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TECHNICAL REPORT

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NYC NPCC4

NPCC4: Climate change and New York City's health risk

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Abstract

This chapter of the New York City Panel on Climate Change 4 (NPCC4) report considers climate health risks, vulnerabilities, and resilience strategies in New York City's unique urban context. It updates evidence since the last health assessment in 2015 as part of NPCC2 and addresses climate health risks and vulnerabilities that have emerged as especially salient to NYC since 2015. Climate health risks from heat and flooding are emphasized. In addition, other climate-sensitive exposures harmful to human health are considered, including outdoor and indoor air pollution, including

aeroallergens; insect vectors of human illness; waterborne infectious and chemical contaminants; and compounding of climate health risks with other public health emergencies, such as the COVID-19 pandemic. Evidence-informed strategies for reducing future climate risks to health are considered.

KEYWORDS
climate change, climate-sensitive exposures, exposure pathways, flood-related health outcomes, health outcomes, heat-related health outcomes, NPCC4, public health

CONTENTS

1 | CHAPTER SUMMARY

This chapter considers climate health risks, vulnerabilities, and resilience strategies in New York City's unique urban context. It updates evidence since the last New York City Panel on Climate Change (NPCC) health assessment in 2015 as part of NPCC2[1] and addresses climate health risks and vulnerabilities that have emerged as especially salient to New York City (NYC) since 2015. Climate health risks from heat and flooding are emphasized. In addition, other climate-sensitive exposures harmful to human health are considered: (1) outdoor and indoor air pollution, including aeroallergens, (2) insect vectors of human illness, (3) waterborne infectious and chemical contaminants, and (4) compounding of climate health risks with other public health emergencies, such as the COVID-19 pandemic. At the end of this chapter, evidence-informed strategies for reducing future climate risks to health are considered.

Key Message 1: Climate change-related health risks are a threat to all New Yorkers, but especially those most vulnerable because of age, poor health, racial and social inequities, and social isolation. Inequities in household and neighborhood physical environments also mediate vulnerability to climate–health impacts. Addressing key environmental and social drivers of vulnerability is an essential adaptation strategy. Many current NYC policies and strategies, (e.g., improving access to residential air conditioning, tree planting), aim to accomplish this. These efforts can be informed and evaluated using data on climate–health vulnerabilities, such as components of the heat vulnerability index (HVI) and a flooding vulnerability index (FVI) under development (VIA Interim Report).

Key Message 2: Heat waves are, on average, the deadliest type of extreme weather in NYC and in much of the United States. Even hot, but not extreme, summer weather causes serious illness, death, and other harms to wellbeing. Because of climate change, NYC will experience more dangerous hot weather. Most heat-related deaths are due to exacerbation of chronic health conditions, such as cardiovascular disease. Indoor exposures can be especially deadly for people without air conditioning who have one or more physical or mental health conditions, are energy insecure, or are older adults. Also vulnerable are those with jobs exposing them to unsafe temperatures. These risk factors can be consequences of structural racial, social, and economic inequities. Adaptive measures are needed that protect vulnerable populations from season-long heat-health risks, including from nonextreme but hot weather. Evidence-informed strategies include enhanced access to air conditioning, reducing energy insecurity, engaging community and health provider networks to reach vulnerable populations, and augmenting tree canopy cover.

Key Message 3: Public health can be impacted before, during, and after flooding, which exposes New Yorkers to risks of drowning and other injuries, stressful evacuation, short- or long-term displacement from home, and exposures from clean up, repair, water contaminants, and mold from water damage. Climate projections for NYC anticipate an increase in extreme precipitation days and sea level rise contributing to more frequent flooding over wider areas. Socioeconomic disadvantage, racial inequities, pre-existing health conditions, and flood-vulnerable housing and infrastructure amplify health impacts of flooding. Adaptation strategies that modify these factors can reduce future flooding impacts on health.

Key Message 4: Hotter weather can increase concentrations of harmful air pollutants, including fine particles and ground-level ozone, by increasing emissions of precursor pollutants and the formation of ozone on warm, sunny days. These pollutants are harmful to health for all New Yorkers, but especially for the very young and old, people with certain chronic health conditions, those without residential air conditioning, and those living where emissions from buildings and traffic are concentrated. Most of these vulnerability factors are more common among Black, Latino, and low-income households. Despite a warming climate, air quality has improved in NYC because of reduced local and regional emissions. Recent wildfire smoke plumes affecting much of the eastern United States indicate the potential to reverse a trend of improving air quality. Efforts to further reduce emissions and exposures of vulnerable populations can prevent or mitigate climate-related air quality impacts.

Key Message 5: Nationally, pollen monitoring data show that climate change is causing an earlier, longer, and possibly more intense plant pollen production season, but this trend is less evident in the northeast. Within NYC, pollen from several common tree species, ragweed, and grasses contribute to seasonal allergic rhinitis and asthma exacerbations. The burden of asthma exacerbations from any cause is greatest in communities with less access to health care and more household asthma triggers leading to less well-managed asthma. Ambient pollen levels are influenced by local weather, allergenic plant density, and species composition. Air conditioning and filtration can reduce indoor pollen exposure. Attention to local tree cover density and species composition along with improved access to care, evidence-based asthma management, and patient education can reduce pollen exposure, vulnerability, and future allergic illness.

Key Message 6: In the northeast, changes in climate, landcover, habitat, and host animal ranges continue to shift the spatial and seasonal distribution of mosquitos and ticks that are current or potential vectors of human illness. Within NYC, the spatial distribution of these vectors and potential for human infection and serious illness varies with differences in the built environment, natural habitat and host animal abundance, human behaviors, and population vulnerability. Seniors, those with chronic illnesses, and people who are homeless are more susceptible to complications from West Nile virus (WNV) infection. Lyme disease risk among New Yorkers is increased among those engaged in outdoor activities mostly outside the city, but also in Staten Island and a limited area in the Bronx. Vector-borne disease (VBD) risk is also increased by international travel to and immigration from disease-endemic areas. Disease surveillance, vector monitoring and control, and public and clinician awareness can reduce future risks in a changing climate.

Key Message 7: Climate change may increase risk of exposure to waterborne pathogens in surface waters and wastewater in and around NYC and could threaten its drinking water sources and distribution system. Increased flooding can cause exposure to contaminants from household sewage backups and in surface waters from combined sewer overflows (CSOs). Rising temperatures facilitate the growth and spread of pathogens such as bacteria that cause gastrointestinal illness, Legionnaire's disease, and a range of illnesses from harmful algal blooms (HABs). Extreme weather and climate change impacts on NYC's source and distribution infrastructure could compromise water quality and quantity. Continued maintenance and adaptation of infrastructure along with coordinated surveillance of water quality, human, and animal health can help prevent adverse impacts on health.

Key Message 8: Climate risks can be compounded when they disrupt lifeline infrastructure systems or overlap with nonclimate public health emergencies. Examples include power outages during recent extreme heat events and the COVID-19 pandemic creating potential disease transmission risks in cooling centers and other publicly accessible indoor spaces. The health risks from compound hazards can be reduced through investing in lifeline and other critical infrastructure and building mechanical systems that are adapted to extreme weather, redundant, and flexible. Rapid, flexible, collaborative, multisectoral responses are needed to respond to pandemics and other unanticipated compound hazards.

2 | INTRODUCTION

2.1 | Chapter scope: NYC's human habitat, weather, and health

A premise of this chapter is that "Cities are for people and therefore human health, wellbeing, safety, security, and opportunity should be central considerations in sustainable urban development."[2]

Protection from the direct harm of climate extremes is just one of many basic biophysical and psychosocial needs that New Yorkers share with all people.[2] In a changing climate, NYC shares with all cities the imperative of continually adapting its social and physical infrastructures to provide healthy human habitat, especially for its most vulnerable people and communities. As a coastal, densely developed city, New York has both inherent challenges and advantages for protecting people from climate change health risks, while enabling sustainable, low-carbon living. These health risks and per capita carbon emissions vary considerably within the city and between the city and other parts of the region.

Variation in human vulnerability to climate risks and in contributions to carbon emissions are shaped by NYC's unique and varied built and natural environments, its racial and ethnic diversity, and the enduring legacy of racial and economic injustice and inequality shared with the region, state, and nation. Racial injustice, historical land disposition, and more contemporary land use policies and practices are among the social and economic forces that have shaped an inequitable distribution of access to healthy, climate-adapted human habitat. The topic of climate equity is addressed more fully and in-depth in *NPCC4: Advancing Climate Justice in Climate Adaptation Strategies for New York City*.[3]

Climate-adapted human habitat includes but is not limited to shelter, especially housing, that protects people from unsafe temperatures and flooding, energy services that affordably and reliably meet essential needs, and outdoor environments with natural and built features that enable healthy activity and mobility while also reducing exposure to heat, flooding, and other climate-sensitive weather hazards. Thus, vulnerability and resilience to climate risks are mediated and modified by the social and population context, by characteristics of the physical environment, and by causal interactions among these factors and characteristics (see Figure 1). This framework is the organizing structure for this assessment of health risks, vulnerabilities, and adaptation/resilience strategies for NYC.

2.2 | Chapter organization and scope

This assessment will consider climate health risks, vulnerabilities, and resilience strategies in NYC's unique context. It will also provide an update on evidence since the last NPCC health assessment in 2015

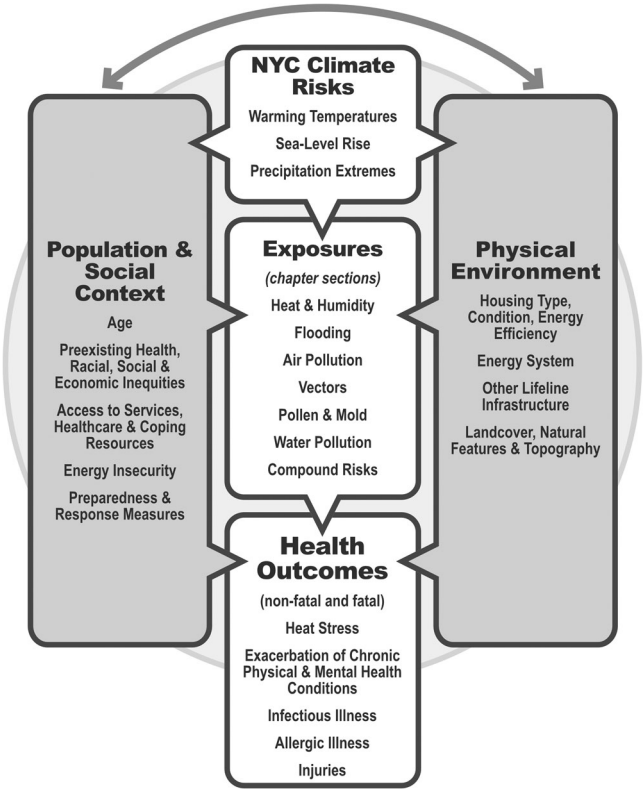


FIGURE 1 Urban Climate Change Health Impact Framework. Sections of this assessment correspond to exposures. Separate assessment reports cover the topics of racial, social, and economic inequities[3] and energy (insecurity, system, and housing energy efficiency).[4] Framework adapted from chapter 1, fig. 14.1 in Balbus et al.[5]

as part of NPCC2[1] and address climate health risks and vulnerabilities that have emerged as especially salient to NYC since 2015.

Climate health risks from heat and flooding will again be emphasized, as these represent the largest present threats and because—absent continued adaptation—anticipated climate change[6] will increase health risks from hotter summers, and the increasing frequency and severity of flooding. An assessment of life-safety and health risks from pluvial (cloudburst or extreme rain) flooding will complement a synthesis of coastal storm and flooding health impact evidence, including new studies since NPCC2.

In addition to the two climate risks that are the focus of this chapter—heat and flooding—other climate-sensitive exposures harmful to human health are considered: (1) outdoor and indoor air pollution, including aeroallergens, (2) insect vectors of human illness, (3) waterborne infectious and chemical contaminants. This assessment also considers compound health risks from co-occurrence of extreme weather events and of extreme weather with other public health emergencies, such as the COVID-19 pandemic. At the end of this chapter, evidence-informed strategies for reducing future climate risks to health are considered.

In addition to topics covered in this chapter, a large and growing body of evidence demonstrates how energy insecurity can amplify both overall climate impacts on health and their inequitable distribution among communities and populations, including in NYC. Energy insecurity's role in vulnerability to climate risks is noted in this chapter and addressed more fully in a separate chapter, *NPCC4: Climate Change, Energy, and Energy Insecurity in New York City*.[4] That chapter also notes how protecting public health requires that local, state, and national energy transition policies and investments reduce energy insecurity and preserve and enhance reliability and resilience of NYC's energy system.

Other topics related to climate change and health that are amenable to adaptation at the local level will be addressed in other chapters of this NPCC4 assessment, including health impact assessment to estimate benefits of climate action, adaptive and maladaptive uses of air conditioning in NYC in *NPCC4: Concepts and Tools for Envisioning New York City's Futures*, and potential for health co-benefits of modifying the public right of way (streets and sidewalks; also in *NPCC4: Concepts and Tools for Envisioning New York City's Futures*).[7]

Climate impacts on some domains relevant to the health of New Yorkers, such as agriculture, oceans, larger scale ecosystems, and global health, conflict, and international migration, require adaptations and responses primarily at the state and national levels. These domains are considered in other assessments, including the Fourth and upcoming Fifth National Climate Assessments,[8,9] and the Sixth Intergovernmental Panel on Climate Change Impacts Adaptation and Vulnerability Report.[10] Finally, while this assessment does consider mental health impacts of, and vulnerabilities to, local climate risks and exposures, the topics of climate anxiety and other mental health effects of awareness about global climate and ecological change and how to best respond—areas of active and evolving research[11–15]—are beyond the scope of this assessment.

3 | CLIMATE–HEALTH EXPOSURES, IMPACTS, AND VULNERABILITIES IN NYC

3.1 | Heat: Extreme heat events and higher warm season temperatures

3.1.1 | Current and projected future climate and local health risks

The NPCC3 noted that observed summer temperatures from 2010 to 2017 largely fell within the range of NPCC2 projections, continuing warming trends observed at Central Park since 1900 and somewhat steeper increases at LaGuardia and JFK airports. Using updated models, the NPCC3 projected that on average heat waves will be more numerous, intense, and longer in the coming decades.[16] The NPCC4 climate projections update and refine these but are qualitatively similar in forecasting a future with warming temperatures, more hot days, and more frequent extreme heat events for NYC (see Ref. 6).

Climate and emissions projections generally align in pointing to anthropogenically driven climate change causing a continued increase in global warming. This is due in part to the inertia inherent in the global climate system and a significant "emissions gap" between commitments and actions.[17] Unavoidable, anticipated increases in

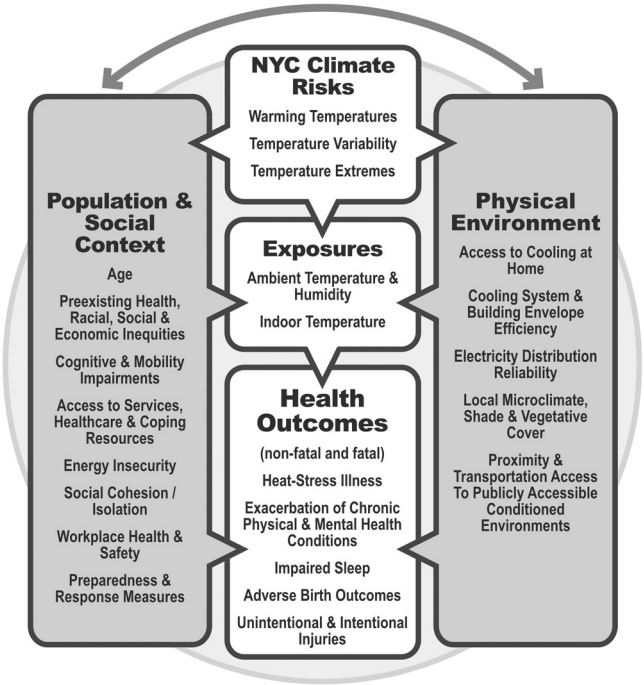


FIGURE 2 Heat-health impact pathways and vulnerabilities. Framework adapted from chapter 1, fig. 14.1 in Balbus et al.[5]

multiple climate hazards, including hotter weather, are creating and will increase multiple risks to humans, health infrastructure, and ecosystems.[10] In addition, in New York and other large cities, heat exposure is amplified by the urban heat island (UHI) effect,[18] which is discussed in more detail later in this chapter and will be addressed more fully in *NPCC4: Tail Risk, Climate Drivers of Extreme Heat, and New Methods for Extreme Event Projections*.[19]

3.1.2 | Health impacts and pathways

Hot and humid weather is dangerous and can cause a range of serious health impacts (Figure 2). In a typical summer, heat-related deaths and illnesses are not highly visible because they often happen behind closed doors in homes and without much news coverage. This can make it hard for the public to recognize the dangers of heat. In recent years, however, news coverage of the devastating and historically unprecedented heat waves in India and Pakistan in 2015 and 2022, Canada and the US Pacific Northwest in 2021, and many extreme heat events globally has underscored the increasing dangers of heat and warming climate for the general public and some policymakers.[20,21]

Heat exposure can directly cause heat-related illnesses such as heat cramps, heat exhaustion, and heat stroke (life threatening high body temperature caused by heat exposure).[18,22] It can also exacerbate existing chronic conditions such as cardiovascular, pulmonary, or renal diseases as discussed further below. Both heat-related illnesses and heat-related exacerbations of chronic conditions can lead to emergency department (ED) visits, hospital admissions and, in the most severe cases, death.

Surveillance of deaths identified on death certificates as caused or accompanied by heat-related illnesses—often referred to as heat stroke deaths and hereafter referred to as heat-stress deaths—has the advantage of timeliness and can give insights into circumstances for individuals succumbing to heat. However, heat-stress deaths are likely under ascertained and underreported, and certainly underestimate the true mortality burden from hot weather.[23] Most epidemiologic studies use a comprehensive approach of statistically estimating excess mortality from natural causes (i.e., chronic conditions), all causes, or broad causal categories.[24] Consistent with this practice, the NYC Department of Health and Mental Hygiene (NYC Health Department) conducts surveillance for both heat-stress deaths and excess mortality from natural causes, referred to as heat-exacerbated deaths. In its 2023 report,[25] the NYC Health Department estimates that hot weather, defined as days with a maximum temperature reaching 82°F or hotter, kills an estimated 352 NYC residents each year, on average. This includes an annual average of seven heat-stress deaths from 2012 to 2021. By contrast an annual average of 345 heat-exacerbated deaths occurred from 2016 to 2020; 115 of those deaths occurred during extreme heat events, defined by the National Weather Service (NWS) heat advisory threshold for NYC[26]: "at least two consecutive days with a maximum heat index (HI) of 95°F or higher or any day with a maximum HI of 100°F or higher".

