Partial	Low to medium
Developing cities	Low to medium low	High	High	Medium to high	Strong	Low to medium
Advanced middleweight cities	Medium to medium high	Low to medium low	Medium to high	Low to medium high	Partial to strong	Medium to high
Highly resourced cities	High	Low	Low to medium low	Low to medium	Strong	Medium to high
Established economic centers	Medium	Medium	Low medium to high	Low to medium	Partial to strong	Low medium to medium
Emerging cities	Low to medium	High to medium	High to medium	Low to medium	Strong	Low

Appendix 3: Adaptation action library

Type	Category/ Hazard	Action	**Benefit** (5=high, 1=low)	**Cost** (5=easy, 1=hard)	**Infrastructure** (5=easy, 1=hard)	**Stakeholder complexity** (5=easy, 1=hard)
Systemic resilience	Increasing awareness	Risk assessment: hazard maps, impact assessment, and spatial analysis	5	2	5	5
Systemic resilience	Increasing awareness	Public-awareness campaigns and outreach programs for citizens, building awareness and knowledge (eg, town halls, marketing campaigns)	4.75	3	5	3
Systemic resilience	Increasing awareness	Climate response and resilience training for city staff and civilians	4	3	5	4
Systemic resilience	Increasing awareness	Tools and metrics to measure climate risk and climate scenarios (eg, improved physical-hazard modeling)	3	4	5	3
Systemic resilience	Incorporating risk	Incorporating climate risk into urban planning (eg, limiting construction in high-risk areas)	5	3	5	1
Systemic resilience	Incorporating risk	Critical-systems efficiency to build resilience (eg, power, transport, water)	4	3	3	3
Systemic resilience	Incorporating risk	Infrastructure design and maintenance plans updated to include climate risk (eg, vegetation management)	3	4	4	2
Systemic resilience	Incorporating risk	Strategic and managed retreat (eg, buyout programs)	3.5	1	5	2
Systemic resilience	Incorporating risk	Redundant and diversified critical systems (eg, microgrids, water reservoirs)	5	1	1	4
Systemic resilience	Incorporating risk	Integration of climate risk into procurement (eg, utility-rate cases)	4	2	3	4
Systemic resilience	Incorporating risk	Rating schemes assessing resilience of physical assets	2	4	5	4
Systemic resilience	Incorporating risk	Risk assessment and volatility test for critical services (eg, food services)	1.5	3	5	4
Systemic resilience	Optimizing response	Emergency center	5	2	5	4
Systemic resilience	Optimizing response	Early-warning systems and protocols	5	2	5	5

Type	Category/ Hazard	Action	**Benefit** (5=high, 1=low)	**Cost** (5=easy, 1=hard)	**Infrastructure** (5=easy, 1=hard)	**Stakeholder complexity** (5=easy, 1=hard)
Systemic resilience	Optimizing response	Evacuation plan for all relevant hazards	5	3	3	3
Systemic resilience	Optimizing response	Disaster-relief funds	5	1	5	3
Systemic resilience	Optimizing response	Critical-systems operability and resilience	5	1	3	5
Systemic resilience	Optimizing response	Hardened peripheral networks to critical infrastructure	4	3	3	5
Systemic resilience	Optimizing response	Storage of key inventories for critical services	4	3	5	5
Systemic resilience	Optimizing response	Continuity plan for critical supply chains	4	3	5	5
Systemic resilience	Enhancing finance	Climate insurance provision and alignment	4	4	5	3
Systemic resilience	Enhancing finance	Component of disaster-relief funding allocated to adaptation	4	4	5	3
Systemic resilience	Enhancing finance	Programs for increasing the affordability of climate insurance (eg, voucher programs)	3	3	5	3
Systemic resilience	Enhancing finance	Integration of climate risk into municipal bond ratings and creditworthiness assessments	3	4	5	1
Systemic resilience	Enhancing finance	Hardening or retrofitting requirements for insurance, or both	3	2	4	1
Systemic resilience	Enhancing finance	Climate bonds	2	2	5	5
Systemic resilience	Enhancing finance	Mandated climate insurance	2	3	3	3
Hazard-specific resilience	Extreme heat	Cool surfaces (eg, white roofs, white walls, cool pavement)	4	4	3	5