National counts of heat stress also greatly underestimate the lethality of hot weather. The annual average of 153 heat deaths in the United States according to data compiled by the NWS[27] and 702 heat-related deaths according to the US CDC[28] do not include heat-exacerbated deaths. A recent study using data from 297 counties representing 62% of the US population estimated that more than 5500 deaths were attributable to heat (i.e., were heat-exacerbated deaths) annually from 1997 to 2006.[23]

In addition to mortality from exacerbation of chronic health conditions, higher-than-normal warm season temperatures are associated with an increased risk of deaths from external causes in the United States. These include deaths from drowning and transport injuries, as well as homicides and suicides.[29] Higher ambient temperature is associated with homicide and interpersonal violence in cities, including New York, especially during the warm season.[30] Two studies have found that the risk of cocaine overdose deaths in NYC increased with ambient temperature, a relationship also seen in other jurisdictions.[32–34]

Nationally, ED visits for all causes increase somewhat on extreme heat days. ED visits for heat-related illness increase much more during heat waves,[35] and are a better indicator for assessing heat-health severity during an extreme heat event than increases in all-cause ED visits. Heat-associated mortality in NYC has been shown to correlate with heat-related illness ED visits by a roughly 1-day lag.[36] For timely heat related health surveillance, NYC monitors EMS calls for heat and ED visits for heat-related illness using syndromic surveillance data.[37]

A wide variety of chronic health conditions can be exacerbated by heat exposure. In NYC, hospital admissions for renal, cardiovascular, respiratory conditions and mental health conditions increase during

hot weather.[38,39] For this reason, and others discussed below, people with one or more of several chronic health conditions are more susceptible to heat-related illness (see Subsection 3.1.4.2). In addition, a recent review and meta-analysis of US studies found an increased risk of both pre-term birth and low birthweight associated with higher temperatures and extreme heat, especially during the third trimester; a smaller number of studies have found associations between high temperature and still birth.[40]

Heat-related health problems can also have adverse financial repercussions for individuals, especially for those without health insurance or adequate insurance.[41,42] Prior work documents some of the heat-mortality impacts that have occurred in NYC.[43] When assessed by applying a *Value of Statistical Life* approach, these total at least $20.1 billion (in 2023 dollars), from heat-related excess mortality in 2016–2020, and heat-stress deaths 2012–2021.[44,45] A wider range of societal cost estimates to NYC for care of climate-sensitive illnesses and premature loss of life are being developed for the city and will be reported separately in the *Climate Vulnerability, Impact, and Adaptation Analysis* (*VIA*),[46] a multi-disciplinary research effort, led by faculty at the New School in NYC, focused on future potential climate conditions and associated socioeconomic impacts.

Hot weather can strain the power grid, resulting in power outages. Although NYC already experiences substantial heat-related mortality each summer, in recent years the city has not had to contend with prolonged and unprecedented temperatures seen in other parts of the world, such as the weeks-long extreme heat that affected Pakistan and India in 2022 with temperatures in some cases exceeding 120°F.[47] Such extended heat waves could be catastrophic in NYC if accompanied by a power outage. Lack of mechanical cooling for New Yorkers is a critical concern during a heat wave, especially because indoor temperatures can be higher than outdoor temperatures in the absence of air conditioning due to building thermal inertia.[48] In 2003, in NYC, there was a 2-day power outage during hot but not extreme weather. Even so, there was a 122% increase among accidental deaths and a 25% increase among nonexternal cause deaths attributable to the outage, resulting in 90 excess deaths over the period.[49] A 2003 heat wave in Europe resulted in more than 70,000 deaths.[50] Of those, about 15,000 occurred from August 1 to August 20 in France,[51] where home air conditioning prevalence is also low. Record, extreme heat in the Pacific Northwest in 2021 over about a week resulted in more than 600 deaths directly attributed to the heat in British Columbia,[52] many of them in Vancouver where only about one third of the population has home air conditioning.[53] Nearly all—98%—of these deaths occurred in homes without cooling.[54] In addition to loss of air conditioning, other threats during a heat event complicated by a power outage include lack of subway service, elevators and pumped potable and other water to upper floors of NYC's many high rises, and strain on emergency responders. Outages can also strain the health care system as more people require medical care when they lose home cooling, the ability to charge electrically powered medical devices, such as oxygen concentrators, and access to other essential services that require electricity. A heat wave accompanied by a major flooding event that damages energy infrastructure or impedes emergency responders could also be particularly deadly. The public health impacts of power outages are discussed further in Yoon et al.[4]

The reliability of the energy grid is key to maintaining population health and supporting emergency response efforts (see NPCC4, Yoon et al.[4]). Building-level back up energy systems, for example, solar panels with battery storage, or microgrids can help buildings maintain essential services during power outages.

Backup systems can also help the health care sector respond during hot weather with power outages. Nationally, hospitals certified by the US Centers for Medicare & Medicaid Services are required to have generators capable of running air conditioning, but there is no similar explicit federal requirement for nursing homes.[55] In New York State, nursing homes and long-term care facilities are required to maintain safe temperatures but are not required to have generators capable of running air conditioning.[56]

Heat impacts may be felt in other areas, such as schools, that could eventually affect educational attainment, economic opportunity, lifetime income and health. Higher temperatures are associated with lower scores on high stakes academic exams in the United States[57] and China.[58] An analysis of NYC Regents high school exit exams found that higher temperatures on exam days were associated with substantially lower test scores.[59] Data on air conditioning were incomplete and only available at the school (not classroom) level but indicated that 38% of schools lacked air conditioning and that the temperature effect on test scores was larger in such schools. Cumulative hot days during the school year were also associated with a reduction in student performance. In 2017, NYC announced plans to air-condition all classrooms to provide a safe and comfortable learning environment for students.[60] NYC school buses are required to provide air conditioning on buses transporting children with special needs. There have been reports of dangerously hot conditions on school buses, however, including those transporting kids with special needs.[61,62]

Increasing temperatures may also impact food safety. Warm temperatures have been associated with more food safety violations for insufficient refrigeration equipment and cold food holding in the summer in NYC restaurant inspection data, indicating that even during current summer temperatures some restaurant infrastructure is strained.[63]

3.1.3 | Temperature, other heat-stress metrics, and health outcomes

Environmental heat stress is influenced by several factors, including air temperature, humidity, velocity, and radiant heat such as from sunlight or hot pavement. A variety of heat exposure metrics have been developed to consider both ways in which humans respond to heat stress and environmental conditions in different settings: indoors and outdoors, in sun and shade, and by populations that engage in physical activity during hot weather and those who are able to avoid strenuous activity.

In hot conditions, body heat is shed to maintain a safe body temperature. This happens in several ways, including evaporation of sweat,

contact with cooler air and radiation of heat from skin warmed by increased blood flow.[64] Heat-related illness results when a person's ability to maintain a safe body temperature or stay hydrated is overwhelmed by environmental conditions. As noted earlier, heat exposure can also exacerbate chronic health conditions, such as through stress on compromised respiratory and cardiovascular systems, and dehydration that decreases kidney function.[65] Physical activity generates more body heat and increases heat stress. People living or working in a locality can acclimatize, generally within a few weeks, to hotter weather to a certain extent, as their bodies become more able to shed heat, such as through sweating.[66]

Heat-stress metrics commonly used include the air temperature, HI (which includes humidity), Humidex, and the Wet Bulb Globe Temperature (WBGT).[64] Humidity can impact sweat evaporation, a key cooling mechanism. The WBGT is based on temperature, humidity, sun angle, cloud cover, and wind speed. It was designed to assess heat-stress risk in people who are outdoors in unshaded locations and to guide activity limitations and cooling breaks for populations such as workers, soldiers, and athletes.[64,67]

Temperature and the HI have been widely shown to predict population risk of increased deaths and serious illness during hot weather in different countries, in US cities, and in NYC in particular.[70–72] An NYC study showed that the maximum HI predicted excess mortality as well or better than many other metrics and that the risk of heat associated death rose in a nonlinear way,[70] though this study did not include the WBGT, which is appropriate for use in outdoor occupational and athletic settings. Despite the influence of humidity on individual heat stress, a recent multi-country study suggests humidity measures may not improve prediction of mortality risk at the population level.[73] This does not mean that humidity does not contribute to heat stress, however. Because temperature and HI are highly correlated, population-level studies may be unable to disentangle the relative contributions of heat and humidity to associations with health impacts.

The relationship between unseasonably warm and extremely hot daily temperatures and health is both nonlinear and cumulative.[74,75] As temperatures rise, the risk of heat-related death begins to increase more steeply and grows with more consecutive days of hot weather. Taking the nonlinear and cumulative effect of higher temperatures into account, there may be little if any additional "heat wave effect" on mortality risk.[76] It is nonetheless useful to set criteria for extreme heat events, calibrated to health risks in a particular locale, so that heat advisories can be issued to the public and heat emergency plans can be activated on days when the health risk from heat is highest. Even during periods of extreme heat, risk can vary; heat waves that are long and/or those with higher peak temperatures are particularly dangerous.[76,77]

In NYC, heat-health advisory levels have been set according to analyses of the local relationship between heat and mortality. An NYC study found that when the HI reaches 95°F or higher for two or more days, or 100°F or greater for any period, the risk of death from chronic conditions increases more steeply.[70] On the basis of this study, the NWS and the NYC Office of Emergency Management in 2008 agreed to lower the threshold for issuing NWS heat advisories and activating NYC's heat emergency plan to these levels[78,79] (see Section 4).

Although the hottest days of summer are the most dangerous to health, even moderately hot days can be harmful. About two-thirds of NYC's annual heat mortality are associated with moderately hot days when the temperature is between 82°F and 95°F.[65] One reason why these moderately hot days have a greater cumulative impact is that they occur much more frequently than extreme heat days (Figure 3).[65] For example, from 2011 to 2020, more than 20% of late June through mid-August days reached 90°F or higher.[65] Although the proportion of days above 90°F is highest in July, hot days historically can happen in May through September. In NYC, from 2016 to 2020, heat-exacerbated deaths occurred most frequently in July (37%), followed by August (28%), June (18%), September (10%), and May (7%). Interventions to address the season-long risk on moderately hot days, as well as the heightened risk during extreme heat events, will protect public health.[25] Ongoing health surveillance can help elucidate risks as the NYC warm season lengthens.

In an analysis of trends in heat-exacerbated mortality, the Health Department found that deaths declined substantially between 1971 and 2000 but leveled off after 2000 and began increasing in the past decade as NYC's climate has warmed and the increase in residential air conditioning plateaued.[25] The increases in heat-exacerbated deaths are attributable to a corresponding increase in moderately hot, but not extreme heat days (Figure 3), indicating that heat adaptation measures such as residential cooling, need to be available to people during entire the warm season.

The relationship between temperature and mortality varies geographically[9] even to the building level. Research at the global scale suggests that the minimum mortality temperature (MMT) collected from 658 communities in 43 countries was between 14.2°C (58°F) and 31.1°C (88°F) decreasing by latitude.[72] Research at the national scale indicates that heat-mortality rates are higher in the northeast and midwest compared to the south.[80] Another study in 11 large US cities suggests that MMT for heat varies between 65.2°F (18.4°C) and 90.4°F (32.4°C) with higher temperatures at lower latitudes,[71] reflecting in part less adapted physical environments (e.g., less air conditioning) in northern cities like NYC. Differences in building types and in the prevalence of indoor cooling account for some of the geographic variation (see Subsection 3.1.5). Less population acclimatization may also play a role, especially when temperatures rise faster than physiologic acclimatization in normally cooler locations and seasons,[81] such as during an early spring heat wave.

3.1.4 | Who is most vulnerable and why? Health, demographic, and social factors

Race and income

Heat risks to health are greater for people with lower household incomes, and other limited financial resources, and higher energy cost burdens, which reduce their ability to avoid heat exposure. The energy cost of air conditioning, for example, must be weighed against other

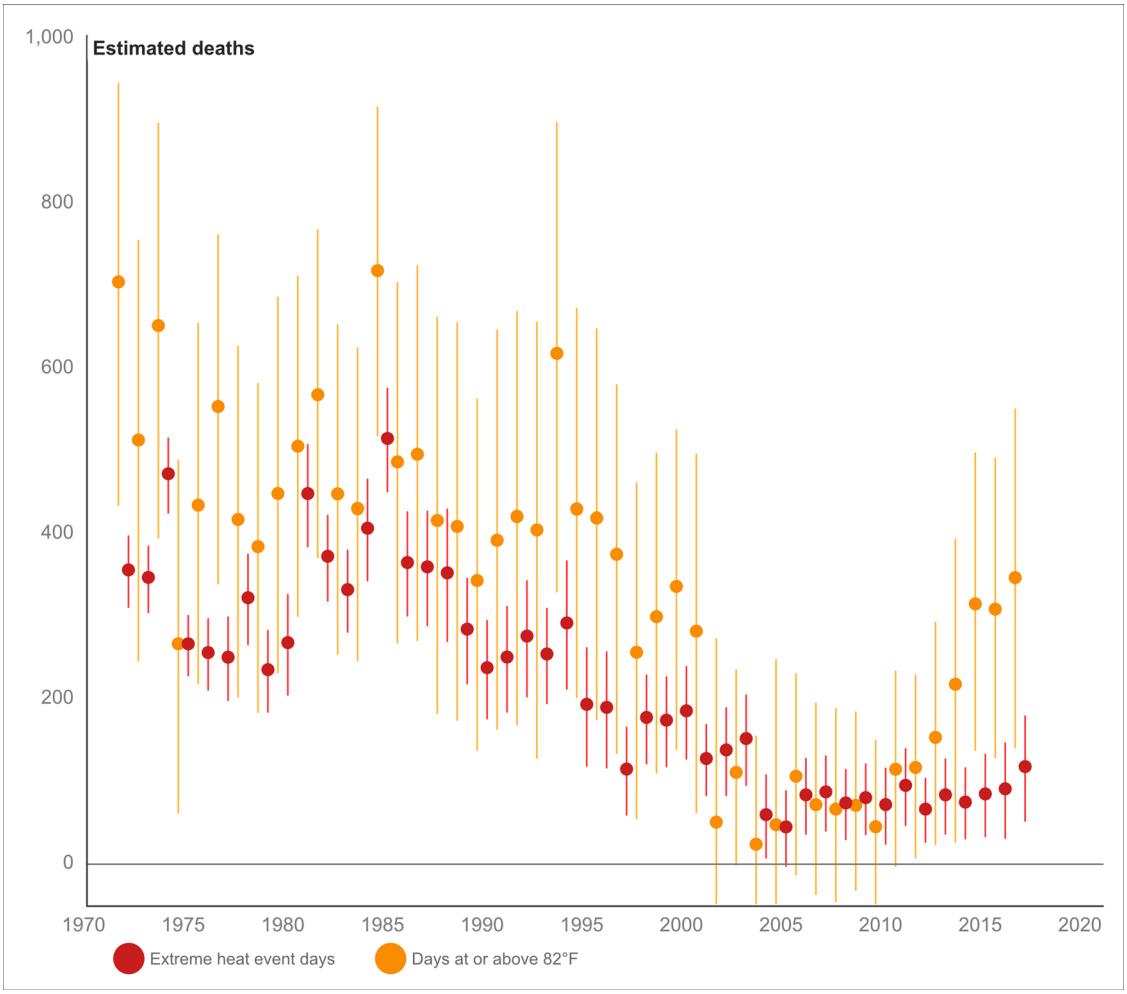


FIGURE 3 Annual average heat-exacerbated deaths for extreme heat event (EHE) days, and days reaching a maximum temperature of 82°F or higher, including EHE days, in 5-year moving time windows, 1971–2020, New York City. EHE days were defined as at least 2 consecutive days with 95°F or higher daily maximum heat index (HI) or any day with a maximum HI of 100°F or higher. The EHE and days at or above 82°F estimates come from separate regression models. *Source*: 2023 New York City Heat-Related Mortality Report.[3,25]

pressing priorities, such as purchasing food or medicine.[82,83] Racist and socially unjust policies have also created differences in economic opportunities, neighborhood environments, housing, energy access, and have led to overlapping health and environmental burdens[84] among communities of color and low-income residents. Black New Yorkers in particular are more likely to be exposed to heat and, as a consequence, have higher rates of heat-health impacts—inequities that are caused by past and current racism.[3,25]

The historical roots and current pathways linking structural racism and other unjust policies to present climate risk disparities are complex and the social context itself is also continually changing. The historic and future linkages of inequity to climate vulnerability are considered more fully in Foster et al.[3] Some of these pathways most relevant to heat-health risks are briefly considered here. For example, beginning in the 1930s, the practice of "redlining" at the federal level designated over 80% of the Black population in NYC at that time as living in "hazardous" mortgage risk zones. Climate researchers have shown that surface temperatures in formerly redlined areas across the country are on average 2.6°C (4.7°F) warmer than in nonredlined areas, due in part to less tree canopy and more impervious surface.[85] Redlining, zoning, and land-use planning and patterns over time, and how they interact to create and maintain climate inequities, are discussed in depth in Foster et al.[3] These factors, as well as displacement (i.e., gentrification), have shaped heat-health risk in the city. Although some formerly redlined neighborhoods have relatively low heat vulnerability indices,[86–88] inequities in heat vulnerability persist. Neighborhoods that are home to more people living below the poverty line and Black residents tend to have less vegetative and tree cover and less access to air conditioning at home.[65,87,89] These pathways for increased heat exposure are some of the reasons why Black New Yorkers are disproportionately affected by heat-exacerbated mortality[90] and experience rates of heat-stress mortality that are twice as high as White New Yorkers.[91]

Racism and economic disadvantage create health vulnerabilities through multiple, interacting pathways including, but not limited to, access to affordable and healthy food, access to safe places for

physical activity, and health care systems that do not provide care to all who need it. For example, there are large inequities in access to health insurance by race, income, and documentation status. People without health insurance are less likely to have access to primary care, receive preventative health screenings, and have fewer resources to manage chronic conditions.[92–97] Suboptimal management of health conditions because of these barriers may, in turn, predispose individuals to heat-related illness or exacerbation of their health conditions. Even when care is accessible, people of color may receive substandard treatment due to racial bias.[84]

Households experiencing energy insecurity are much less able to afford air conditioning purchases, maintenance and repair, efficiency upgrades, weatherization, or utility costs of using air conditioning during hot weather (see NPCC4, Yoon et al.[4]). Hotter summers caused by climate change will raise these already high cooling energy cost burdens for low-income households[98] and will further strain the electric grid, which tends to be more prone to outages and brownouts in marginalized communities.[99,100]

During the deadly 1995 Chicago heat wave, a comparison of the social conditions in two low-income neighborhoods found that the neighborhood with high levels of social connectedness and vibrant public spaces fared much better. By contrast the community with declining population levels, high levels of empty housing stock and abandoned buildings, reduced levels of business and other street activities, higher crime rates, socially isolated seniors, and neglected public spaces like parks and sidewalks, fared much worse. People living in this neighborhood, which was also home to more Black residents and comparatively more people living below the poverty line, may have felt discouraged from interacting with their surrounding community, making it harder to maintain social connections to call upon during times of emergency. Klinenberg[101,102] posits Black Chicago residents were more likely to live in communities with high levels of disinvestment, and that is one reason why that population suffered higher death rates during the heat wave. There were also some neighborhoods in Chicago with more Black residents that stayed safe during the heat wave, but those areas were not experiencing population decline and other forms of neighborhood depletion.

Chronic and mental health conditions

Chronic physical health conditions, including diabetes, obesity, high blood pressure, respiratory conditions like chronic obstructive pulmonary disease (COPD), congestive heart failure, and kidney disease also increase vulnerability to and risk of illness and death from heat-stress exposure.[39,103–106] People with these conditions may be less able to maintain a safe body temperature or be more prone to dehydration because of their condition or medications they must take.[104] People of color and people with lower incomes bear an inequitable burden of chronic conditions, as discussed above, and this is evident in NYC for diabetes and other chronic health conditions (Figure 4).

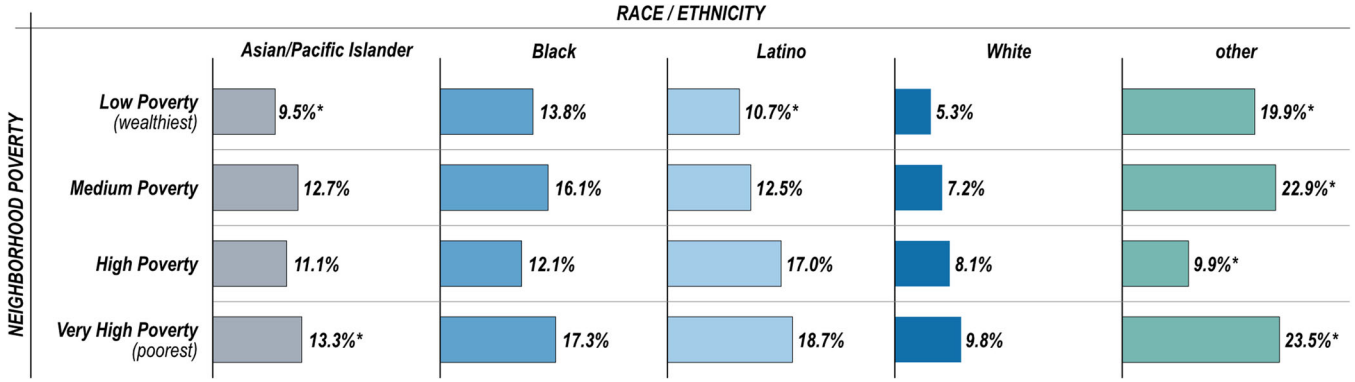
People with mental health and cognitive conditions are more vulnerable to heat-related illness and to exacerbation of their pre-existing conditions by heat exposure. In a national multi-city study of Medicare participants, those with chronic cardiovascular, respiratory, or neurologic conditions, including dementia, were associated with an increased risk of hospitalization during extremely hot weather.[108] Recent studies in NYC have shown an increase in ED visits for mental health and cognitive conditions[109] associated with increases in daily outdoor ambient temperatures above 27°C (~81°F), including schizophrenia, mood disorders, anxiety, self-harm, substance use, Alzheimer's disease, and dementia.[109] Nationwide studies among US adults also demonstrate these relationships.[35,110] In addition, several studies have documented increases in suicide attempts associated with increases in temperature and/or humidity.[29,111–114]

There are multiple drivers of risk for people experiencing mental health conditions that likely play a role in increased susceptibility during hot weather. Mental health drivers include medication interference with body temperature regulation, coexisting physical health conditions, and reduced ability to recognize the heat risks and engage in self-care.[115,116] Heat can impact sleep quantity and quality, which may exacerbate mental health conditions.[117] Limited evidence suggests that schizophrenia patients may be physiologically sensitive to environmental heat stress independent of medication.[118] These factors, combined with social and environmental factors, such as social isolation, worse housing quality, or inability to pay for or run air conditioning, can compound risk. Men are more likely than women to be socially isolated through their 50s, in general, and at older ages, when they are never married or experienced relationship disruption.[119]

Age

Aging is associated with changes in physiology, adaptive capacity, and greater likelihood of social isolation that can increase risk to heat.[120] Thirst and thermoregulatory mechanisms, including evaporative heat loss, and adaptive behaviors may decline with age. Older adults are more likely to have chronic health conditions and take medications that predispose to heat-related illness.[120–123] Although NYC has a younger age structure than other parts of the state or country, it too is aging and in the coming decades will see sizable increases in the proportion of population over age 65.[124] Women are more likely to live longer than men, and by themselves in those older ages, increasing their chances of becoming socially isolated, which may increase risk for mortality associated with heat or other causes.[125–127] Older adults are more vulnerable to a range of climate risks to health, as discussed further in Box 1. Importantly, age increases the likelihood of social isolation[119] which itself increases the likely impact of climate-related stresses and may be associated with living alone. For example, most of the heat-related deaths in British Columbia, Canada in 2021, discussed more in Subsection 3.1.2, occurred among older adults who lived alone and had multiple chronic conditions.[54] Notably, 67% of the deaths were among adults over age 70 and 56% were of those who lived alone.

Heat creates health risks across the life course. Although children and adolescents do not suffer the highest burden of heat-related disease compared to other age groups in epidemiologic studies, they are sensitive to heat exposure. Infants and children (particularly young children) must rely on adult caregivers to help them stay safe, cool, and hydrated.[128,129] Children and adolescents may also spend more time outside during play and sports, and may take longer to acclimatize to



Neighborhood poverty (based on ZIP code) is the % of residents with income below 100% of federal poverty level (American Community Survey 2007-11: Low Poverty (<10%), Medium Poverty (10-19%), High Poverty (20-29%), Very-High Poverty (>=30%)

Black, White, Asian/Pacific Islander, and Other races do not include Latino. Latino ethnicity includes Hispanic or Latino of any race.

Women who were only told they had diabetes while pregnant are included in the 'no' category.
Adjusted to the year 2000 U.S. Standard Population except when estimates are displayed by Age Group.

* Estimates should be interpreted with caution. Estimate's Relative Standard Error (a measure of estimate precision) is greater than 30%, or the 95% Confidence Interval half-width is greater than 10, or the sample size is too small, making the estimate potentially unreliable.

FIGURE 4 Prevalence of people who have ever been told they had diabetes by neighborhood poverty and race/ethnicity, 2017. *Source*: City of New York Department of Health and Mental Hygiene.[107]

warmer temperatures.[129,130] Few studies have been able to investigate to what extent children's physiological differences influence heat risk, however,[116,130] and there are also few studies that assess heat impacts among children. In NYC, one study found that higher temperatures were associated with increased rates of ED visits for children aged 0–18, with the greatest risk for children 0–4. Increased rates of hospital admissions for children aged 0–4 and 13–18 were also associated with warmer temperatures. ED visit risks were elevated for heat-specific, general symptoms, and injury diagnostic codes.[131] In addition, the prevalence of any mental illness and serious mental illness is higher among younger adults, compared to those aged 50 and older in the United States, contributing to potential heat risk among this age group.[132]

Pregnant people

Pregnant people are more susceptible to heat-related illness because of pregnancy-induced changes to thermoregulation, including increased weight gain, which may make it harder to release heat, and heat production by the developing fetus.[148] Heat exposure may also lead to pre-term birth, reduced birth weight, and still birth,[40] as noted in Subsection 3.1.2. Pregnant people who work outdoors, work in unair-conditioned environments or lack access to home cooling are likely most at risk.[149] A recent study in New York State found associations between extreme heat and increased ED visits for a number of pregnancy-related complications, including threatened/spontaneous abortion, renal diseases, infectious diseases, diabetes, and hypertension, with effects strongest among Black and low-income residents.[149]

People experiencing homelessness

People experiencing homelessness may be at a high risk for exposure to extreme heat, especially in urban areas due to increased heat exposure from the UHI effect. It is unclear how well heat alert messages reach unhoused populations and how they are perceived.[150] Unhoused populations have fewer financial resources, resulting in reduced ability to address health conditions that can contribute to heat susceptibility.[150] A limitation of heat-related illness and death data for this population is that denominators and standard, consistent definitions for people experiencing homelessness are not available to compute absolute rates or relative risks. In NYC, between 2000 and 2011, people experiencing homelessness accounted for an estimated 5%, 3%, and <1% of heat-stress deaths and heat-related illness hospital admissions and ED visits, respectively.[151] NYC's most recent annual report on deaths among people experiencing homelessness showed a more than threefold rise in deaths from fiscal years 2018 to 2022, with drug-related deaths increasing most rapidly.[152] Although this report does not examine excess mortality associated with hot weather in this population, it may have risen substantially given the increase in people experiencing homelessness in the city,[153,154] and the lack of access to cooling among unsheltered homeless people. Other studies show an association between heat and natural cause and drug overdose deaths in NYC[33,65] and with injury deaths nationally.[29] Exposure to cold temperatures, however, still presents a larger risk in NYC for people experiencing homelessness. Cold exposure was the second most common external cause of death (19 deaths, 4% of the total) among New Yorkers experiencing homelessness in FY 2022.[152]

Incarcerated people

In NYC, incarcerated people are exposed to unhealthy hot and cold indoor conditions due to a lack of federal, state, and local protections against dangerous indoor temperatures.[155–159] Thermal conditions inside these facilities are also a racial justice issue—incarcerated people in NYC and across the United States are disproportionately Black or Brown due to a long and ongoing legacy of racist criminal justice

BOX 1 Aging and climate vulnerability in NYC

About 15% of the population of NYC **is above age 65 and this proportion is expected to increase.**[133] This is a lower proportion than state- or nation-wide (17.3% of the US population is over age 65), but like elsewhere, the proportion of the city's population over age 65 is expected to increase substantially in coming decades.[124,133] Between 2010 and 2021 NYC's median age rose considerably, increasing from 35.6 up to 38.2 years and the proportion of NYC's population over age 65 is expected to increase by about 15% between 2020 and 2030 alone, and with disproportionately greater increases in the Bronx and Staten Island.[124,134] In big diverse cities like New York, older urban residents are more likely to come from historically disadvantaged or immigrant communities and have lower levels of education, income and insurance.[135,136]

As NYC**'s population ages and climate impacts unfold, the vulnerability of older adults to hazards such as temperature extremes (heat and cold), storms and flooding is a growing concern in part due to physical and neurological aspects of aging**. Chronic conditions (e.g., dementia, diabetes, and kidney disease) and acute conditions (e.g., heart attacks, falls, and pedestrian accidents) are more common in older adults, with disparities in many conditions by race with higher rates among Black than White adults.[137–139] Aging may also bring a decreased ability to complete activities of daily living (ADLs) and yield changes in physiology, including mechanisms associated with thermoregulation.[121,122,140] Older adults, and those with chronic conditions, may be more likely to experience adverse health outcomes during periods of extreme cold and heat.[120,121,141] Dehydration is also a concern in older adults[122] and drugs taken for chronic conditions may contribute to dehydration risk.[142] People with dementia may have a reduced capacity for adaptive behaviors in response to temperature or extreme weather events. Evacuation is a concern, especially for those with mobility or sensory impairments, and since when evacuating, medication may be lost or forgotten.[143]

Socioeconomic and demographic characteristics compound these vulnerabilities. These include living arrangements, kin networks, social networks, and housing characteristics as well as ideas and perceptions about risk and planning in old age. Though living alone, loneliness and social isolation are risk factors for mortality at all ages, these increase with age, with risk modified by gender and relationship history.[119,125] Nearly one out of three older adults living in NYC live alone and one out of three older adults live in a multigenerational household with differences by race and ethnicity.[144] Older immigrants may be more likely to experience loneliness and social isolation.[145] One third of older adults in New York report that they have limited or no English proficiency.[144] City dwellers live in a wider range of housing types from high-rise apartments to single-family homes, and a wider range of housing tenure arrangements,[146] which place them at different vulnerabilities in the aging-health-climate interface. Approximately 6% of New Yorkers are New York City Housing Authority (NYCHA) residents (including public housing, PACT, and housing, Section 8), representing 11.2% of the rental housing stock of the city.[147] Ten percent of older New Yorkers do not have working air conditioning (and 21% of older public housing residents) and 13% use supplemental heating (28% of older public housing residents).[144] Energy insecurity highlights how poverty, housing, and aging interact to place more vulnerability on people at risk of morbidity and mortality in a warming climate (see NPCC4, Yoon et al.[4]).

practices.[84] The US prison population is also aging and has high rates of mental and physical health conditions, putting individuals at increased risk during extreme weather conditions.[157] A recent national study found that 3-day heat waves were associated with a 7.4% increase in total mortality in US state and private prisons, with the largest regional effects in the Northeast.[160]

Occupation

Journalistic investigations of 2010–2020 Occupational Safety and Health Administration (OSHA) records reported that over 380 workers across 37 states in the United States died from occupational heat exposure.[161] Risk varies by occupation. The construction industry, an important employer in NYC,[162] ranks second nationally behind agriculture in the rate of heat-related death.[163] Deaths directly attributed to occupational heat stress are relatively infrequent among NYC construction workers,[164] though heat stress may indirectly contribute to other more common fatal construction injuries, such as falls,[165] which accounted for 58% of the 144 construction worker deaths in NYC from 2007 to 2014.[164]

A meta-analysis of international studies of occupational injury due to heat exposure from 2004 to 2020 found that there was sufficient evidence for a 1% increased risk of occupational injury for every 1°C (1.8F) temperature increase compared to a regional reference temperature and limited evidence of a 17% higher risk during heatwaves, with the highest occupational injury risk in humid subtropical climates like that of NYC.[166] Research suggests that people are comfortable and productive at stable temperatures between 20-25C (68-77F).[167,168] For every 1C (1.8F) exceeding this range, between 25-32C (77-90F), work productivity decreases by 2%.[169]

Outdoor workers and those who work in unair-conditioned indoor spaces are at increased risk of heat exposure and illness during hot weather. Heat-related illness and death have been documented in mail and package delivery workers in the United States.[170] Recent media reports highlighted worker concerns about heat exposure and a lack of air conditioning in trucks and warehouses in the NYC area and across the country during the summer 2022 heatwave.[171,172] One source estimates that more than 2.2 million workers in New York State are in high-risk occupations for heat exposure.[173] Professions at heightened

risk of indoor heat exposure include kitchen, warehouse, and manufacturing workers.[174,175] Workers exposed to high temperatures who wear personal protective equipment such as health care workers and firefighters may also be at increased risk of heat stress due to reduced ability shed excess body heat.[176–179]

3.1.5 | Influence of buildings and the built environment

Outdoor urban environment

NYC is experiencing higher summer temperatures because of climate change and the UHI effect. The UHI occurs when cities are hotter than surrounding suburban and rural areas—sometimes up to 15°F–20°F hotter.[180] The annual average magnitude of NYC's UHI (comparing Central Park to surrounding suburban and rural locations) has been rising gradually and has been observed to be about 2.5°C.[181] The UHI is caused by more dark paved surfaces that absorb heat, less vegetation and cooling from evaporation, more waste heat from buildings and vehicles, and less ventilation in urban canyons created by tall buildings.[18] The increasing UHI may explain one third of the warming trend in NYC during last century.[181] In NYC, overnight minimum temperatures are increasing the most compared to mean and maximum daytime temperatures,[65] as expected with UHI amplification. The physical processes influencing NYC's UHI are considered in more detail in Ortiz et al.[19] The rest of this section addresses how the UHI and outdoor landcover influence vulnerability to heat exposure.

Higher overnight temperatures can impair sleep quality[182] and reduce the respite vulnerable people need to recover from heat exposure. In addition to the regional temperature gradient caused by the UHI, neighborhood environments within cities also cause variations in surface and ambient temperatures and modify the health risks of hot weather. The UHI can worsen human health risks and discomfort by locally increasing ambient temperatures during extreme heat episodes, increasing energy demand for cooling (which can lead to blackouts), and generating higher emissions of air pollutants from associated cooling energy production[183] and modify the health risks of hot weather. Greenery can decrease ambient and surface temperatures through shade and evapotranspiration. Local temperature reductions depend on the amount of space greened, however. For example, a study of overnight temperature and green space in NYC found that an association between local ambient temperature and vegetative cover was only observed where vegetative cover was 32% or greater in a 200 m buffer zone around temperature monitoring sites.[184] Forested natural areas within cities are significantly cooler than other locations, including landscaped areas under trees.[185] Thus, NYCs several large urban forests in parks can provide a respite for those able to visit them because they live nearby, can reach those that are accessible by transit, or are able to drive or bike to them. Trees and other nature in locations closer to where most residences and human activity occurs in the city can provide health benefits. In addition to reducing air temperature and providing shade from radiant heat exposure, neighborhood greenspace, such as tree canopy, parks and forests, has been associated with better physical health, reduction in morbidity in some disease categories, lower levels of depression, and lower levels of stress and helps mitigate poor air quality.[186,187] A greater proportion of tree and vegetative cover in a community has been associated with a reduced risk of heat-exacerbated deaths.[188,189] The intersection of the physical environment factors (i.e., lower levels of green space) with neighborhood racial composition and other social factors has been used to construct compound heat vulnerability indices, including one for NYC[90,190] (Figure 5).

Indoor environments and health risks

The home is often a setting for dangerous heat exposure among vulnerable people. Those who die of heat stress in NYC are most often overcome by heat in dangerously hot homes.[65] In addition, heat-exacerbated deaths occur more often at home than in hospitals or other institutions.[90] Although place of exposure is not consistently recorded, exposure at home is also the most reported setting for NYC heat-related illness hospital admissions.[151] Vulnerable New Yorkers most often stay home during hot weather, even if they are unable to stay cool because of a lack of air conditioning.[191]

In NYC homes without air conditioning, it can be up to 10°F hotter indoors than outdoors.[48] Warm indoor conditions in homes without AC can persist for up to 3 days after the temperatures have cooled off outside following extreme heat[48] due to thermal inertia of the buildings and lack of cross ventilation. This may play a role in the delayed effects of up to 3 days documented in studies of NYC heat-exacerbated deaths.[70,192] Elevated indoor temperatures also play a role in deaths and illnesses that occur when the outdoor temperature is moderately hot but not extreme. Higher indoor temperatures during the summer season can also interfere with sleep quantity and quality,[117,193] which could exacerbate mental health conditions associated with hot weather.[194]

National studies have documented declines in excess mortality that occurred as residential air conditioning increased from 10% in 1960 to nearly 90% nationally by 2004.[195] In NYC during the latter part of the 20th century, there was a substantial decline in excess mortality associated with higher temperature during the warm season.[196] Analyses of data from 1971 to 2020 showed that heat-exacerbated mortality in NYC decreased until 2000, and then plateaued until 2010. Heat-related mortality rates have begun to increase in the recent decade as NYC warm season temperatures have risen and residential air conditioning rates citywide have remained flat.[65] Although more than 90% of NYC Households now have air conditioning, the proportions without access vary more than fourfold across neighborhoods.[87] People with lower incomes and Black New Yorkers are less likely to have access to home air conditioning.[89] Racial disparities in central air conditioning prevalence across four other northern US cities explain some of the racial differences in heat-related mortality.[197] Adaptive and maladaptive uses of mechanical cooling in NYC are addressed in NPCC4, Balk et al.[7]

Increased heat directly impacts thermal conditions in indoor environments, particularly in the absence of air conditioning.[18,198] In a study in NYC, apartments without AC on upper floors receiving