Type	Category/ Hazard	Action	**Benefit** (5=high, 1=low)	**Cost** (5=easy, 1=hard)	**Infrastructure** (5=easy, 1=hard)	**Stakeholder complexity** (5=easy, 1=hard)
Hazard-specific resilience	Extreme heat	Street trees (climate-resilient species prioritized in heat risk areas)	4	5	4	4
Hazard-specific resilience	Extreme heat	Urban parks	5	3	3	3
Hazard-specific resilience	Extreme heat	Evaporative cooling (eg, large and small cooling water bodies within a city)	4	2	3	3
Hazard-specific resilience	Extreme heat	Green-buildings envelope (eg, green roofs, green wall systems)	4	2	3	3
Hazard-specific resilience	Extreme heat	Passive building cooling and heat-sensitive architecture (eg, incorporating design elements for buildings that enable shading, breeze, insulation)	3	4	3	2
Hazard-specific resilience	Extreme heat	Urban design for heat reduction (eg, managing sky-view factor, design street grids with wind ventilation)	5	3	1	2
Hazard-specific resilience	Extreme heat	Policies to reduce waste heat (eg, policies to reduce volume of vehicles)	4	2	3	2
Hazard-specific resilience	Extreme heat	Cooling systems for critical systems	3	2	1	5
Hazard-specific resilience	Extreme heat	Shading structures	2	4	4	5
Hazard-specific resilience	Extreme heat	Public drinking water and its source	2	4	4	5
Hazard-specific resilience	Extreme heat	District cooling	3	2	3	3
Hazard-specific resilience	Extreme heat	Cooling technology (eg, air-conditioning units, fans)	2	3	3	5
Hazard-specific resilience	Extreme heat	Adjustment of work hours	2	5	5	1
Hazard-specific resilience	Extreme heat	Cooling centers	2	3	3	4

Type	Category/ Hazard	Action	**Benefit** (5=high, 1=low)	**Cost** (5=easy, 1=hard)	**Infrastructure** (5=easy, 1=hard)	**Stakeholder complexity** (5=easy, 1=hard)
Hazard-specific resilience	Extreme heat	Maximum residential temperature ordinances	1	5	5	2
Hazard-specific resilience	Inland flooding	River-catchment management (eg, river basin plans, infiltrating and retaining water in upcatchment, renaturalizing the river, creating a buffer protection for the rivers)	5	3	5	2
Hazard-specific resilience	Inland flooding	Green solutions for water permeability and flood protection - Sustainable urban drainage systems (SUDS) (eg, floodplains and green riverbanks, bioswales, rain gardens, depaving)	5	2	3	3
Hazard-specific resilience	Inland flooding	Blue infrastructure - SUDS (eg, artificial lakes, reservoirs, and retention ponds)	4	2	3	3
Hazard-specific resilience	Inland flooding	Artificial barriers against flood (eg, levee, dike)	5	1	3	3
Hazard-specific resilience	Inland flooding	Optimize stormwater and sewage interdependencies (eg, separating systems at source)	4	2	2	3
Hazard-specific resilience	Inland flooding	Flood-proof energy infrastructure	4	2	3	2
Hazard-specific resilience	Inland flooding	Artificial barriers against flood (eg, geotextile tubes and sandbags)	2	4	4	5
Hazard-specific resilience	Inland flooding	Permeable pavements	2.5	3	3	4
Hazard-specific resilience	Inland flooding	Improving waste-collection systems to avoid clogging of pipes	4	3	2	4
Hazard-specific resilience	Inland flooding	Flood-resilient buildings (eg, flood- and storm-resilient building standards, hardening or retrofitting buildings)	2.75	2	3	2
Hazard-specific resilience	Inland flooding	Underground stormwater storage	3	2	2	3
Hazard-specific resilience	Inland flooding	Build canals to increase water flow	3	2	2	3