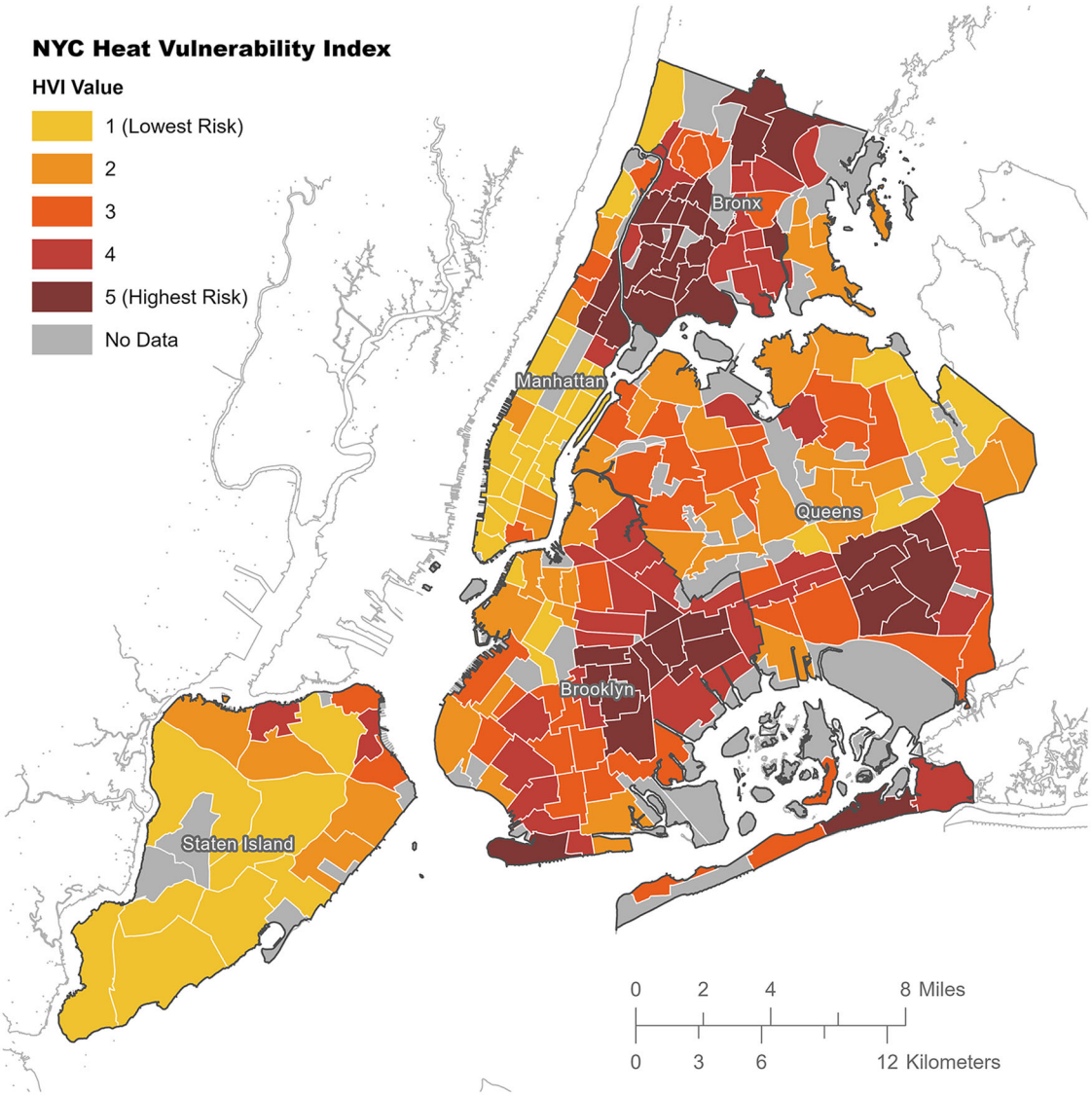


FIGURE 5 The Heat Vulnerability Index (HVI) for New York City identifies neighborhoods where the risk of death associated with extreme heat episodes is higher. It uses a statistical model based on surface temperature, green space, access to home air conditioning, a measure of income, and racial-ethnic composition - all at the neighborhood tabulation area (NTA) level. It was adapted and updated from an earlier epidemiologic study.[90]

direct sunlight with southern exposures were warmer.[48] The facades of the building and building albedo affect the heat absorption in a building,[200,201] as does insulation. Some building types and materials require more energy to cool interiors and heat up more rapidly without air conditioning. For example, all-glass high rises and pre-2000 high-rise buildings tend to heat more rapidly during power outages.[202,203]

Neighborhood-level vulnerability

Heat risk is not distributed uniformly across NYC neighborhoods. The city's HVI (Figure 5) is a composite measure of social and environmental factors used to identify neighborhoods that are at increased risk of heat-exacerbated mortality during hot weather.[204,205] Components are derived from an epidemiologic study of heat mortality in NYC[90] and has been validated to show that higher HVI levels are associated with greater heat-exacerbated excess mortality. Components include measures of surface temperature, green space, residential air conditioning prevalence, median income, and the percentage of Black New Yorkers, the population most impacted by heat mortality in NYC due to persistent structural racism, described in Subsection 3.1.4.1.

3.2 | Flooding

3.2.1 | Synopsis of NPCC2 Health Assessment

The NPCC2 2015 report was the last detailed assessment of public health risks of flooding in NYC.[1] Coastal storms and flooding were

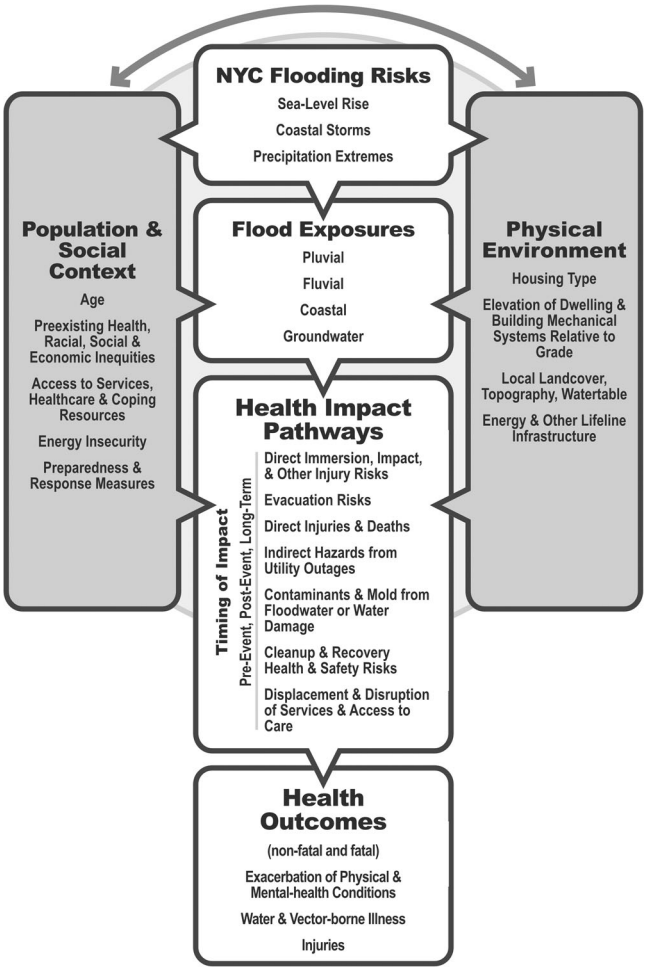


FIGURE 6 Flooding health impact pathways and vulnerabilities. Framework adapted from chapter 1, fig. 14.1 in Balbus et al.[5]

identified as principal climate–health hazards, along with extreme heat. Following the devastating impact of Post-Tropical Cyclone Sandy (also sometimes referred to as "Hurricane Sandy," "Superstorm Sandy," or "Sandy"), NPCC2 focused on health impacts of storm surge flooding as well as other coastal storm risks related to wind and evacuation. The Post-Tropical Cyclone Sandy experience showed how health vulnerabilities from floods are "magnified when critical infrastructure is compromised" and storm surge-related health risks are compounded by sea level rise and more intense storms.

Drawing on then-available studies of impacts of Sandy and other coastal storms, such as Hurricane Katrina, the NPCC2 identified seven causal pathways for health impacts from flooding: (1) direct impact phase injuries and deaths such as from immersion, moving debris, or electrocution, (2) evacuation risks, (3) secondary hazards from utility outages, (4) exposure to contaminants or mold from floodwater or water damage, (5) displacement and disruption of services and access to care, (6) stress, trauma, and other mental health impacts, and (7) cleanup and recovery health and safety risks. These same health impact pathways apply to all types of flooding, though their relative importance will vary by type (see Figure 6).

3.2.2 | Recent and projected NYC flood risks

Pluvial and fluvial flooding and health

Despite predictions of increasing extreme precipitation events, the 2015 NPCC2 public health report stated, based on experience at that time, that in contrast to Post-Tropical Cyclone Sandy's deadly surge, extreme rain flash flooding was "not a major threat to life safety" in NYC. Hindsight has shown this to be incorrect. Cloudburst events that can cause pluvial (rainfall) flooding continue to grow in magnitude,[206] and the NPCC3 noted increasing observed precipitation trends that tracked NPCC2 projections while recommending research and NYC-commissioned studies of heavy rainfall levels that could cause severe flooding in NYC.[207] Following those recommendations, the NYC Stormwater Resiliency Plan (SRP) and an associated study identified areas of inland flooding from heavy rain.[208] NYC had long been under an EPA Clean Water Act mandate to reduce CSOs that occur during heavy precipitation. The SRP understandably focused on bolstering green and built infrastructure measures for CSO prevention as well as property protection—noting an 80% reduction in CSOs since the 1960s. Thus, efforts to understand and plan for extreme precipitation (pluvial) flooding in NYC came before the lethal risk of cloudburst events was made clear.[209] As recently as September 29, 2023, unexpected widespread flooding associated with a stalled weather system dropped over 8 inches of rainfall on JFK Airport, exposing the city's risk of inundation from even indirect storm hits. This emphasizes the benefits of addressing basement apartment vulnerability as part of the city's overall affordable housing efforts and expanding efforts to flood-harden subways beyond coastal surge areas. A detailed discussion of flooding relevant to NYC is presented in NPCC4, Rosenzweig et al.[210] and general flooding-related definitions and terms are included in this assessment's companion glossary. The topics of changes in the public right of way and the importance of acknowledging flood risks to drivers are also mentioned in NPCC4, Balk et al.[7]

Events since 2015 and the climate and flooding assessments covered in NPCC4, Braneon et al.[6] and NPCC4, Rosenzweig et al.[210] have made it clear that life safety and other public health risks for New Yorkers are not limited to flooding from coastal storms. Pluvial (rain-related), fluvial (from rivers and streams), and groundwater flooding hazards also threaten NYC. However, FEMA's Special Flood Hazard Area maps are based only on fluvial and coastal surface water body flooding, and do not consider pluvial or groundwater flooding, both important in NYC (see NPCC4, Rosenzweig et al.,[210] Key Message 2).

The potential for cloudburst events to cause deadly pluvial flooding was made clear by Tropical Storm Elsa, in July 2021, and the Ida Remnants Cloudburst (also sometimes referred to as "Hurricane Ida," or "Ida") in September 2021. Heavy rain from Elsa flooded NYC subways and streets, requiring rescue workers to intervene to assist people trapped in below grade dwellings and other low-lying areas that were inundated in that event. Ida's unprecedented 3 or more inches of rainfall in 1 h in some neighborhoods, warranted NYC's first flash flood emergency in the city's history. Storm sewers were quickly overwhelmed in parts of the city. The rapid onset, extensive flooding of roads and below-grade spaces of inland areas outside established flood

plains caused numerous drowning deaths among residents trapped in basement apartments in NYC and in their cars in New Jersey.[210]

Fluvial flooding occurs when a river, creek, or stream stage exceeds the elevation of its banks. Streams across most of NYC's inland areas have been filled over time, with most surface water flow now redirected to subsurface stormwater sewers. Only a few freshwater stream channels and small inland creeks remain in NYC.[210] There are relatively limited areas in NYC with high fluvial flood vulnerability.[210] Current understanding of fluvial flood risks and projected future changes are limited by the shortage of stream gauges in the city, but FEMA does include fluvial flood hazard, along with coastal flooding, in the modeling to develop its Special Flood Hazard Area maps.[211]

Coastal flooding and health

Although future risks are difficult to quantify, coastal flooding is very likely to increase in frequency, extent, and height because of climate change and other factors covered in depth elsewhere in this assessment.[6,19,210]

Sea level rise increases the range of coastal flooding and introduces lingering effects as areas of New York become increasingly uninhabitable due to chronic flooding, potentially decreasing the available housing stock and increasing the mental stress of unplanned as well as planned relocation. There are interactions between coastal sea level rise and groundwater flooding, and these complex saline-freshwater systems can be further affected by increases in annual precipitation, or subterranean drainage and sewer infrastructure.[210] In addition to these interacting coastal flooding risks, recurrent tidal flooding is now a regular occurrence in low lying coastal areas such as Edgemere in Queens. Nationally, the National Oceanic and Atmospheric Administration (NOAA) identified a 200% increase in high tide flood days from 2000 to 2021 and projected average high tide flooding by 2050 to occur on 45–70 days per year.[213] Social and economic risks include loss of neighborhood functions such as shared beaches or piers that support community cohesion and recreation, and loss of housing, businesses, and associated revenues. Notably, flood insurance claims are paid for damages to communities impacted by recurrent overland tidal flooding that affects two or more acres, or two or more properties, but the National Flood Insurance Program (NFIP) does not cover flooding due to groundwater entering a basement, or for backups of sewer systems.[212] These flood events can be insured against through purchase of a rider often referred to as a basement backup or sewer backup rider on homeowners' insurance policies.

Prior to coastal storm landfall, evacuation can disrupt health care, increase stress, and create other health risks, especially for the most vulnerable people, such as those dependent on dialysis or other types of frequent health services. Although long-range weather forecasting improves awareness of incoming storms and increases the lead time available to prepare, resident preparedness does not necessarily increase, particularly for those with fewer resources or fewer alternatives.[214] Immediate event-phase health effects include fatal injuries, especially from immersion (drowning) and blunt trauma (from flood debris). During the post-storm phase, health risks persist as residents deal with flooded properties and struggle with access to basic services such as power and transportation. Additional post-storm health risks can arise from exposures to insect disease vectors, waterborne pathogens in floodwaters and from sewage backups and overflows, construction-related hazards, as well as exposure to various hazardous materials and toxic chemicals. Long-term health effects can include chronic physical and mental stress from property and monetary loss, displacement from neighborhoods, social networks and services, and interruption of health care.

Groundwater and health

Rising groundwater threatens to flood structures in a number of areas in NYC, particularly in eastern Brooklyn and southern Queens,[210] and especially below-grade spaces. Groundwater was pumped for drinking water in parts of southeastern Queens until 2007, but has not been used since then.[211] Intrusion from rising or fluctuating underground water levels during especially wet seasons can cause flooding that damages sanitary infrastructure and mobilizes subsurface sources of waterborne pathogens or chemical contaminants. Groundwater flooding can also compromise building and underground infrastructure stability, and can threaten ecosystems.[215] Although globally the greatest health-related threat from groundwater relates to arsenic contamination of drinking water systems, NYC's drinking water comes from upstate surface reservoirs, and as a result, arsenic is not detected in NYC drinking water.[216]

Compound flooding

Climate change will likely increase risks and health impacts from all four types of flooding under consideration, and from their co-occurrence. Compound flooding (the co-occurrence of coastal, fluvial, pluvial, and/or groundwater) is not well-understood due to limitations in modeling and less available research on household or individual health impacts of compound flooding as compared to singular types of flooding. A 2021 study compared various types of flooding to household outcomes, noting significant differences in financial, psychological and physical impacts and resulting coping and preparatory measures.[217] Although the NYC VIA Team is currently analyzing compound flooding,[210] compound flood-related health impacts are not part of the VIA analysis, leaving questions as to impacts of various combinations of flooding types to New Yorkers. Compound flooding impacts are also not included in current FEMA flood maps, which do not consider pluvial or groundwater flood risks.

3.2.3 | Updated flooding-health epidemiology evidence

Flood event phases and health-relevant exposure pathways

There are multiple possible pathways that can result in flood-related adverse health impacts. The various phases of flooding events—pre-event, event phase, and post-event—are each associated with different pathways of potential disruptions and harms,[218,219] depending in part on the cause of flooding and associated hazards, such as high winds.

Because of this complexity, as with heat waves, the complete health toll from flooding cannot be fully ascertained by immediately available reports of injuries or deaths. Recent excess mortality studies have revealed a much greater toll[220] and still more health impacts can be experienced months later by those relocated to far off communities. As with all climate–health risks, pre-existing factors increase vulnerability, including health, sociodemographic, and environmental factors. The following sections describe these overlapping flood phase-related pathways and pre-existing vulnerability factors.

Pre-event phase pathways

Emergency preparation and evacuation: Pre-event health risks relate to the extent to which New Yorkers have awareness of impending events and readiness to prepare themselves or have the ability and means to evacuate to a safe shelter. Emergency preparation could occur through multiple methods, including cell phone alerts, e-mail notifications, signage, and increasingly, clinical settings.[89,221–223] Social media posts also have value, particularly when they permit two-way communication between authority and respondent and provide information on who evacuated or is in the process of doing so.[224–226] However, the decision to evacuate is a complex one, even under an evacuation order.[227] Although awareness of evacuation zones may positively correlate with evacuation behavior, exposure to prior alerts that over- or under-estimated the severity of a storm may also impact the decision to evacuate.[214] The issue of language equity can exacerbate preparedness challenges faced by low English proficiency communities.[228]

Insurance and housing: Many people living in flood prone areas, remain uninsured from flood losses. After Post-Tropical Cyclone Sandy, it was estimated that infrastructure damages cost at least $19 billion.[229] Just over half of the one to four family homes in the high-risk zone were insured when Sandy hit NYC.[41,230] Moreover, even with recent changes to more risk-based pricing of insurance coverage under the NFIP, some residents are unable to afford premiums.[230–232] Also, residents outside of FEMA designated floodplains may not recognize their flood risks and may not choose to insure for flooding. Most tools show coastal flooding risk but are not clear enough about the types of flooding not shown, leading to a false sense of security about flood risks.[233] Even when risks are known, residents may have few choices given housing availability and affordability.[41,234] Moreover, while NFIP is available to owners and renters, the risks they face may be different. Flood risk disclosure legislation and planned voluntary housing mobility programs may help alleviate this challenge.[235,236] In 2022, statewide legislation was enacted that requires landlords to disclose past flood damages and risks to renters[237]; in 2023, similar legislation was passed for home buyers. See NPCC4, Rosenzweig et al.,[210] for more details on flood vulnerability.

Event phase pathways

Event phase pathways include direct exposure to fatal and nonfatal immersion, wind-blown debris, and electrocution from downed and submerged power lines. Emergency communications, system failure, access to care, and short-term displacement, and affordable housing shortages contribute to this pathway.

Direct injury risks: Paterson et al.[238] note that drowning is the most immediate cause of death from flooding particularly among men who may have greater risk-taking behaviors. Among direct injury deaths in NYC due to Sandy, about 70% were drownings; among those who drowned at home, at least 30% (nine people) were found in basements or lived in basement apartments.[239] Paterson et al.[238] also identify expected acute events such as orthopedic injuries and lacerations, and unexpected ones such as burns from flammable liquids spreading on the surface of floodwaters. Chronic health conditions may also worsen with flooding due to noncompliance with medication from interruption to availability, challenges accessing care, and the physical workload of recovery. For example, mortality rates in those with cardiovascular disease and diabetes may increase. Paterson et al.[238] also identify increases in acute events in those with chronic respiratory diseases due to disrupted maintenance therapy, loss of power to life-saving medical devices, reduced glycemic control, reduced physical activity, poorer nutrition and disrupted treatment leading to increased risks of ketoacidosis and death. Among older adults in nearby New Jersey, ED visits during Sandy increased for the injuries already mentioned as well as a range of other ailments.[240]

The majority of the Ida Remnants Cloudburst deaths in NYC resulted from drowning in basement apartments[209,241] (also see Yuan A, et al. https://pubmed.ncbi.nlm.nih.gov/38577778/). These tragic deaths revealed the need to evaluate risk based on locations within buildings, with heightened risks to those on lower floors with greater exposure to floodwaters. This is further explored in Rosenzweig et al.,[210] and in the NYC *Flood Vulnerability Index* (FVI) developed in the NYC *Climate Vulnerability, Impact, and Adaptation Analysis* (VIA).[46] Additionally, the loss of life from Ida brought into sharp relief how NYC's climate vulnerability is increased by its scarcity of affordable housing, which has long caused households to live in illegal basement dwellings that do not meet building codes for safety.[242] Although any lower level could be suddenly inundated by pluvial flooding, those that lack emergency exits or fail to meet other life safety measures increase occupant risks.[243–247]

Emergency communications: Surveys conducted by Yong[248] and Kreslake[249] provide insight into opportunities for improving emergency communication by surveying some of the most vulnerable populations on their risk perception and disaster preparedness. Black, Hispanic, and lower income households placed a strong importance on receiving high-quality information and assistance from the government during a flood disaster as well as on policies to both reduce emissions and pollution and offer rebates and loans to add cooling roofs and other interventions.[249] Importantly, given the diversity of NYC, providing information in multiple languages and via trusted community-based organizations, particularly for immigrant populations, is key. In Yong's survey, risk perceptions and "societal trust" were found to differ between Canadian-born and immigrant populations in Canada, affecting emergency preparedness positively and negatively, respectively.[248]

Systems failure: The Ida Remnants Cloudburst resulted in MTA and roadway flooding, impacting resident access to home or work. Interruptions to transportation systems in turn introduces challenges to those dependent on others to provide daily support, such as home health workers or home food and pharmacy delivery. In 2012, Sandy led to widespread and lengthy power outages. Health effects of power outages are discussed in NPCC4, Yoon et al.[4]

Access to care: Access to emergency care is limited during flood events. Some emergency responders may not be able to travel to emergency rooms or to access New Yorkers in need, for example, when flooded streets cannot be traversed by ambulances. People dependent on buses or subways to access care are similarly challenged. Pharmacies may not be open and health care facilities may be unable to serve patients with standing appointments for dialysis and other procedures or types of visits. Health care workers may be unable to get to their designated facilities, resulting in staffing shortages. Simultaneously, hospital admissions may increase, particularly for geriatric patients, as evidenced following Post-Tropical Cyclone Sandy.[250,251]

Post-event and recovery phase pathways and health impacts

Post-event and recovery phase pathways and health impacts include greater potential exposure to (1) waterborne and vector-borne illness, (2) aeroallergens, (3) other harmful exposures, as well as (4) adverse birth outcomes, stress, fatigue, and mental health burdens due to flood-related destruction of homes and interruptions to workplaces.[252,253] NYC health risks from aeroallergens and waterborne or vector-borne illnesses are considered later in this chapter. After tropical cyclones, increased hospitalizations from respiratory diseases, infectious and parasitic diseases, and injuries have been observed, along with higher death rates from these as well as neuropsychiatric conditions.[218,219] In addition, the flood recovery phase introduces (1) access to care challenges, (2) building repair risks, and (3) long-term displacement risks. A recent systematic assessment identified the need for research on disability, chronic disease, relocation populations, and social interventions.[223,254] Workers involved in clean up and recovery are also at greater risk.[255]

Waterborne illness: Increasing temperatures can contribute to the types of more intense rainfall-flooding events described earlier, with associated potential for contact with enteric pathogens[215] in floodwater or surface water contamination from CSOs. Nationally, tropical cyclones are associated with an increased risk of several waterborne infectious diseases, lasting days to weeks.[256] A fuller consideration of climate change related exposure to pathogens, other contaminants in water and human illness is in Subsection 3.6.