Type	Category/ Hazard	Action	**Benefit** (5=high, 1=low)	**Cost** (5=easy, 1=hard)	**Infrastructure** (5=easy, 1=hard)	**Stakeholder complexity** (5=easy, 1=hard)
Hazard-specific resilience	Inland flooding	Strategic and managed, long-term climate retreat from floodplains	4	2	2	1
Hazard-specific resilience	Inland flooding	Flood-proof homes (wet and dry)	2.5	2	3	2
Hazard-specific resilience	Inland flooding	Pumping stations	3	2	1	3
Hazard-specific resilience	Inland flooding	River or canal rehabilitation (eg, expand riverbeds)	2	2	3	4
Hazard-specific resilience	Inland flooding	Stormwater and rainwater harvesting	2	2	3	4
Hazard-specific resilience	Inland flooding	Green roofs for flooding	2	2	3	4
Hazard-specific resilience	Inland flooding	Flood-proof public transportation infrastructure	2	2	3	2
Hazard-specific resilience	Coastal flooding and storm surges	Coastal nature-based solution barriers (eg, mangroves)	5	4	4	4
Hazard-specific resilience	Coastal flooding and storm surges	Artificial barriers against flood (eg, seawalls, floodgates)	5	2	2	3
Hazard-specific resilience	Coastal flooding and storm surges	Flood-proof energy infrastructure	4	2	3	2
Hazard-specific resilience	Coastal flooding and storm surges	Optimize stormwater and sewage interdependencies (eg, separating systems at their source)	4	2	2	3
Hazard-specific resilience	Coastal flooding and storm surges	Blue infrastructure - SUDS (eg, artificial lakes, reservoirs, and retention ponds)	4	2	3	3
Hazard-specific resilience	Coastal flooding and storm surges	Flood-resilient buildings (eg, flood- and storm-resilient building standards, hardening or retrofitting buildings)	2.75	2	3	2
Hazard-specific resilience	Coastal flooding and storm surges	Flood-proof homes (wet and dry)	2.5	2	3	2

Type	Category/ Hazard	Action	**Benefit** (5=high, 1=low)	**Cost** (5=easy, 1=hard)	**Infrastructure** (5=easy, 1=hard)	**Stakeholder complexity** (5=easy, 1=hard)
Hazard-specific resilience	Coastal flooding and storm surges	Artificial barriers against flood (eg, geotextile tubes and sandbags)	2	4	4	5
Hazard-specific resilience	Coastal flooding and storm surges	Beach-erosion solutions (eg, groynes, artificial reefs, beach-drainage systems, beach replenishment, dune vegetation management)	2	3	3	3
Hazard-specific resilience	Coastal flooding and storm surges	Improving waste-collection systems to avoid clogging of pipes	2	2	5	1
Hazard-specific resilience	Coastal flooding and storm surges	Artificial barriers against flood (eg, revetments and breakwaters)	2	3	3	3
Hazard-specific resilience	Coastal flooding and storm surges	Flood-proof public transportation infrastructure	2	2	3	2
Hazard-specific resilience	Coastal flooding and storm surges	Strategic and managed, long-term climate retreat from floodplains	4	2	2	1
Hazard-specific resilience	Coastal flooding and storm surges	Pumping stations	3	2	1	3
Hazard-specific resilience	Coastal flooding and storm surges	Smart grid technology (eg, detection technology for energy outages)	2	2	3	3
Hazard-specific resilience	Coastal flooding and storm surges	Wind-resilient building standards	5	3	3	3
Hazard-specific resilience	Coastal flooding and storm surges	Nature-based wind reduction strategies (eg, mangrove restoration)	3	4	4	4
Hazard-specific resilience	Coastal flooding and storm surges	Wind-resilient electric and telecom infrastructure	5	2	2	3
Hazard-specific resilience	Coastal flooding and storm surges	Smart grid technology (eg, detectionn technology for energy outages)	2	2	3	3
Hazard-specific resilience	Drought	Behavioral-change programs to conserve water	5	5	5	2
Hazard-specific resilience	Drought	Water-system efficiency improvements (eg, reduce nonrevenue water)	5	4	3	3