Vector-borne illness: Although vector-borne illnesses can increase alongside increased mosquito breeding areas following flood events, for some mosquito vector species, flooding can also wash away preferred habitat and breeding sites, helping to reduce vector populations. The relation of flooding to these illnesses is complex, geographically varied, and depends on vector species (see Vector-Borne Pathogens, Subsection 3.5 of this chapter). As New York experiences more flood events and as temperatures continue to rise, mosquito breeding is expected to increase and in turn generate increases in WNV.[257]

Other harmful exposures: Cleanup of flooded properties can expose residents and workers to mold from water damage (see Subsection 3.4.2) and to hazardous materials including asbestos or toxic chemicals[258] as well as increase risks of electrocution.[259] Tree removal workers without training in flood cleanup are at greater risk of injury.[260] Construction may pose hazards including exposure to sharp or heavy objects as well as dust. Moreover, when power outages require residents to use alternative power supplies, carbon monoxide poisoning increases.[261]

Birth outcomes: A systematic review of research on flood impacts on pregnancy outcomes found increases in the prevalence of low birth weight and gestational hypertension, but no significant differences in preterm birth rates.[262] Power outages associated with Sandy in eight NY state counties increased the number of ED visits for several pregnancy complications, especially among young, Black, Hispanic, and uninsured individuals.[264] A focused study of pregnancy outcomes following Hurricane Harvey in Texas showed significantly higher likelihood for adverse outcomes.[265] Another analysis of birth records in Texas showed coastal storms during pregnancy were associated with an increased risk of labor complications. The authors hypothesize, however, that associations with low birth weight and gestation found in other studies may be an artifact of the method used to define pregnancy interval.[263]

Stress, fatigue, and mental health: Chronic flooding and the challenges of being in continuous recovery mode increase stress. Causes range from the stress of displacement (such as from flooded basement apartments to emergency or temporary housing), from the loss of property/assets, to increased financial burdens for recovery costs or wage losses, which in turn exacerbate mental health challenges for some, and introduce new challenges for others. Stressful conditions have been linked to increased cognitive risks.[266] Increasing frequency of flood events fatigues already overworked health service providers and EMS teams. The loss of sense of home as a safe haven is an emerging area of pediatric research.[267] Following Hurricane Harvey impacting Houston, mental health symptoms consistent with post-traumatic stress disorder (PTSD) were associated with those experiencing impacts to their properties, including displacement and exposure to contaminated floodwater.[268] A more recent analysis of crisis help-seeking in Louisiana before and after Hurricane Ida showed an increase in crisis texts as documented by crisis counseling services including "thoughts of suicide, stress/anxiety, and bereavement, in the 4-week, 3-month, and 4-month post-impact period.[269]"

Short- and long-term damage and displacement risks: Short- and long-term loss of housing such as those immediately homeless following Post-Tropical Cyclone Sandy and the Ida Remnants Cloudburst amplifies the ongoing shortage of affordable housing in NYC. With many affordable units being at or below grade, flooding frequently destroys the unit with recovery requiring full remediation before occupants return home. Short-term displacement also impacts the ability to access transit to jobs, resulting in less earnings, or loss of jobs due to absences. More broadly, children who were evacuated are susceptible to a range of mental health symptoms related to their unique relationship to place and time and the disruption of friend networks.[267] How

inequities shape displacement risk is considered more fully in NPCC4, Foster et al.[3]

Those displaced may face extended recovery time frames, furthering the financial burden. Damage to neighborhood health care facilities, schools, and other services can further threaten physical and mental health among people remaining in their homes and/or faced with displacement and contemplating relocation. Relocation may impact access to jobs, schools, or childcare or may require greater portions of income for better quality housing, such units on higher floors. Continuity of health care services can be compromised when people needing ongoing care must relocate or neighborhood facilities close. Following Post-Tropical Cyclone Sandy, increases in ED, inpatient, and outpatient mental health visits, especially for Medicaid patients, were redistributed to facilities outside the catchment area of two hospitals which closed because of storm damage.[270] Emergency planning that includes pets and companion animals during disasters is important to limit occurrences of trauma among people forced to abandon their pets, or who refuse to evacuate rather than leave their animals.[271]

Following Ida, the city identified the need for evacuation measures and communications to those living in basement and ground level apartments.[209] However, the city has few resources to support evacuations during cloudburst events (such as consistent neighborhood-based shelters prepared to mobilize in advance).[272] Given estimates of over 100,000 basement apartments across NYC,[273,274] the scale of need extends well beyond available resources. In 2022, the NYC Comptroller released a new report, *Bringing Basement Apartments into the Light*, which called for establishing a Basement Board to provide basic rights, responsibilities, and protections for basement apartment residents and owners. Moreover, the NYC Department of Environmental Protection (DEP) is attempting to better understand cloudburst flooding and its impacts in different boroughs, but does not have detailed basement apartment locations.[247]

3.2.4 | Pre-existing factors that impact flood vulnerability (health, sociodemographic, and physical environment factors)

A range of pre-existing factors can increase people's vulnerability to flood risks. Factors include health (e.g., chronic physical and mental illnesses), sociodemographics (age, poverty, and race, among others), and physical environment (such as the type of residential dwelling structure). These factors can increase vulnerability across all or multiple flood event phases; and people are often affected by more than one pre-existing flood vulnerability.

Pre-existing factors that impact vulnerability: Mental and physical health

Preexisting mental health conditions, including depression, PTSD, and substance dependence, have been identified as potentially increasing susceptibility to harm from flooding. Similarly, multiple indicators of chronic physical illness, such as cardiovascular disease, cancer, end-stage renal disease, and being immunocompromised may make people more sensitive to the consequences of flooding, such as prolonged power outage, water contamination, living in congregate shelters and displacement.[275,276]

Pre-existing factors that impact vulnerability: Sociodemographic and physical environment

Household location: Household location is a significant determinant of flood exposure. Households with proximity to the coastal areas, to riverine areas, or to low-lying areas of NYC, have more direct exposure to floodwaters. One of NYC's biggest challenges is its sizable building stock of structures built prior to 1983 when Flood Insurance Rate Maps (FIRMs) were first enacted.[277] Older buildings are frequently challenging to retrofit to accommodate today's changing, climate change-fueled environmental conditions. However, there are few resources available to help residents understand these inherent risks see[210] for flood vulnerabilities in NYC. As noted earlier and discussed in detail in Rosenzweig et al.,[210] FEMA Flood Insurance Maps do not currently identify places at risk of pluvial or groundwater flooding. Also, as recent cloudburst events and recent flooding from high groundwater have shown, additional areas throughout the boroughs have flood exposures. The Ida Remnants Cloudburst showed that location in a designated flood hazard area is not the only indicator of actual flooding risk: below-grade areas not yet mapped as such proved to be at heightened risk of flooding. Moreover, with long-term sea level rise, some households are in places that will be subject to permanent inundation, such as in Edgemere, Broad Channel, and Old Howard Beach, Queens. RISE Rockaway and The Nature Conservancy are currently working with residents of Edgemere to develop more community awareness of long-term sea level rise and a shared community vision for Edgemere's future.[278,279] Particular flooding risks and vulnerabilities occur among mobile homes, which tend to be located in flood plains.[280] Although only one mobile home park is currently in NYC on Staten Island, mobile homes could come under consideration as a future strategy to expand affordable housing stock, making their over-representation in National Flood Insurance Policy claims more locally relevant.[281]

Sociodemographic: Demographics also correlate with certain evacuation behaviors: older adults may be less likely to evacuate, while higher income, White, and female populations may be more likely to evacuate.[282] Many public housing participants in a survey about evacuation behavior did not leave their residences for reasons related to health, responsibility for the care of another family member or neighbor, and distrust of government services and support.[283] Post-Tropical Cyclone Sandy revealed more about those populations who are more sensitive to the consequences of flooding, particularly for recent immigrants lacking documentation and dependent on landlords to restore their homes even as they personally lost their possessions. Similarly a disproportionate number of deaths from the Ida Remnants Cloudburst flooding occurred among recent immigrants.[284] People who are incarcerated, institutionalized or otherwise under government responsibility and living in congregate settings may face unique risks connected to restricted autonomy and movement, and associated vulnerability, especially if living in flood zones.[255] A fuller assessment of

how sociodemographic factors influence vulnerability to flooding is in NPCC4, Foster et al.[3]

Allostatic load: (Please refer to this assessment's companion glossary for a descriptive definition of "allostatic load" and other terms.) Multiple social vulnerabilities and chronic hardship among residents of public housing impacted by Sandy were characterized in a qualitative study as depleting the collective "resilience reserve," limiting the capacity of people to take protective measures before and after the storm impact.[283,285] Following Post-Tropical Cyclone Sandy, the intersection of race, ethnicity, age, and economic disadvantage contributed to greater flooding exposure and post-storm persistent distress in marginalized communities.[286]

Mobility-related conditions: Following Post-Tropical Cyclone Sandy, people with mobility access needs, such as elderly or disabled people, were vulnerable to immediate flooding impacts, such as escaping flood waters, or longer term, such as isolation in high elevation apartments due to lasting flood-related elevator outages.[287]

Physical environment: Injury risks and health effects are mediated through infrastructure and building impacts, especially at home. Building typologies and household location amplify loss of life, physical harms, and chronic mental stress. Beyond the immediate health impacts stemming from compromised shelter, other conditions, such as energy insecurity, sustain exposures longer than the life span of the event. Although energy insecurity is addressed in NPCC4, Yoon et al.,[4] the public realm, water supply, and transportation also warrant attention.

Building typologies: The risk New Yorkers face during a flooding event, whether from storm surge like Post-Tropical Cyclone Sandy, or flash flooding, like the Ida Remnants Cloudburst, differs depending upon several factors, including the location and type of residence. Whether a resident lives in a high- or low-rise building, the risks of sheltering in place depend on the type of construction and its resilience. Multiple studies on building impact show that one- to two-story bungalows are much more likely to take the bulk of structural damage during storm and flooding events, while high-rise buildings are more structurally stable, but may lose lifeline utilities that can reduce access to life-saving medications, potable water, the ability to get and maintain food at safe temperatures, and increase exposure to heat/cold-related illness and stress.[229,288] For example, among NYC injury deaths from Post-Tropical Cyclone Sandy, drowning accounted for 70% of all deaths. In addition, 60% of NYC deaths occurred at home, and disproportionately in Staten Island where mostly low-rise, single family home neighborhoods were impacted by the storm surge.[229,239] Post-Sandy analysis of impacts to building stock recognized that buildings in shoreline areas receiving the brunt of the storm surge had more damage than those that did not have direct storm surge. However, building height, construction type, and age were also predictors of damage, with older and single-story light frame buildings suffering more severe damage (18% of all buildings damaged, yet 73% of structurally damaged or destroyed). High rise buildings in these same areas experienced less structural damage but lost function due to systems (mechanical and electrical) failure.[229] Residents of both types of buildings are at risk and may be asked to evacuate or shelter-in-place, move to higher or lower ground, or a variety of other directives. A recent FEMA report series relates building characteristics, such as un-reinforced weak walls in older NYC buildings, to increased mortality risks from the Ida Remnants Cloudburst, and considers risks to life safety when cellars or basements are occupied.[289]

Moreover, risk can change depending upon the type of material used in a dwelling's walls, roof, and structure. Citywide, a substantial proportion of low-rise (one to two floors) buildings with wood frame construction were completely destroyed or rendered structurally unsound and uninhabitable by severe storm surge damage, while very few multi-story (seven or more floors) "noncombustible" steel and masonry structures sustained such damage.[229] On the other hand, many residents who sheltered in place or returned to mid- and high-rise residential buildings, including many public housing residents,[283] experienced other health impacts as building systems were disabled.[229,275] If mechanical, electrical, or plumbing (MEP) systems are damaged by flood water, elevators, power supply, heat, or water supply/toilets may be compromised. In turn exit routes may be unavailable, particularly for those who require assistance navigating stairs. Moreover, power outages may compromise residents with electrical medical devices or disable air conditioning during a combined flood/heat event, which can lead to heat stroke or other illness. The elderly and medically compromised are particularly vulnerable.[290] Health risks from utility outages are discussed in Yoon et al.[4]

During cloudburst events and coastal storms, health risks are higher for those living in basement apartments and those with mobility limitations or other disabilities. A substantial number of basement apartments are often without adequate emergency exits or windows, leaving residents unable to exit during flood events.[274,277] This phenomenon is not unique to NYC; flooding in Seoul, South Korea due to record rainfall in the summer of 2022 also resulted in drowning fatalities in semi-underground apartments.[292]

Power supply: Given that the loss of lifeline utilities is one of the largest contributing factors to ill health effects after a major storm, NYC has made efforts to improve the power resiliency of buildings. These measures include cogeneration to provide emergency power and retrofitting initiatives to increase energy-efficiency to slow down heat/cooling loss.[229] Similarly, NYCHA and other property owners are elevating electrical and boiler equipment above areas vulnerable to flooding (e.g., basements).[293] Power supply may also impact function of elevators, which are critical to accessing high-rise apartments.

Public realm: In parks, beaches, and surface waters around NYC contaminants from urban runoff caused by flooding can expose people using these for respite, play, and recreation,[294] though better tools and data are needed to characterize the contaminants and human exposure.

Water supply: There are multiple potential pathways for flooding and SLR to impact NYC drinking water supply, distribution, and quality. Sea level rise could cause salt front movement in the lower Delaware River, adding pressure to release more water from reservoirs and impairing supply.[295] Downpours in the watershed could increase turbidity and potentially runoff of other pollutants. Flood damage could

potentially impair the integrity and function of parts of the distribution system.[295] Increased turbidity is often used as an indicator of increased microbial contamination, which can increase the risk of gastrointestinal illness (GI).[296,297]

Transportation: NYC transportation systems, including roadways that serve as conveyances and buses and subway cars that move people, continue to be overwhelmed during cloudburst events.[298] Sidewalks, underpasses, subway access stairs, and tunnels continue to flood,[299] compromising transit and introducing toxins to riders trying to leave subways or navigate city streets. These transportation challenges further compromise New Yorkers' ability to safely move about the city and may disrupt health care services.

3.3 | Air pollution

3.3.1 | Synopsis of NPCC2 assessment

The NPCC2[1] projected increases across the New York metropolitan region in morbidity and mortality attributable to climate change through effects on air pollution, especially increases in ground-level ozone but also from increased emissions from electric power generation for cooling during hot weather. The magnitude of projected ozone changes depended on future emissions scenarios, and the greatest increases were projected in more suburban counties outside the city.[300] Health impacts of air pollution will continue to depend on demographic and neighborhood variation in vulnerability to air pollution, long evident within NYC, especially disparities in asthma prevalence. Also highlighted was the potential for combined health effects of heat waves and associated high ozone levels. Building-level resilience and vulnerability factors include the potential for air conditioning to reduce indoor ozone and pollen exposure and for tighter building envelopes for energy efficiency to increase exposure to some indoor allergens. Finally, black carbon in PM2.5 deposited on surfaces has the potential to accelerate both atmospheric warming by absorbing solar visible and infrared radiation in the atmosphere and snow and ice melt by darkening the surface.[301,302]

3.3.2 | Projected climate change and influence on future air pollution exposure

Air quality is affected by local and regional emissions and by weather. For ozone, higher warm season temperatures and more long, sunny days increase its formation in the atmosphere from chemical reactions involving precursor emissions including nitrogen oxides (NOx) and volatile organic compounds (VOCs). Braneon et al.[6] project that rising temperatures observed from 1991 to 2020 will continue for the next several decades. Increases in average precipitation levels are projected, but in larger amounts and with greater confidence during the winter season. Smaller increases or possibly decreases during the summer and fall may occur. Thus, weather conditions favoring ozone formation during the summer will occur more frequently in the region, with the net effect depending on trends in regional ozone precursor emissions. However, the climate change penalty to ozone air quality is an area of active research, and knowledge gaps and uncertainties remain due to complex dynamics of ozone chemistry and feedback mechanisms not accounted for in models.[303] For example, NOx is both an important precursor and when present in high concentrations can "quench" of ozone (react chemically with it) and reduce its concentration, especially at night and during the winter. Falling NOx emissions have contributed to higher ozone concentrations during the winter and in the warm season at night.[304] Nonetheless, heat waves in NYC, which are projected by NPCC4 to increase in frequency and intensity, cause metro area increases in ozone levels to exceed health advisory levels, driven in part by short term increases in local emissions of ozone precursor pollutants.[305]

Local and regional $PM_{2.5}$ concentrations are also influenced by weather, albeit less directly than ozone. Higher electric power demand for summer cooling can increase emissions from fossil fuel power plants—including more polluting peaker plants located within the city–of both primary $PM_{2.5}$ and precursors that form secondary $PM_{2.5}$. A national modeling study predicted increases in average population-weighted $PM_{2.5}$ and ozone exposures in the coming decades, but the projections varied between two climate models used and were substantially reduced when reduced emissions anticipated by 2040 were assumed rather than stable 2011 emissions.[306]

Higher temperatures and drought can cause wildfires that emit large quantities of smoke $PM_{2.5}$ and other pollutants. Modeling and monitoring show a modest fraction of $PM_{2.5}$ in the region from 2005 to 2018 was caused by wildfire smoke, enough to cause roughly 0.3% of asthma ED visits in the Northeast. From 2005 to 2020, marked increases in smoke $PM_{2.5}$ levels from 2005 to 2020 in the western United States caused little if any increase in smoke $PM_{2.5}$ pollution in the eastern United States and New York State.[307] As noted below, $PM_{2.5}$ levels in NYC continued to decline during this period, thanks to reductions in local and regional emissions.[308]

The potential for local air quality progress to be reversed by wildfire smoke was made clear in June 2023, when smoke from wildfires in Canada caused a dramatic increase in $PM_{2.5}$ pollution levels at real-time monitors in southern Ontario, New York, and other northeast states.[309] Concentrations of $PM_{2.5}$ in the NYC metro area exceeded any measured at regulatory monitors since regular measurements began in 1999.[310] State and city officials issued air quality health advisories,[311,312] advising that outdoor activity be limited, that masks be worn outdoors and will be distributed, and that people close windows and use air conditioning if possible. Several school districts in New York State canceled outdoor activities. The potential effectiveness and limitations of advisories and public health measures to reduce risks of acute air pollution episodes is discussed in Section 4.

Recent observed local and regional trends of key pollutants (NOx, ozone, PM2.5)

Even as NYC temperatures have risen in recent decades (see Ref. 19), regional emissions contributing to climate-sensitive pollutants have fallen. Across the NYC metro area, annual average $PM_{2.5}$ and nitrogen dioxide ($NO_{2)}$ concentrations were more than 40% lower in 2015–2019 than in 2000–2004; average of the fourth highest daily maximum

ozone concentration (used by the EPA for regulatory purposes) fell by about 20%.[313] Air quality has improved within the city as well.[308] Because of both regulations and economic influences on fuel usage, a reduction in emissions of upwind, regional and local sources of $PM_{2.5}$ contributed to concentrations falling by close to 50% from 2002 to 2018.[314] The air quality improvement was attributable to reduced emissions from multiple sources, conversion to cleaner heating fuels in large NYC buildings, natural gas replacing coal in regional electric power generation, and reduced tailpipe emissions in trucks, buses, and passenger vehicles[314–316] (see also Box 2).

Updated health effects epidemiology

Research continues to expand the recognized health effects of air pollution beyond those long-established: exacerbation of cardiovascular disease and respiratory diseases, including asthma, and respiratory tract cancers. Because common air pollutants from fuel combustion are ubiquitous worldwide and statistical power is more limited in local studies, pooled evidence from multi-city studies and global research is increasingly used to estimate health burden and determine policy. The most recent review of global evidence on air pollution and health found sufficient evidence to quantify health impacts of $PM_{2.5}$ on birthweight, gestational age, lung cancer, COPD, lower respiratory infections, type 2 diabetes, ischemic heart disease, and stroke; and of ambient ozone pollution on COPD.[317] Health effects of wildfire smoke are usually studied via contributions to total ambient $PM_{2.5}$ concentrations and include exacerbation of asthma and other respiratory diseases. Other effects may include exacerbation of cardiovascular conditions, all-cause mortality, and mental health outcomes. Children, seniors, and other groups may be more vulnerable. Exposure assessment challenges and method differences are limitations in current evidence.[318,319]

Ozone has long been known to cause lung inflammation and decreased lung function, as well has exacerbating asthma and COPD, leading to hospital and ED visits; emerging evidence suggests ozone exposure may exacerbate diabetes and contribute to complications.[320] Traffic-related air pollution as indicated by exposure to NO_2 is linked not only to exacerbation of asthma, but to its onset and to impaired lung development. Growing evidence also links air pollution exposure to functional impairments and diseases affecting nearly all organ systems, neurologic and behavior disorders and cognitive function in young children and older adults.[321,322] Lower birthweight and preterm delivery effects can produce lasting harm on child health and development.[317] A number of local studies have observed health effects in NYC, consistent with national and global evidence, for example,[323–326] Health harm from air pollution occurs at levels well below US National Ambient Air Quality Standards (NAAQS).[327] Thus, measures to reduce ambient pollution can have large health benefits, even where NAAQS are already met.

3.3.3 | Vulnerable populations

Health, social, and demographic factors

Children are more susceptible to air pollution because rapid development of their lungs and other organ systems, greater respiration rates relative to body size, and the potential for air pollution harm to have lifelong consequences.[321] Older adults are at higher risk of death and serious illness caused by air pollution, in part because they are more likely to have chronic cardiovascular, respiratory, and metabolic conditions that air pollution exacerbates.[340] Nationally and in NYC, Black, Latino, Indigenous, and low-income populations also have higher burdens of chronic diseases that are exacerbated by air pollution.[107] Improved management of conditions exacerbated by air pollution can help reduce impacts[341]; disparities health care access and quality may contribute to vulnerability. Research suggests that chronic psychosocial stress, associated with social disadvantage, shares biologic pathways with air pollution, effects, increasing susceptibility to health effects.[342–344]

Geography and physical environment

Nationally, communities with higher proportions of Black, Latino, Asian and low-income residents have higher than average exposures to $PM_{2.5}$,[345] and are more likely to be located near busy highways, refineries, and other industrial facilities.[346,347] In NYC, air pollution concentrations are associated with the density of emissions from buildings, including heating and commercial cooking, and from motor vehicles. Large buildings and their emissions are most abundant in parts of Manhattan, while traffic is more widely distributed, with the greatest contributions to emissions from diesel trucks and buses. As a result, in NYC, disparities in community ambient air pollution concentrations differ from the national pattern, with more affluent neighborhoods in Manhattan having concentrations of $PM_{2.5}$ and NO_2 that are among the highest in the city; when sensitivity to air pollution harm because of population health is accounted for, communities with more Black, Latino, and low-income populations are by far the most impacted.[348] Traffic-related air pollution exposures, especially from heavy-duty diesel vehicles, is more concentrated in low-income NYC neighborhoods, where populations are most vulnerable and traffic pollution impacts are greatest.[349] Household exposures and health effects of some outdoor air pollutants, including ozone, $PM_{2.5}$, and pollen, are greater among occupants of dwellings lacking air conditioning or high efficiency particle filters.[350–353] Disproportionate exposure to industrial land use and hazardous pollutants among low-income people of color is addressed further in NPCC4, Foster et al.[3]

Despite steady citywide improvements[308] (Figure 7a–d), higher $PM_{2.5}$ and NO_2 pollution levels within the city are observed in locations with more nearby boilers using heating oil or natural gas, traffic density, industrial structures, commercial cooking, and ship traffic.[354] Reductions in emissions during the spring 2020 COVID-19 shutdown were associated with $PM_{2.5}$ and NO_2 levels in NYC decreasing by roughly 25%, with the greatest improvements in the central business district due to reduced commercial cooking and traffic.[355,356]

Citywide, annual average levels of four of key pollutants have gone down between the first year of monitoring, 2009, and the most recent year of data, 2021: Fine particles ($PM_{2.5}$): 40%, nitrogen dioxide (NO_2): 38%, nitric oxide (NO): 58%, sulfur dioxide (SO_2): 97%. Maps for all pollutants monitored are available in a full report on methods, trends, and sources of spatial variation in air quality (Figure 7).

BOX 2 Gas stoves, indoor air pollution, and health

Gas stoves are used in more than 75% of NYC metro area dwellings.[328] Although climate change is not expected to directly affect gas stove emissions or health impacts and the contribution of gas cooking (including methane leaks) to NYC greenhouse gas emissions is likely small compared to emissions related to heating, (nationally, cooking accounts for less than 5% of residential natural gas use[329]), replacing gas stoves with electric induction stoves could have important health benefits.

Modeling and measurement studies show that: (1) emissions form natural gas burners in unvented kitchens can rapidly increase concentrations of nitrogen dioxide (NO_2) and carbon monoxide (CO), potentially to levels that exceed health-based standards and guidelines for short-term exposure to NO_2; (2) replacing gas with electric stoves effectively reduces indoor NO_2 concentrations while exhaust hoods effectiveness varies.[330–333]

A pilot study in NYCHA apartments demonstrated that increases in indoor NO_2 concentrations caused by use of gas stoves was prevented by replacement with electric induction stoves, which were preferred by households receiving them.[334]

An extensive body of evidence, mostly focused on ambient air pollution, links higher NO2 concentrations to exacerbation of asthma, lung inflammation, and impaired lung growth.[320,335] Because outdoor NO_2 concentrations are an indicator of a mixture of other pollutants from fuel combustion, including diesel exhaust particles, NO_2 concentration–response relationships may not apply to other settings and emission sources,[335] such as household exposure to gas stove emissions. Nonetheless, studies focused on indoor exposure to gas cooking and NO_2 exposure have shown associations with respiratory symptoms, including asthma and wheezing.[336,337] Gas cooking could account for an estimated 18% of asthma cases in New York State.[338]

At present, direct evidence of the effectiveness of replacing gas stoves with electric ones on occupant health is limited. A randomized study of an air cleaner intervention showed a benefit of particle filtration but not NO_2 removal on symptoms of children with asthma.[339]

Another health benefit of replacing gas stoves would be eliminating a source of interior gas leaks that can contribute to deadly explosions and fires.

3.4 | Aeroallergens

3.4.1 | Pollen

The NPCC2 health assessment noted the potential for climate change, the UHI, and increased CO_2 concentrations to lengthen the seasons for and increase concentrations of allergenic pollen in NYC. Local epidemiologic studies demonstrated that pollen from several tree species common within the city are important contributors to allergic illness, including allergic rhinitis and increases in ED visits for asthma, during the spring season. Grass and ragweed pollen also contribute to seasonal allergies in the late summer and early fall.[1] Consistent with the NPCC2 assessment, across 60 pollen monitoring locations in North America, warmer weather caused by climate change has led to earlier, longer pollen spring seasons and higher average pollen concentrations during the period 1990–2018. However, pollen trends varied geographically; the northeast region showing little or no average trend in pollen concentration or spring onset date.[357] A prior study of New York metro area tree pollen levels from 1990 to 2007 observed a shift to an earlier spring tree pollen season with a decline in average concentrations, attributed to regional construction and land use change.[358]

NPCC2 also noted that studies of the role different tree species play in seasonal allergy could inform urban tree planting programs.[1] Since then, studies have added to local evidence pointing to the importance of local tree species in seasonal allergy. In NYC, pollen counts from trees peaking in the middle of spring pollen season (maple, birch, beech, ash, oak, and sycamore/London plane tree) are associated with over-the-counter allergy medication sales (an indication of seasonal allergy symptoms) and ED visits for asthma syndrome.[359] In NYC and other locations, nearby tree canopy cover increases average springtime ambient tree pollen levels.[360,361] In a birth cohort study of children born to women living in Northern Manhattan and the Bronx, tree canopy coverage near the prenatal address was associated with tree pollen allergic sensitization and asthma at age 7.[362] As with air pollution and health disparities, differences in the burden of asthma as well as in access to and quality of care could contribute to greater vulnerability to pollen-related asthma exacerbation in low-income communities and among Black and Latino populations.

3.4.2 | Mold and fungi

The NPCC2 health assessment briefly summarized the influence of climate change on mold and health, noting that increased temperatures, coastal flooding, and heavy precipitation events can promote growth of mold and other fungi indoors, which in turn may cause respiratory symptoms and exacerbate asthma. Workers and residents could be exposed to unhealthy levels of mold during post-flood mold remediation without proper precautions.[1]

Studies and reviews of evidence since NPCC2 have largely been consistent in concluding that climate change and especially flooding events will promote indoor mold growth and increase risks to human health among residents of affected homes and workers involved

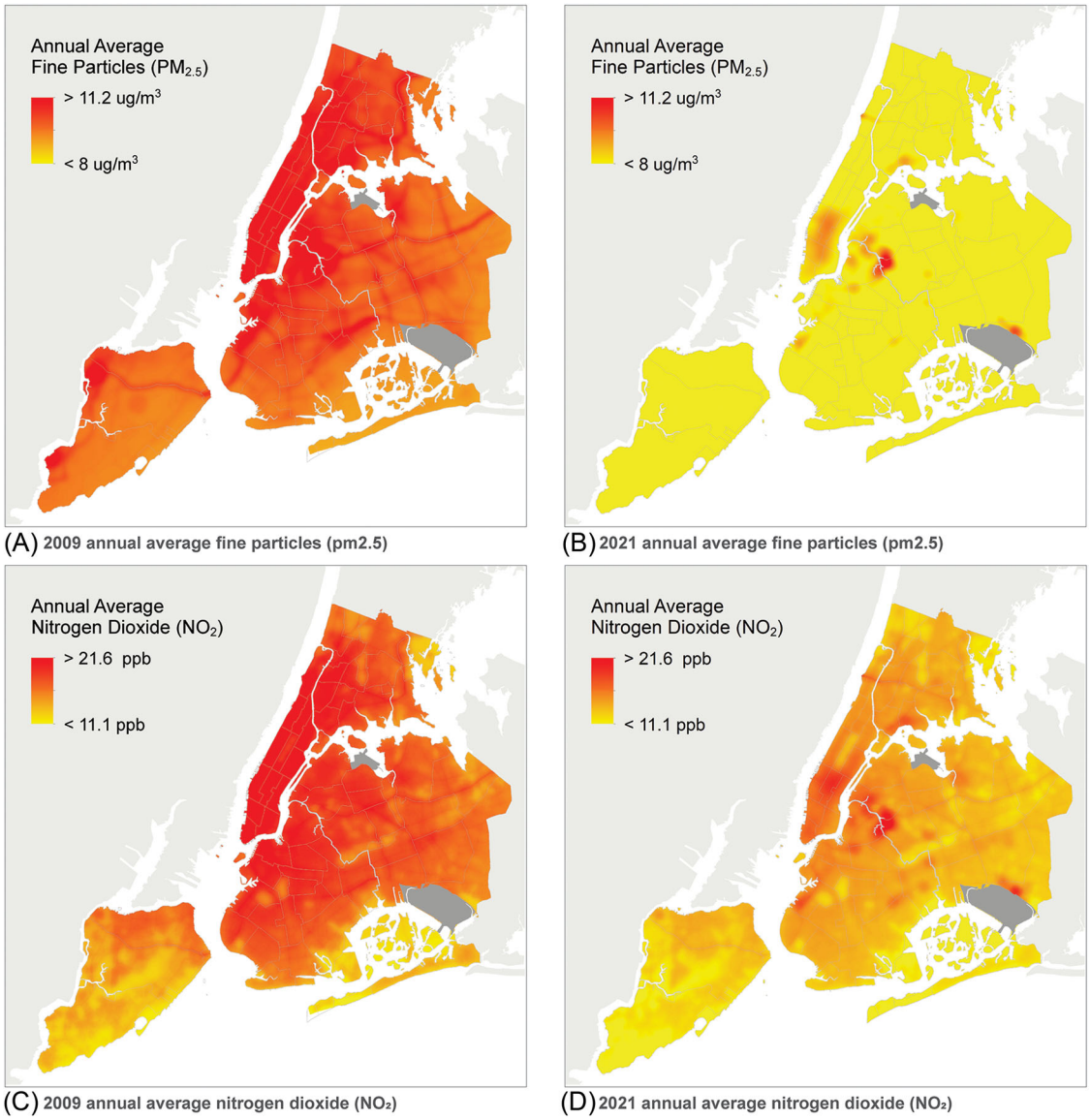


FIGURE 7 Pollutant distribution throughout New York City in 2009 and 2021. Particulate matter 2.5 μm or smaller ($PM_{2.5}$) in panels a and b; nitrogen dioxide (NO_2) in panels c and d. *Source*: City of New York Department of Health and Mental Hygiene.[308]

in mold remediation. Health impacts include respiratory illnesses and exacerbation of asthma in sensitive individuals.[363–365] Outdoor concentrations of fungal spores involved in allergy and respiratory disease are also influenced by weather and climate change.[366,367]

Excess moisture in homes, whether from flooding, leaking roofs or walls, chronically damp basements, or inadequately vented bathrooms can contribute to mold growth in building materials that provide a suitable growth medium. Occupants of these homes, particularly children, are more likely to experience respiratory illness.[368] Mold growth on moist building materials in a basement can contaminate other living spaces of a typical single-family home through passive air movement.[370] In 2017 in NYC, occupants reported leaks in an estimated 13% of dwellings; those living in low-income communities in northern Manhattan, the Bronx, and central Brooklyn were more likely to report leaks compared with residents of other neighborhoods.[371] These same communities have greater proportions of people with asthma who are more susceptible to mold and other aeroallergens in the home.[372] Compounding these impacts, with COVID-19, those with lung damage from mold are at greater risk (e.g., populations in public housing, elderly populations, young children, people with asthma and other respiratory comorbidities, disabled populations and lower income populations).[373]

3.5 | Vector-borne pathogens

3.5.1 | Synopsis of NPCC2 assessment

NPCC2 noted that some mosquito- and tick-borne illnesses such as WNV and Lyme disease are endemic in New York State. Climate

change, including warming temperature and changes in precipitation patterns, can shift the seasonal cycle and/or spatial distribution of mosquito and tick vectors of these and other diseases affecting humans. Locally, climate change is expected to produce warmer weather in all seasons of the year as well as more flooding from extreme rain, rising sea levels, and coastal storms. Without adaptation, climate change will increase the risk of vector-borne illnesses among New Yorkers, including the potential introduction of diseases not currently transmitted in the metro area. However, climate change is only one of multiple factors influencing vector habitat and disease risk for humans.[1]

3.5.2 | Climate change projections and influence on risk

Life cycles, population, and activities of mosquitos and ticks are sensitive to interactions among climate variables including temperature and rainfall. One national study showed increased temperature, humidity, and heavy precipitation to predict human WNV infection rates in the United States,[374] but more recent studies show the importance of drought preceding WNV epidemics.[375,376] Climate change is shifting and will continue to shift the geographic distribution of ticks that transmit Lyme and other human diseases.[377]

Although climate is undoubtedly important, complex, dynamic interactions among climate, animals, land use, human settlement and behavior patterns limit the utility of climate-disease modeling for predicting future VBD risks and informing prevention strategies.[378] Historical trends show how complex, nonclimate factors introduced malaria and yellow fever to the Americas, and the role these factors likely played in their elimination in the United States. Malaria and yellow fever likely came to the Americas during the slave trade in the 17th century and caused recurrent outbreaks in NYC and as far north as New England.[379,380] Because humans are the primary host for amplifying these mosquito borne diseases, improved living conditions that reduced indoor mosquito contact, such as screens, elimination of open cisterns, and air conditioning, likely played a major role in eliminating sustained local transmission of malaria and yellow fever in the United States.[379,380]

The Fourth National Climate Assessment concluded that climate change will alter the geographic range, seasonal distribution, and abundance of disease vectors, but also the influence on future risks of interactions with "changing ecosystems and land use, demographics, human behavior, and the status of public health infrastructure and management".[9] Future risk estimates depend on how these complex interactions are modeled. For example, an increase in WNV, the most common mosquito-borne illness in NYC, is anticipated under a changing climate,[257,381] but in one study, a mosquito biology model contradicted a climate model, predicting decreased WNV-risk in currently high-risk locations leading to an overall decline in population-weighted risk.[381] In addition, human acquired immunity after regional outbreaks may also limit WNV transmission.[375]

Similarly, a warming climate is expanding the northern range of the blacklegged tick (Ixodes scapularis)—the vector for Lyme disease,[377] and Lyme disease cases and exposure to the tick vector in New York State are associated with warmer days and mild winter temperatures,[382] but nonclimate factors have also played a role as described in Subsection 3.5.3.2.

3.5.3 | National, regional, and local vector-borne disease trends

WNV and other mosquito-borne illnesses

The WNV in the United States was first identified in NYC in 1999, and it has remained a threat to public health ever since. Nationally, more than 55,000 cases and 2600 deaths from WNV have been reported to CDC from 1999 to 2021, with the highest rates of neuroinvasive disease among older adults and residents of West North Central, East South Central, and Mountain regions.[383] Cases have fluctuated substantially from year to year during that period; national rates were fairly stable from 2013 to 2018.[384]

Within NYC in 2015–2020, reported cases ranged between 6 and 38, with no clear trend.[385] 377 cases of neuroinvasive (severe) presentations of West Nile and 47 deaths have been recorded in NYC residents from 1999 to 2021.[386] WNV infection is asymptomatic in 70%–80% of cases. People with symptomatic infection can experience fever, headache, weakness, muscle, and joint pain. Less than 1% of cases will develop WNV encephalitis and/or myelitis meningitis, which is inflammation of tissues surrounding the brain, brain stem, or spinal cord and can lead to serious morbidities and even death.[387] Because most infections are asymptomatic and symptoms are variable, reported cases are much less than the true number of infections.