Type	Category/ Hazard	Action	**Benefit** (5=high, 1=low)	**Cost** (5=easy, 1=hard)	**Infrastructure** (5=easy, 1=hard)	**Stakeholder complexity** (5=easy, 1=hard)
Hazard-specific resilience	Drought	Source-water management policies (eg, surface water, groundwater, spring water)	4	4	4	2
Hazard-specific resilience	Drought	Water treatment and reuse	5	3	3	3
Hazard-specific resilience	Drought	Water-demand management (eg, water metering, caps on water use, rewards like tax breaks for limiting use)	5	3	4	1
Hazard-specific resilience	Drought	Sustainable agricultural practices	4	3	4	1
Hazard-specific resilience	Drought	Artificial lakes, new reservoirs, and watercourse rehabilitation	5	2	2	3
Hazard-specific resilience	Drought	Artificial recharge	4	3	3	2
Hazard-specific resilience	Drought	Rain gardens and green streets	4	2	2	4
Hazard-specific resilience	Drought	Permeable paving	3	3	3	4
Hazard-specific resilience	Drought	Stormwater and rainwater harvesting	3	2	3	4
Hazard-specific resilience	Drought	Xeriscaping	2	5	4	4
Hazard-specific resilience	Drought	Green and blue roofs	2	2	4	2
Hazard-specific resilience	Drought	Desalination plants	3	1	1	2
Hazard-specific resilience	Wildfires	Development planning (eg, restricting development in fire-prone areas)	4	4	5	2
Hazard-specific resilience	Wildfires	Preventive forestry management (eg, prescribed burns, planting fire-resistant vegetation, chemical treatments, and fuel breaks)	4	2	4	3

Type	Category/ Hazard	Action	**Benefit** (5=high, 1=low)	**Cost** (5=easy, 1=hard)	**Infrastructure** (5=easy, 1=hard)	**Stakeholder complexity** (5=easy, 1=hard)
Hazard-specific resilience	Wildfires	Vegetation management (eg, clearing vegetation from transmission lines)	2	1	2	2
Hazard-specific resilience	Wildfires	Wildfire-detection technology	4	3	3	5
Hazard-specific resilience	Wildfires	Wildfire-response preparation (eg, purchasing planes for fighting wildfires)	3	2	2	5
Hazard-specific resilience	Wildfires	Wildfire-resilient buildings (eg, retrofitting, standards, etc)	4	3	3	2

Endnotes

1 Physical risk refers to the direct and indirect loses expected to be incurred by people, assets, and services due to climate change.

2 Our Climate Risk and Response research estimates the inherent risk from climate change without adaptation and mitigation to size the potential impact and highlight the case for action. Our estimates use the Representative Concentration Pathway (RCP) 8.5 scenario of greenhouse-gas concentration because the higher-emission scenario it portrays enables us to assess physical risk in the absence of further decarbonization. For more, see “Climate risk and response: Physical hazards and socioeconomic impact,” McKinsey Global Institute, January 2020.

3 *Adapt now: A global call for leadership on climate resilience,* Global Commission on Adaptation, September 2019, gca.org.

4 *Climate finance provided and mobilised by developed countries in 2013-18,* OECD, 2020, oecd-ilibrary.org.

5 *Explaining extreme events of 2019 from a climate perspective,* American Meteorological Society, January 2021, ametsoc.org.

6 Katie Lebling et al., *State of climate action: Assessing progress toward 2030 and 2050,* World Resources Institute, November 2020, publications.wri.org.

7 “68% of the world population projected to live in urban areas by 2050, says UN,” United Nations, May 16, 2018, un.org.

8 Charlotte Edmond, “Cape Town almost ran out of water. Here’s how it averted the crisis,” World Economic Forum, August 23, 2019, weforum.org.