NYC collects and tests pools of mosquitos for the presence of WNV at 53 permanent locations across the 5 boroughs, with additional collection sites deployed based on surveillance data. In 2022, the number of WNV-positive mosquito pools, 1555, was the highest ever detected.[388,389] This could be due to increased extreme precipitation events, warmer air temperature, lack of behavioral vigilance, or some combination. Summer of 2022 in NYC was its sixth hottest in recorded history, and rainfall was 4 inches below average.[390] The combination of hotter temperatures and dry conditions could have contributed to an increase in WNV infected mosquito pools.

Aedes aegypti, the species of mosquito that most commonly transmits chikungunya, dengue and Zika, is not found in NYC, and cases of these diseases among New Yorkers are typically attributed to travel to other places with this vector.[391] *Aedes albopictus* is present in NYC and is capable of transmitting Zika, dengue, chikungunya, and other viruses, but less efficient at doing so compared to *Aedes aegypti*.[392]

Lyme disease and other tick-borne diseases

Nationally, between 30,000 and 40,000 Lyme disease cases are reported annually; the number of confirmed and probable cases fluctuated with no clear trend between 2008 and 2019.[393] According to the

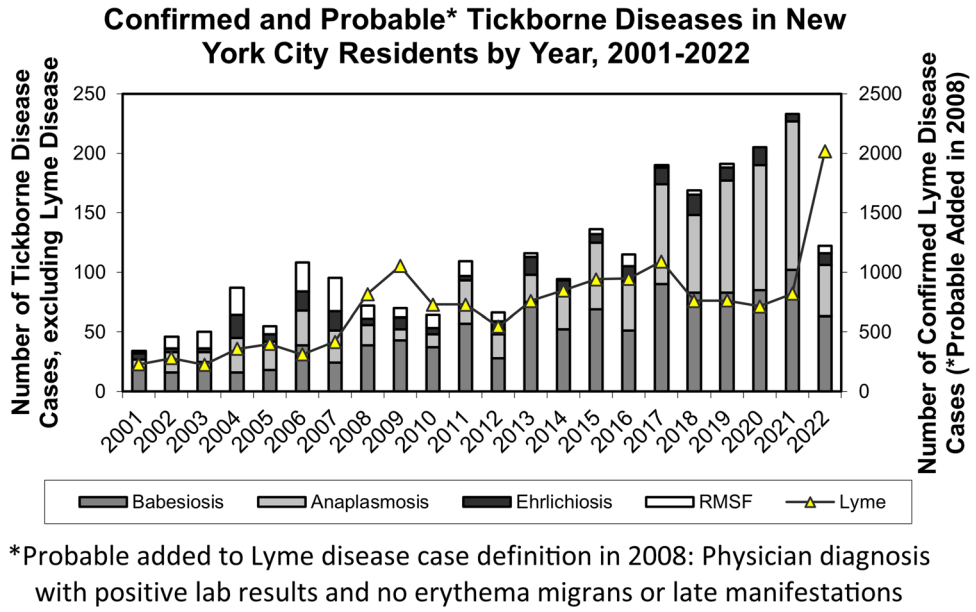


FIGURE 8 Case counts are by year of diagnosis. The 2022 increase in Lyme Disease cases is attributed to changes in the Centers for Disease Control and Prevention (CDC) case definition. *Source*: City of New York Department of Health and Mental Hygiene.[395]

most recent NYC Health Department surveillance report,[394] Lyme disease and other tick-borne disease (TBD) cases among NYC residents have been trending upward for more than 15 years (Figure 8). The abrupt increase in 2022 Lyme diseases cases is an artifact of a changed CDC case definition.[395] TBDs among New Yorkers are mainly acquired through travel outside of NYC to surrounding areas where the diseases are endemic. Locally acquired Lyme disease cases are most common in Staten Island.[395,396] Lyme disease remains the most reported TBD.

People acquire TBDs when bit by a tick carrying the infectious agent, usually during outdoor activity among residents or visitors to regions with a temperate climate and local habitat that supports the lifecycles of the tick vector. For Lyme disease, the blacklegged tick (*Ixodes scapularis)* is the vector, and the causal agent is the spirochete *Borrelia burgdorferi*. Lyme disease cases can occur at any time of the year, but are highest in the spring and summer, both due to the activity of the nymphs and an increase in outdoor activities.[397]

New and emerging tick vectors and TBDs are being detected in New York State and in the city. In addition to the blacklegged or deer tick vector for Lyme disease, anaplasmosis, babesiosis, and Powassan virus, the American dog tick, which can transmit Rocky Mountain spotted fever, the lone star tick, a vector of ehrlichiosis, the Asian long horned tick, and Gulf Coast tick have been detected in NYC.[394]

The Asian long-horned tick and lone star ticks are also established in Staten Island and parts of the Bronx. The Asian long-horned tick was first reported in the United States in 2017 but has not yet been shown to transmit disease, though internationally they have been shown to spread several animal and human diseases.[398] The American dog tick is found in all five boroughs of NYC.[399] The Gulf Coast tick is also in Staten Island. These established ticks, along with the blacklegged tick, have tested positive for multiple pathogens.[395]

3.5.4 | Factors influencing population vulnerability

The differences in population vulnerability to a mosquito- or tick-borne illness is influenced by a combination of individual health and behavioral factors, socioeconomic factors and living conditions, and nearby landcover, habitat, and ecosystem factors that influence disease vectors abundance, behavior, and encounters with people.

Mosquito-borne illness

Those considered the most susceptible to severe WNV infections include the elderly, homeless, and those with underlying conditions or compromised immunity.[400] Outdoor workers are at increased risk of exposure to WNV-infected mosquitos.[401] Those living in homes with poorly fitting doors and windows or without door and window screens are also at increased risk.[386]

Landcover, including both natural, agricultural, and urban features, can create mosquito breeding habitat. These interact with climate and nearby populations, living conditions, and behaviors to influencing potential exposure to mosquitos carrying WNV and other diseases.[402,403] Examples of places where standing water can support mosquito breeding include puddles, pools, catch basins, bird baths, rain gutters, portable swimming pools, and puddles.[386] The NYC Health Department recorded 1661 complaints of standing water in NYC in 2021 for mosquitoes.[386]

In addition to climate change influencing trends in locally endemic mosquito-borne illness, another concern is the risk of reintroduction and sustained local transmission of once endemic diseases. A recent report documents locally transmitted cases of malaria in 2023 in Florida (seven cases), Texas (one case), and Maryland (one case), the first in the United States since 2003. Although the risk of sustained local transmission of malaria in the United States remains

extremely low, these cases demonstrate the importance of public health surveillance and prompt treatment of human cases.[404]

Human hosts are also important for local transmission of the mosquito borne illnesses dengue, chikungunya, and Zika viruses. Each year, multiple travelers return to NYC with active dengue or malaria infections acquired in places where those diseases are endemic, but *A. aegypti*, the insect vector for these diseases, is not currently found in NYC and local transmission has not been sustained. This could change if *A. aegypti* or another competent insect vector became established locally.[380,386]

Socioeconomic and living conditions are another factor that could influence the risk of these diseases becoming locally endemic. For example, a study comparing the incidence of dengue fever in adjacent towns of Nuevo Laredo, Mexico and Laredo, Texas found a higher risk in Nuevo Laredo despite the greater abundance of dengue-carrying mosquitos in Laredo. Differences were attributed to living conditions, including Laredo's having more residential screens, air conditioning, spacing between homes, and more indoor space per occupant.[405]

Land cover change and mosquito control efforts likely also played a role in controlling mosquito borne diseases in the United States. These factors will remain important in shaping the future risk for diseases like WNV, which require animal, rather than human hosts to sustain local populations and transmission. The development and urbanization of the mid-Atlantic and northeast states in the 20th century resulted in salt marsh wetlands being modified or lost to alternative uses or for mosquito control efforts. Over time, integrated marsh management (IMM) methods have been developed to support or enhance habitat[406] and aid in the control mosquito vectors of human disease in combination with integrated pest management (IPM) methods, such as those employed by NYC's mosquito control program.[386]

Tick-borne illness

Nationally, reported Lyme disease is more common among men than women; the age distribution of cases is fairly uniform, but the proportion with neurologic, arthritic, or cardiac manifestations is highest among children and middle-aged adults.[407] In a survey of people reported with Lyme disease in Pennsylvania, lack of health insurance was a risk factor for delayed treatment, which in turn is a risk for more serious and post-treatment symptoms.[408] An electronic health record study in Pennsylvania found access to primary or urgent care was protective and that Medicaid-insured patients were at higher risk of more severe illness.[409] Among occupations, agricultural and forestry workers are at increased risk.[410]

Because Lyme disease is the most common tick-born illness in the United States and NYC area, its vector, the blacklegged tick, has been extensively studied. Historically, its range may have spread in the northeastern United States as forest habitat and deer populations expanded during the last century.[411] Today, blacklegged ticks are established in Staten Island, in Pelham Park in the Bronx but not in Manhattan, Queens, and Brooklyn.[412] A study of NYC parks showed that the density of nymph blacklegged ticks and carrying the spirochete causing Lyme was greatest in parks with high connectivity and vegetated buffers, favorable habitat for the white-tailed deer, which is a host species for adult ticks.[413] Since 2006, the NYC Health Department has conducted tick surveillance annually in a subset of NYC parks, however, the department notes that information on tick populations in the city is limited.[414]

3.6 | Waterborne pathogens and other contaminants

Globally, increasing temperatures and flooding related to climate change can increase water borne disease risk such as from enteric pathogens and legionella (Box 3).[215] Local waterborne disease risks and their relationship to climate change are highly dependent on infrastructure, including that involved in drinking water supply and treatment, wastewater and stormwater management and treatment, and building systems including potable water supply, cooling towers, and fountains. For NYC's drinking water supply to be impacted, damage to the upstate source watershed and/or water mains typically would have to occur. However, power outages will cause loss of potable water supply in tall buildings when rooftop tanks are exhausted.[254]

Yet, there are multiple potential pathways for flooding and SLR to impact NYC drinking water supply, distribution, and quality. Sea level rise could cause salt front movement in the lower Delaware River, adding pressure to release more water from reservoirs and impairing supply.[295] Downpours in the watershed could increase turbidity and potentially runoff of other pollutants. Increased turbidity has been associated with an increased risk of gastrointestinal illness (GI), though by itself does not cause GI illness.[296,297]

Pathogen growth and availability increase with warmer temperatures, so flooding in warmer months, such as that with Hurricane Ida, introduces additional risks.[415,416] Vibrio bacteria naturally live in coastal salt and brackish waters and include species that cause human infections, most often gastrointestinal illness caused by ingestion of raw or undercooked shellfish. Less often, vibrio contact with open skin wounds can cause infection. About 110–140 vibrio infections are reported to the NYC Health Department annually. Recently, the US CDC issued a national health alert concerning potentially life-threatening infections caused by *Vibrio vulnificus* that have been associated with warming coastal waters. In 2023, so far, one *Vibrio vulnificus* case was reported in an NYC resident (compared to about one to three annually), who reported eating shellfish but not exposure to coastal waters.[417]

In general, waterborne illnesses reported after major storms demonstrate increases in cases of gastrointestinal illness due to resident exposures to sewage contaminated floodwaters.[418] Following extensive flooding caused by Post-Tropical Cyclone Sandy, the overall risk of food and waterborne illness in the NYC area receiving inpatient or outpatient treatment did not increase, but there was a small increase in outpatient food and waterborne illness among those age 65 and older.[419]

Degradation in surface water quality around the city is a risk after any major rain or flooding event, potentially exposing recreational water users. This is because combined mains handle stormwater runoff

BOX 3 Legionella

Legionella bacteria are present in the environment and can grow in potable water systems and in cooling towers commonly used for air conditioning and commercial refrigeration in large NYC buildings. If released in aerosol form, community outbreaks of legionella pneumonia can occur.[420] Warm temperatures and humidity are associated with increased rates of Legionnaire's disease,[421] likely related both to favorable conditions for growth of the agent and use of cooling towers. In 2015 an outbreak of Legionnaire's Disease in the Bronx resulted in 138 confirmed cases and 16 deaths. The source was traced to a single cooling tower.[422] A local law and health regulations enacted that same year, created requirements for permitting, maintenance, and inspection.[423] Coordinated surveillance connecting human, animal, and environmental health can help with early detection of waterborne disease outbreaks.[215]

and sewage in many parts of the city can overwhelm treatment facilities during significant rain events and cause discharge of untreated sewage. The NYC Department of Health and Mental Hygiene[424] maintains beach monitoring and surveillance and issues advisories and closures during the summer season.

HABs are caused when algae and cyanobacteria grow rapidly in bodies of water. Illness in people and pets is most often from exposures to toxins produced by these organisms via skin contact, inhalation, ingestion of contaminated water, or consumption of contaminated seafood. HABs are more common in warm months and in fresh water. A wide range of symptoms and illnesses can result, including skin and respiratory tract irritation from contact with contaminated water or inhalation of droplets, gastrointestinal and neurologic illness from ingestion of contaminated food or water. Dogs, livestock, and wildlife are also harmed by HABS.[425]

A global increase in HABs is being driven by climatic and nonclimatic factors. National data also show an increase in the number, types, and geographic range of HABs.[426] The increase in HABs driven by several factors, including climate change and rising water temperatures, improved detection and reporting, nutrient pollution, introduction of species to new areas.[427] In New York State, HAB reports increased in frequency from 2012 to 2020,[428] and HABs regularly impact some NYC freshwater ponds and lakes.[429] More recent, detailed state level data are available, and show 53 HABs reported for water bodies within the five boroughs from 2019 to 2022.[430]

3.7 | Other compound impacts

Hot summer weather combined with the risk of COVID-19 transmission for the first time in summer 2020. Indoor gatherings such as at public cooling centers, which can provide a respite for those unable to stay cool at home, were limited. A pilot survey of members of an environmental justice organization during the summer of 2020 suggested people were more likely to stay indoors, avoid crowded green spaces, and rely on home AC units.[431] A racial disparity in access to AC was also shown, consistent with prior surveys. Another evaluation study of the short-term impacts of an NYC program that distributed and installed 73,000 air conditioners in summer 2020 indicated that program participants were more likely to report that they stayed home during hot weather compared to nonparticipants, with similar levels of staying home among the two groups in 2019. Program participants were also less likely to report that hot weather made them, or household members feel sick at home during summer 2020. Concern about cost of cooling, a hallmark of energy insecurity, was common among both groups and was a barrier to accessing air conditioning.[432] Limited access to outdoor green space was noted in another survey;[433] power outages during hot weather[434] would amplify these risks.[433,434] The co-occurring emergencies of extreme heat and COVID-19 highlighted the need to continue, expand, and evaluate efforts to address disparities in cooling access, energy affordability, and green space in high heat-vulnerable neighborhoods.[435] Similarly, urban flooding preparations, as well as efforts to address basement apartments, were interrupted due to COVID-19 demands for budget reallocations.[436]

Other compound impacts have been considered in earlier sections, including the co-occurrence of hot weather and higher ozone levels, amplification of heat and flooding impacts by power outages, and the potential for hot weather and flooding to cause exposure to pathogens and other contaminants in water. Hurricanes and other storms that cause power outages and occur during hot or cold weather can be dangerous. The 2017 example of Hurricane Irma in Florida is discussed in Yoon et al.[4] Most recently, when extreme heat combined with wildfire smoke, as prominent in June 2023, potential concurrent exposures introduced greater health risks[437] increasing the importance of residential air conditioning for protecting vulnerable people.

4 | REDUCING FUTURE IMPACTS

Many cities are implementing measures to provide immediate public health protections from the health impacts of climate change. Several of NYC's measures and plans as well as those of some other cities are discussed below. Structural measures that rely less on behavior change and individual efficacy are generally more effective at the population level. Hence, measures that advance health, equity, and safety by adapting the built and natural environment, while enhancing natural features and ecosystems and supporting greenhouse gas reduction targets where feasible, are the most important.

4.1 | Public health messaging and risk awareness

General principles: Climate risks to health vary greatly among communities and populations, making clear, actionable communication,

especially to vulnerable groups, essential for effective emergency preparedness and response. Vulnerable populations are most reliant upon government services when an evacuation order is issued, making the timely deployment of those services and their context-dependent response extremely important to reduce negative health impacts. Evacuation behavior and response may differ throughout the population of NYC for a wide variety of reasons, so a coordinated effort from the city to address this reality will improve outcomes, particularly for those in public housing, those who have health conditions and disabilities, and the elderly. Public health strategies reliant on individual agency and behavior change are inherently less effective than structural interventions that address socioeconomic determinants or the environmental context for health.[438] Thus, to reduce future climate change impacts on health, policies and investments that reduce housing and energy insecurity and ensure the resilience of dwellings and infrastructure are essential complementary approaches to effective public health communication. A population that is informed about climate risks and options for avoidance of risks will be better able to engage in collective advocacy for structural measures and act in the near term to reduce exposures and risks. Specific strategies and approaches are described below.

Heat-health warning systems: NYC activates its heat emergency plan when the NWS forecasts extreme heat. The NWS definition of extreme heat—2 or more days when the maximum HI is predicted to reach 95°F or any period when it reaches 100°F—is based on analyses of NYC heat and mortality data.[70] One study estimated that reducing the heat emergency threshold from 105°F to these lower levels in 2008 reduced heat-related illnesses among Medicare beneficiaries in NYC in the 2 years after 2008 compared to the 2 years before.[78] During emergencies, NYC officials disseminate public messaging about the health dangers of heat to the public, health care and social service providers, and faith- and community-based organizations. People are urged to use air conditioning if they have it or visit an air-conditioned space, such as a Cooling Center. Messaging around setting AC to low-cool or 78°F is also typically included to help with costs of cooling and reducing energy use to protect the power grid. Members of the public are also asked to check in on family, neighbors and friends who may be at risk during hot weather to help them stay cool (see NYC's *Be a Buddy* program[439]). More outreach workers are deployed to offer shelter to people experiencing homelessness, and shelters are open to anyone who needs them.[440]

It is important to note that warning systems have several limitations. People without air conditioning who have limited mobility may have difficulty accessing public cooling resources, people may be reluctant to leave home during heat waves to visit a cooling center (see section on Cooling Centers below), and emergency warnings are released only on the hottest and most dangerous days to avoid alert fatigue. These limitations highlight the need to couple emergency warning and response systems with other strategies to maintain safety throughout the warm season, including hot but not extreme heat days.