9 “India’s heatwave turns deadly,” Al Jazeera, June 18, 2019, aljazeera.com.

10 Hillary Leung, “66 people have died in Indonesia’s devastating floods. Here’s what to know.” *Time*, January 8, 2020, time.com.

11 Rowena House and Pascaline Wallemacq, “Economic losses, poverty & disasters: 1998-2017,” UNDRR, 2018, undrr.org.

12 “Physical Risk and Response,” January 2020; *The future we don’t want: How climate change could impact the world’s greatest cities,* a joint report from C40 Cities, Global Covenant of Mayors, Acclimatise, and the Urban Climate Change Research Network, February 2018, c40.org.

13 This is based on analysis of 2,586 global cities by C40 Cities.

14 *The future we don’t want,* February 2018.

15 Aromar Revi et al., *Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of working group II to the fifth assessment report of the Intergovernmental Panel on Climate Change. Urban areas,* IPCC, 2014, ipcc.ch.

16 Olga Pilfosova and Barry Smit, “Adaptation to climate change in the context of sustainable development and equity,” *Climate Change 2001: Impacts, Adaptation, and Vulnerability,* edited by James J. McCarthy et al., 877–912. Cambridge, UK: Cambridge University Press, 2001.

17 *Adapt now*, September 2019.

18 Mitigation refers to actions that reduce greenhouse-gas emissions, such as replacing fossil-fuel energy sources with renewable ones. Adaptation refers to actions that can help safeguard people, assets, services, and systems from the impacts of climate change. Mitigation was the focus of *A strategic approach to climate action in cities—focused acceleration,* a joint report from McKinsey and C40 Cities, November 2017, McKinsey.com. The premise of this report is that, to remain livable, cities must adapt to current and future physical-climate risks.

19 *Infrastructure interdependencies + climate risks report,* C40 Cities, spring 2017, unfcc.int; Neuni Farhad et al., Understanding infrastructure interdependencies in cities, a joint report from C40 Cities and AXA, 2019, c40.org.

20 *Climate change 2014,* 2014.

21 Jawhar Bouabid et al., *Benefit-cost analysis of FEMA hazard mitigation grants,* December 2016, bechtel.colorado.edu.

22 “Evaluating the effect of flood damage-reducing measures: A case study of the unembanked area of Rotterdam, the Netherlands,” *Regional Environmental Change,* June 2014, Volume 14, Number 3, pp. 895–908, link.springer.com.

23 Fouad Bendimerad et al., *Quezon City risk atlas: Building a disaster resilient Quezon City project,* a joint report from QGC and EMI, January 2014, quezoncity.gov.ph.

24 *Flood mapping for the nation: A cost analysis for the nation's flood map inventory,* Association of State Floodplain Managers, March 2013, floodsciencecenter.org.

25 Rober Lempert et al., *Impacts, risks, and adaptation in the United States: Fourth national climate assessment, volume II. Reducing risks through adaptation actions,* US Global Change Research Program, 2018, nca2018.globalchange.gov.

26 *Benefit-cost analysis of FEMA hazard mitigation grants,* December 2016.

27 *UNISDR annual report 2015,* UNDRR, 2016, undrr.org.

28 Paul Hudson and W. J. Wouter Botzen, "Cost–benefit analysis of flood-zoning policies: A review of current practice," *WIREs Water,* November/December 2019, Volume 6, Issue 6, onlinelibrary.wiley.com.

29 A*hmedabad heat action plan 2016: Guide to extreme heat planning in Ahmedabad, India,* a joint report from Ahmedebad Municipal Corporation and the NRDC, 2016, nrdc.org.

30 *Adapt now,* September 2019.

31 Ibid.

32 "Global effort to strengthen early warning systems expands," World Meteorological Organization, December 13, 2019, public.wmo.int.

33 "Early warning systems," UN, June 23, 2021, un.org.

34 Krisztina Campbell and Mehrnaz Ghojeh, *Playbook: Inclusive community engagement,* a joint report from C40 Cities and Arup, May 6, 2021, c40knowledgehub.org.

35 Mehrnaz Ghojeh et al., *Roadmap: Inclusive planning,* a joint report from C40 Cities, Ross Center for Sustainable Cities, and the World Resources Institute, May 6, 2021, resourcentre.c40.org.

36 "Risks posed by natural disasters: Economic losses caused by natural catastrophes are trending upwards," Munich RE, May 12, 2021, munichre.com.

37 "For cities, the heat is on," C40 Cities, December 16, 2020, c40.org.

38 Wet-bulb temperature is a temperature measure that incorporates humidity in addition to air temperature. By including humidity, wet-bulb temperatures are a better measure of heat stress on a human body.

Our Climate Risk and Response research estimates the inherent risk from climate change without adaptation and mitigation to size the potential impact and highlight the case for action. Our estimates use the Representative Concentration Pathway (RCP) 8.5 scenario of greenhouse-gas concentration because the higher-emission scenario it portrays enables us to assess physical risk in the absence of further decarbonization.

For more, see "Will India get too hot to work?" McKinsey Global Institute, November 2020.

39 Ibid.

40 Megan Rowling, "Feeling the heat? Scientists warn of climate shocks to global health," Reuters, December 3, 2020, news.trust.org.

41 For example, the heat wave in the summer of 2003 in Europe is estimated to have caused more than 30,000 fatalities, with over 14,000 of those in France. "Impacts of summer 2003 heat wave in Europe," UNEP, May 13, 2021, unisdr.org.

42 "Cities100: Medellín's interconnected green corridors," C40 Cities, October 2019, c40knowledgehub.org.

43 "Cities100: Barcelona - managing trees for a healthier city," C40 Cities, September 14, 2017, c40.org.

44 "Using trees and vegetation to reduce heat islands," US EPA, December 19, 2021, epa.gov.

45 Paul Osmond and Ehsan Sharifi, *Guide to urban cooling strategies,* CRC for Low Carbon Living, July 2017, lowcarbonlivingcrc.com.au.

46 *Reducing urban heat islands: Compendium of strategies,* US EPA, 2008, epa.gov.

47 Britta G. Bierwagen et al., "Urban adaptation can roll back warming of emerging metropolitan regions," *Proceedings of the National Academy of the Sciences of the United States of America,* February 25, 2014, Volume 111, Number 8, pp. 2909–14, pnas.org.

48 *Guide to urban cooling strategies,* July 2017.

49 *Guide to urban cooling strategies,* July 2017.

50 "Seoul city government to additionally install cool roofs to cool down the sweltering rooftop houses," Seoul Metropolitan Government, August 16, 2018, english.seoul.go.kr.

51 "Keeping it cool: How cool roofs programs protect people, save energy and fight climate change," NRDC, July 2019, assets.nrdc.org.

52 "Using cool roofs to reduce heat islands," US EPA, June 27, 2021, epa.gov.

53 Inland flooding refers to pluvial (rainfall) flooding and fluvial (riverine) flooding in cities.

54 "New data shows millions of people, trillions in property at risk from flooding — but infrastructure investments now can significantly lower flood risk," World Resources Institute, April 23, 2020, wri.org.

55 "South African municipalities take part in exchange on riverine management," C40 Cities Financial Facility, July 13, 2020, c40cff.org.

56 "Manage flood risk," US EPA, June 1, 2021, epa.gov.

57 "Cloudburst management plan, Copenhagen," Oppla, May 13, 2021, oppla.eu.

58 Nathalie Badaoui et al., *Integrating climate adaptation: A toolkit for urban planners and adaptation practitioners,* C40 Cities, October 26, 2020, c40knowledgehub.org.

59 Nell Green Nylen and Michael Kiparsky, *Accelerating cost-effective green stormwater infrastructure: Learning from local implementation,* Center for Law, Energy & the Environment, UC Berkeley School of Law, February 2015, law.berkeley.edu.

60 *The future we don't want,* February 2018.

61 Jan Corfee-Morlot et al., "Future flood losses in major coastal cities." *Nature Climate Change,* 2013, Volume 3, pp. 802–6, nature.com.

62 "Costliest U.S. tropical cyclones tables updated," National Hurricane Center, January 26, 2018, nhc.noaa.gov.

63 Anna McIvor et al., *Mangroves for coastal defence: Guidelines for coastal managers & policy makers,* a joint report from Wetlands International and The Nature Conservancy, 2014, nature.org.

64 "Putting nature to work: Integrating green and gray infrastructure for water security and climate resilience," World Bank, March 21, 2019, worldbank.org; "Helping Colombo hold back the next flood," World Bank, July 2, 2014, worldbank.org.

65 "Retain and restore: Practical ways cities can manage and preserve urban wetlands," World Wetlands Day, February 2, 2018, worldwetlandsday.org.

66 "Putting nature to work," March 21, 2019.

67 *Mangroves for coastal defence,* 2014.

68 "The global value of mangroves for risk reduction," Coastal Resilience, coastalresilience.org.

69 Ibid.

70 Richard Bellerby et al., "Coastal wetland loss, consequences, and challenges for restoration," *Anthropocene Coasts,* January 3, 2018, Volume 1, Number 1, cdnsciencepub.com.

71 Cameron S. Fletcher et al., "Economic, equitable, and affordable adaptations to protect coastal settlements against storm surge inundation," *Regional Environmental Change,* 2016, Volume 16, pp. 1023–34.

72 "The Number of People Affected by Floods Will Double Between 2010 and 2030," World Resources Institute, April 23, 2020, wri.org.

73 Typhoon Yolanda was also known as Typhoon Haiyan.

74 Sarwell Meniano, "DPWH chief eyes Leyte 'Great Wall' completion by 2020," Philippine News Agency, August 7, 2018, pna.gov.ph.

75 Ivy Sauner, "'Yolanda' survivors protest billion-peso seawall project," *CNN Philippines*, December 12, 2016, cnnphilippines.com.

76 Multi-Hazard Mitigation Council, *Natural hazard*

mitigation saves: 2019 report, National Institute of Building Science, 2019, 2021.nibs.org.

77 *One New York City: One Water,* NYC Department of Environmental Protection, www1.nyc.gov.

78 Mark G. Stewart, “Risk and economic viability of housing climate adaptation strategies for wind hazards in southeast Australia,” *Mitigation and Adaptation Strategies for Global Change,* 2015, Volume 20, pp. 601–22, link.springer.com.

79 Ibid.

80 *Climate resiliency design guidelines,* Mayor’s Office of Resiliency, September 2020, www1.nyc.gov.

81 *The future we don’t want,* February 2018.

82 Ammaarah Martinus and Faisal Naru, “How cape town used behavioral science to beat its water crisis,” *Behavioral Scientist*, October 19, 2020, behavioralscientist.org.

83 Ibid.

84 “Water dashboard,” City of Cape Town, May 6, 2020, coct.co.

85 Paul J. Ferraro and Michael K. Price, “Using non-pecuniary strategies to influence behavior: Evidence from a large scale field experiment,” National Bureau of Economic Research working paper, number 17189, July 2011, nber.org; Paul Ferraro and Juan Jose Miranda, “Can behavioral change support water conservation? Examples from the US, Colombia and Costa Rica,” World Bank Blogs, March 28, 2017, blogs.worldbank.org.

86 Bill Kingdom, Gerard Soppe, and Jemima Sy, “What is non-revenue water? How can we reduce it for better water service?,” World Bank Blogs, August 31, 2016, blogs.worldbank.org.

87 “Water audits and water loss control for public water systems,” US EPA, July 2013, epa.gov.

88 Sukuk Yi et al., *Case study of Seosan smart water management,* a joint report from K-water and IWRA, 2018, iwra.org.

89 “Non-revenue water,” Phnom Penh Water Supply Authority, May 12, 2020, ppwsa.com.kh.

90 William Costa, “Wildfires tear through drought-racked Paraguay amid record heat,” *Guardian,* October 2, 2020, theguardian.com.

91 Susan Fowler, “Six months after Australia’s wildfires, recovery continues,” DirectRelief, June 24, 2020, directrelief.org.

92 Jeff Masters, “Reviewing the horrid global 2020 wildfire season,” Yale Climate Connections, January 4, 2021, yaleclimateconnections.org.

93 Kendra Pierre-Louis and Jeremy White, “Americans are moving closer to nature, and to fire danger, *New York Times*, November 15, 2018, nytimes.com.

94 Patricia M. Alexandre et al., “Rapid growth of the US wildland-urban interface raises wildfire risk,” *Proceedings of the National Academy of Sciences,* March 2018, Volume 115, Number 13, 3314–9, pnas.org.

95 “14-5.6 – escarpment overlay district,” *Santa Fe City Code,* City of Santa Fe, November 30, 2020, library.municode.com.

96 Kirk Siegler, “How houses themselves become fuel for wildfires,” NPR, December 24, 2018, npr.org.

97 “Explanation of bushfire protection measures,” Country Fire Authority, June 17, 2021, cfa.vic.gov.au.

98 Lauren Sommer, “Getting back what you lost — rebuilding in a wildfire zone,” NPR, October 16, 2018, npr.org.

99 Hermínio S. Botelho and Paulo M. Fernandes, “A review of prescribed burning effectiveness in fire hazard reduction,” *International Journal of Wildland Fire,* 2003, Volume 12, pp. 117–28, fs.fed.us

100 “Proactive fuel breaks protect nearly $1B in homes, infrastructure during wildfire,” US Forest Service, June 28, 2018, fs.usda.gov.

101 Alex Brown and Sophie Quinton, “California may need more fire to fix its wildfire problem,” Pew Charitable Trusts, September 18, 2020, pewtrusts.org.

102 Jesse Paul, “The Buffalo fire, near Silverthorne, was one of the first big tests for fire breaks in Colorado. Now, communities are changing their tune toward them.” *Colorado Sun*, September 26, 2018, coloradosun.com.

103 “London sustainable drainage action plan,” Greater London Authority, December 13, 2016, london.gov.uk.

104 “About,” City of New York, www1.nyc.gov.; “Mayor’s Office of Resiliency,” City of New York, www1.nyc.gov.

105 Allison Bridges et al., *State of climate knowledge: 2021,* City of New York, 2021, www1.nyc.gov.

106 “§ 3-123 New York city climate change adaptation task force.” *New York City Administrative Code,* American Legal Publishing Corporation, June 11, 2021, codelibrary.amlegal.com.

107 *Understanding infrastructure interdependencies in cities,* 2019.

108 Ximena Giraldo Malca, “Proyecto del plan local de cambio climático de la Provincia de Lima,” a joint report from C40 Cities and Municipalidad de Lima, January 2021, congreso.gob.pe.

109 *London environment strategy: Implementation plan,* Greater London Authority, May 2018, London.gov.uk.

110 “Buenos Aires ‘citizens ready against climatic change’ programme,” C40 Cities, January 30, 2020, c40.org.

111 *Civic engagement and participatory governance in climate action,* City of Dakar, July 2020, cdn.locomotive.works.

112 “FY21 climate and open space priorities,” City of Boston, March 23, 2021, boston.gov.

113 “Financing resilience: City of Miami invests $400 million to build a stronger future,” Southeast Florida Regional Climate Change Compact, May 12, 2021, southeastfloridaclimatecompact.org; “Miami Forever Bond,” City of Miami, May 13, 2021, miamigov.com.

114 “C40 good practice guides: Johannesburg - green bond,” C40 Cities, February 15, 2016, c40.org; “Cities100: Paris - dedicated climate bonds for cities,” C40 Cities, October 30, 2015, c40.org; Monica Filkova and Camille Frandon-Martinez, *ASEAN green finance: State of the market,* Climate Bonds Initiative, January 2019, climatebonds.net.