Surveys have also shown that while heat warning awareness is generally high among New Yorkers, awareness is lower among those who may be more at risk, which may be in part due to perceived lack of risk of hot weather, which occurs every summer, and because messages may not effectively reach those most at risk. Trusted messengers for heat-health warnings and information included health professionals, local TV health and medical correspondents, and meteorologists.[191]

Flood risk awareness: Additional measures to help New Yorkers to understand the health and property risks associated with flooding are needed. FEMA recently published a series of online resources that highlight ways that building owners and tenants can reduce flood risks in urban buildings.[441] Emergency preparedness education, such as *Know Your Zone* and *ReadyNYC*, are ongoing local programs to increase awareness of neighborhood risks. Education on finding safe local shelters as well as sheltering in place are important to limit compound risks from transmissible illnesses. Existing programs could be enhanced by increasing awareness of precipitation-driven flooding. Recent NYS legislation to inform renters and homeowners of flood history,[442] or to improve community awareness of climate hazards, requires sustained engagement to become part of the New York experience. Assuring translation into multiple languages and offering multiple means of delivering these messages, with assistive technologies for sight, hearing, or mobility impairment is key. Otherwise, those with vision or hearing impairments and without assistive technology may not receive such warnings. NYC Emergency Management translates public materials, outreach materials, and Notify NYC messages and website into the 10 languages designated by Local Law 30[443] as well as two additional languages, Yiddish and Italian, which are two of the top 10 languages spoken in NYC hurricane evacuation zones. To assess and support Local Law 30 implementation, the Mayor's Office of Immigrant Affairs works with NYC Emergency Management and other agencies and issues regular public reports.[444] Although most of these resources are accessible online, 16% of households in NYC remain without broadband access. Finally, it is important to help New Yorkers to understand how personal choice impacts flooding in NYC. For example, DEP's ongoing WAIT program encourages New Yorkers to monitor and where possible to reduce their potable water use during flooding events, in turn reducing the amount of sewer water combining with stormwater outflows.[445]

Air quality health advisories and related public health measures: High levels of $PM_{2.5}$ caused by wildfire smoke and high levels of ozone during hot weather generally cause poor air quality across the NYC metro area. Computer models of weather and pollutant emissions as well as monitor data are used to forecast harmful pollution episodes. The New York State Department of Environmental Conservation (NYSDEC) and the NYS Department of Health issue regional air quality health advisories when "DEC meteorologists predict levels of ozone or $PM_{2.5}$" that are greater than national ambient air quality criteria for short term exposure.[311] These advisories use the EPA's Air Quality Index (AQI), a ratio of the forecast or measured pollutant level to a "short-term national ambient air quality standard for protection of public health".[446] Advisories recommend actions to reduce exposure, such as reducing outdoor exercise during times of high pollution. NYSDEC shares data with the national AirNow program, which makes data and advisories publicly available through smartphone apps and weather forecasts, via a partnership with the NWS.[447] Air quality health advisories are almost always for elevated ozone or $PM_{2.5}$ con-

centrations. Prior to 2023, $PM_{2.5}$ advisories in the NYC metro area were infrequent in recent years. The AQI (based on a 24-h average $PM_{2.5}$) was 100 or greater, fewer than three times per year from 2010 to 2022, and the maximum $PM_{2.5}$ AQI was 154. Smoke from wildfires in Canada caused the $PM_{2.5}$ AQI to exceed 100 nine times to date in 2023, reaching a maximum of 254[448] (concentrations were much higher over shorter averaging times).

Experts have noted the limitations of an AQI based on a single-pollutant's regulatory threshold, noting that air pollution harm is not limited to concentrations above regulatory standards and much more common days with moderate levels of multiple pollutants do not trigger warnings.[449] Evidence shows some benefits of actions recommended by air quality advisories, but with important limitations. Staying indoors and avoiding physical activity during times or near locations with elevated air pollution and using room or central air filtration may reduce exposures and health risks, but more studies are needed to better quantify effectiveness, safety, and cost.[449]

The use of particle filtering masks outdoors by the public has not been part of standard guidance issued with air quality health advisories but was widely recommended during the recent smoke episodes affecting NYC. Some evidence shows that if properly worn, masks can reduce exposure and provide health benefits in some settings and populations. But important evidence gaps and implementation concerns remain. Patients with pre-existing lung or heart conditions may have difficulty tolerating some masks, improper fit or use may greatly reduce effectiveness, and evidence of improved outcomes is limited to short term use in populations and settings not directly comparable to regional air pollution episodes. It is important to note that particle filter masks do not reduce exposure to ozone, other gaseous pollutants, or ultrafine particles.[449,450] Indoor central heating, ventilation, air-conditioning (HVAC), and portable air filtration systems can effectively improve indoor air quality during wildfire smoke pollution events, but further study is needed of longevity and maintenance of equipment, pollution mixture effects, and actual health benefits.[451]

Modeling studies suggest that for most people, the large health benefits of regular physical activity, especially for active transportation, outweigh risks of air pollution.[452] Experts note the need for more research to understand these trade-offs and caution against a too low threshold and frequent advisories to limit outdoor activity, could have little benefit or might even be harmful.[449,450]

Equity and practical concerns have also been raised about advice given during air pollution episodes. Knowledge and resource limitations make it harder for some populations to understand concepts like the AQI or comply with recommended actions.[449,453] During hot weather, households lacking air conditioning cannot close windows to reduce ozone or use portable filtration devices without risking harmful heat exposure.[451]

Preventing tick-borne illness: Strategies for preventing tick borne illness include promoting awareness of where and how encounters with disease-bearing ticks occur, proper use of insect repellents effective against ticks for people and pets (especially dogs), IPM practices to minimize tick habitat, populations, and contact in yards and parks, body checks for ticks at least daily, and awareness of signs and symptoms of tick-borne illness and the importance of seeking care promptly for diagnosis and treatment.[454,455] These depend heavily on public education and behavior change and should emphasize risks from outdoor activity in locations where disease-bearing ticks are most likely to be encountered.

4.2 | Emergency response

Cooling and warming centers: Like many other cities, NYC officials encourage people who cannot stay cool at home during periods of extreme heat to visit cooling centers during periods of extreme heat. Cooling centers are senior centers, libraries, community centers, and other public places with air conditioning. Although these spaces are always typically open to the public, during heat events they are advertised as cooling centers and will often open for longer hours. During a heat wave, members of the public can visit an online cooling center finder or call 311 to find their closest center. A NYC Comptroller's report[456] recommends the development of Resilience Hubs that broaden cooling center functionality to include complementary community supports, and the city's 2023 sustainability plan includes an initiative to create Resilience Hubs.[236] NYC Speaks[457] summarizes ongoing Resilience Hub activities.

Population-based NYC surveys indicate that there is a strong preference for staying home during hot weather, even when someone cannot stay cool at home.[89,191] About 10%–15% of those without AC or those who have it but do not use it often report going to a public place similar to a cooling center.[89,191] A 2021 audit of a subset of NYC cooling centers by WE ACT for Environmental Justice found that more signage, information, and consistent standards were needed and recommended, among other measures, more funding and increased community input in center operations.[431] Transport and risk perception may also be barriers to use.[191,458] A 2022 NYC Comptroller's report noted a need for more centers in under-served, high heat vulnerability areas, more centers on weekends, and more options for younger adults, as many senior centers are for people aged 60 and older.[459]

Assessments of cooling center utilization in Phoenix (Maricopa County) found that 22% of respondents used the centers primarily to avoid heat, but most were visiting to access other services offered at the centers. In addition to individuals experiencing homelessness or who did not have home AC, many used cooling centers because they cannot afford the cost of running their home AC.[458]

There have been few, if any, studies conducted to examine cooling center effectiveness in reducing heat-health impacts. A Centers for Disease Control and Prevention (CDC) review on the evidence base for use of cooling centers to prevent heat-health impacts did not identify any research linking cooling centers to health outcomes but noted that there is strong evidence that staying in a cool environment generally is beneficial to health. The review concluded that cooling centers can be useful as part of a larger heat-health response strategy, not as a stand-alone measure.[460] Another recent commentary also noted cooling centers have limited potential benefit in the absence of more comprehensive measures and that even with optimistic assumptions

about their effectiveness, extremely large numbers of people would need to use them to achieve a meaningful reduction in mortality risk.[461] Challenges with cooling centers and COVID-19 in summer 2020 are discussed in Subsection 3.7.

In NYC, warming centers are not typically opened because of strong heating laws in place during cold weather and right to shelter laws for people experiencing homelessness. However, warming centers and warming buses were used following power outages due to Post-Tropical Cyclone Sandy. FEMA and the National Guard also conducted door-to-door welfare checks on residents affected by the flooding and widespread power outages.

Evacuation shelters: Immediately prior to a hurricane, it is common to provide resources to allow residents to get out of harm's way if safe shelter at home is not possible. This includes community-based evacuation centers. New Yorkers demonstrate a preference for staying home versus evacuating, as demonstrated prior to Post-Tropical Cyclone Sandy.[462] In fact, mutual aid proved more effective in preparing and providing for communities.[462] But for residents of basement apartments in flood prone areas, sheltering at home during flood events is not a viable solution. Additional support for evacuation center sustained operations and neighborhood awareness campaigns could help to socialize options available to community members. COVID-19 created a compound risk and additional barrier to using congregate evacuation shelters.[a463]

For those with chronic health issues or disabilities, flood evacuation requires additional support. However, the NYC Emergency Management website notes that those in wheelchairs or with other disabilities affecting mobility should call NYC 311 for evacuation assistance if they have no other options for evacuating safely.[272,464] With prior planning, those most dependent on others for their evacuation, and for ongoing support while away from home, can gain more control over how their health needs are met. NYCEM guidance in the My Emergency Plan workbook notes that those with disabilities can be taken to an accessible evacuation center, in a hospital outside of the evacuation zone (via ambulance) but will not have the option of giving the evacuation team a specific address.

Household disconnection prevention: Disconnection protections vary by jurisdiction and circumstance but can offer important protections during extreme weather. In NYC, residential electricity disconnections for nonpayment are suspended for all residential customers just before, during, and for 2 days after hot days using criteria based on the HI. In 2022, Los Angeles prohibited the Department of Water and Power from practicing water or power shutoffs as a debt collection tool for income-qualified residents and seniors.[466] Health risks of utility disconnections and prevention measures are discussed in more detail in NPCC4, Yoon et al.[4]

Information access: NYC has telephone services such as the 311 call line which in an emergency is regularly updated with information from NYC Emergency Management that can be then conveyed in more than 160 languages.[444]

4.3 | Community and social supports

Strengthening community social networks, cohesion, and community-based organization capacity: Social resilience programs that seek to increase community resources, networks, and connections, led by community groups or community members, may also be beneficial. Direct financial and technical assistance approaches with community participation and co-creation are being used. Some examples include:

- In 2017, the NYC Health Department and Mayor's Office of Resiliency launched *Be a Buddy* as an initiative of Cool Neighborhoods NYC, a citywide heat protection strategy.[468] Through partnerships with Brooklyn Community Services (Brownsville), The Point Community Development Corporation (Hunts Point) and Union Settlement (East Harlem), *Be A Buddy* provided assistance and support to over 1300 New Yorkers through over 60 volunteers. The partner organizations built and fostered hyperlocal networks to provide heat-health information to neighbors, help them identify community resources, and make and implement emergency plans.[91,469]
- The *Billion Oyster Project* now hosts a Citizens water quality testing site to encourage community awareness of water contamination risks as it aligns with their mission. The project directly addresses community and student engagement while also working to improve harbor water quality and reduce coastal storm damage. Most importantly, the project connects more than 15,000 volunteers, 100 NYC schools, over 8000 students, and 60 restaurants in a community science initiative with substantive adaptation benefits.[470]
- Other states such as Virginia and Kansas are garnering attention for their community-focused city-led policy responses such as the *Neighborhood Relief Project* through which various organizations and citizens volunteer to help those vulnerable to extreme heat, such as seniors, people with disabilities or medical conditions.[471]

Community cloudburst planning: Recognizing that FEMA flood zones, even with updated mapping, do not accurately reflect cloudburst flood areas requires broader approaches to capturing cloudburst impacts to help New Yorkers in those neighborhoods better understand their risks. Flood warnings reach those signed up through *Notify NYC*. However, prior to and during the Ida Remnants Cloudburst event, although 29 alerts were dispensed, less than a million of NYC's 8 million+ population received those alerts.[b] Moreover, the high volume of notifications may result in a dismissal of the threat's severity and delay critical action.[298] Or, conflicting warnings may create confusion

[a] In September 2020, FEMA issued special guidance on COVID-19 planning considerations for evacuation and shelter-in-place.[291] This guidance provided a structured approach for hospitals and residential care facilities, for mass care and sheltering services, and for tourist populations to review existing protocols in relation to evacuation needs and COVID-19 factors.

[b] Walker, A. What Went Wrong With NYC's Emergency Alerts, and How Can We Do Better? Curbed https://www.curbed.com/2021/09/ida-emergency-alerts-flooding-new-york-city.html (2021).

(e.g., take shelter from strong winds in basement/find higher ground in case of flooding).[472] Cities that experienced catastrophic events, such as Hurricane Katrina, turned to social and behavioral programs to build risk readiness in standing community activities. In New Orleans, community groups organized neighborhood events in the places where evacuation buses picked up residents who lacked the means to evacuate on their own. Such habituated events intend to strengthen community cohesion while reinforcing the message of evacuation planning.[1] Similar strategies could be considered for NYC in concert with Community Boards or Community-based Organizations. While NYC Emergency Management (NYCEM) preparedness resources identify flash flooding as a risk, community readiness arguably lags. Recent efforts such as the *Rainfall Ready NYC Action Plan* attempt to prepare residents for such events and to help with speed of recovery.[473] However, there is significantly more preparation required given the health impacts of local flooding types.

Smart technologies: Smart technologies can be used to connect people with information about flood risk areas, flood monitoring, warnings, MTA routing, and navigation apps, and housing resources like *StreetEasy* to improve awareness. There is also potential in communication tools used during COVID-19, like LINK messaging,[474] to communicate about climate risks. Resident notification about flooded bus stops/routes and/or subways alongside alternative routing to sustain connections would offer benefits.

4.4 | Health care provider roles

Patient interactions and counseling: Through their relationships and interactions with patients, health care providers can play key roles in preventing health impacts from dangerous weather. For example, health professionals can identify patients at risk of heat-related illness, counsel patients and caregivers, and educate other populations and those that interact with them. Studies to evaluate effectiveness are limited, but clinical judgement and an understanding of climate-related illness risk factors and vulnerabilities support several strategies as proposed for preventing heat related illness: (1) target strategies to specific groups, such as general population, occupational risk groups, and athletes, (2) identify vulnerable individuals, (3) provide tailored education and anticipatory guidance to patients, caregivers, coaches, employers and others about illnesses, prevention, and preparedness strategies.[475] Several of these strategies are included in health advisories provided by the NYC Department of Health and Mental Hygiene[476] to providers at the beginning of the summer season and when heat advisories are issued.

Health professionals could also be encouraged to ask patients about their household energy landscape (e.g., energy use, protective or coping behaviors) and serve as the link between patients and resources to reduce energy insecurity.[477,478] Research has demonstrated the efficacy of connections to medical services for protection against energy insecurity, with connections to medical services sometimes leading to referrals to other resources, such as free legal programs to claim settlements for household energy-related damages (e.g., malfunctioning heating systems leading to health consequences).[477,478] Some screening tools of social determinants of health have already incorporated questions about energy insecurity, asking whether one suffers from lack of heat or malfunctioning stove or oven.[479] Comprehensive screening tools could help systematically identify patients suffering from energy insecurity and refer them to appropriate resources, such as food, financial, legal, tenants' rights services as well as government energy cost and weatherization assistance programs.[478]

Climate–health trainings for providers: The American Public Health Association (APHA) declared climate change a public health emergency in 2022,[480] and some medical schools now host curricula specifically focused on training for climate change risk awareness and response.[481–483] Private health service providers are only beginning to prepare for climate impacts, however. Organizations such as the Medical Society Consortium on Climate and Health (MSCCH) now solicit physicians to support such training and are in the midst of building case studies and curricula to share with physicians.[484] Health Aid Training and Patient Education need further attention as there are few home-health worker training programs related to climate change and fewer patient resources to offer guidance on climate impacts to health. Trainings for home-health aides were included in the city's *Cool Neighborhoods* heat mitigation and adaptation plan.[468] Health care without harm also provides applicable guidance.[485] Mental health care providers and emergency responders are also potential partners for patient-level education and intervention (see Subsection 4.3).

4.5 | Interventions in the housing and energy sectors

Reducing emissions: Local and regional emission reductions are the best way to reduce local air pollution exposures and health impacts. Air quality health impact assessments described in Balk et al.[7] estimate the benefits of reduced illness and death already achieved and possible in the future through measures such as *NYC Clean Heat*, achieving NYC's 80 × 50 greenhouse gas emission reduction targets, and reducing traffic related air pollution.[315,349,486] NPCC4, Yoon et al.[4] considers more fully the potential challenges and opportunities for reducing emissions from the energy sector, while ensuring affordable, reliable energy for all New Yorkers.

Residential cooling: Ability to afford home air conditioning and energy to run it is a major driver of indoor temperature. Air conditioning can lower indoor temperatures and increase ventilation. Improving home AC access can also reduce health inequities by race and income.[89] Some types of facilities housing at-risk people are already required to maintain safe indoor temperatures during hot weather. For example, federal legislation requires long-term care facilities that participate in Medicare and Medicaid to provide comfortable and safe temperatures, and facilities certified after 1990 are required to keep temperatures in a range from 71°F to 81°F.[487] Some jurisdictions, such as Dallas, Tucson, and Tempe, require that rental properties have cooling equipment.[488]

In 2023, NYC announced plans to develop maximum indoor temperature policies to protect all residents by 2030 and require cooling in all new construction by 2025.[236] Energy efficiency measures, such as higher thermostat settings[98] can help reduce cooling cost burdens, as can cool roofs that are painted with white reflective paint to reflect rather than absorb heat, which can reduce indoor temperatures.[433,489] Green roofs also have benefits to the indoor environment but are more expensive to install and maintain. Air conditioning, energy use, and equity is discussed further in Balk et al.[7] and Yoon et al.[4]

Reduce household flood risk: Recommendations from the 2012 NYC Special Initiative for Rebuilding and Resiliency (SIRR) and examples from NYCHA's and Enterprise Community Partners' recent guidance on retrofits offer paths forward to help NYC residents understand what they can do as renters or as owners to reduce their home flood risks. Reducing risk includes addressing basement apartments by making them safer where possible or removing them where flooding is not manageable otherwise. This should occur in concert with increasing safe affordable housing outside of flood prone areas. Additional support following flooding should focus on re-occupancy as soon as possible or offer alternative housing if extended recovery is likely.[41,247,248,272,273,282,286,287,464,490,491]

However, as can be seen in places like both New York and Seoul where affordable housing options are extremely limited,[492] people will continue to reside in converted cellar or basement apartments and remain at risk. NYC began a basement apartment conversion pilot program in 2019,[493] initially limited to East New York and Cypress Hills, to help middle- and low-income homeowners convert their basement or cellar into safe spaces that could be rented out through low- or no-interest loans, but participation in the program was very low.[494] In November 2023, the city announced the launch of another program to fund 15 homeowners to build or retrofit accessory dwelling units (ADUs), including basement apartments, in an effort to inform plans to increase the availability of affordable housing. These plans, outlined in the *City of Yes* proposal, aim to ease zoning restrictions and legalize more basement and other dwellings to create up to 100,000 new affordable homes.[495–497] It will be essential that measures are taken to ensure that location and design of ADUs created through such plans protect the dwellings and occupants from flooding.

For long-term strategies related to homeowner/building-owner options, *FloodHelpNY*[498] offers retrofitting suggestions that range in expense and disruption to daily life. On the more expensive and disruptive end, one suggestion is to fill in the basement, which is an adaptation measure that blocks off the area that could be flooded. Other suggestions for single-family homes include elevating a residence, moving critical mechanical, electrical, and plumbing services out of the basement, installing flood vents, and installing a backwater valve (or check valve), which prevents flooding from sewage overflow that can occur during heavy rains and is incredibly damaging to property and can cause lingering health risks. The site also offers more budget-friendly options, such as replacing carpeting with nonporous tiles, replacing porous finishes in below-ground areas with nonporous materials and installing a sump pump, which helps remove water during and after flooding.

The *Climate-Driven Rain Response Plan*, released in July 2022, is a citywide action plan specifically meant to address the risks of flash flooding and includes an interactive map to help renters and homeowners determine the risk-levels of their neighborhoods and streets to flooding. The plan also organizes workshops to spread awareness of techniques that can minimize damage and risk to homes, and distributed sandbags and signage at 75 likely-to-be-flooded locations in the summer of 2022. The installation of 1300 more green infrastructure assets is also an initiative within the plan, which will help divert water away from taxed sewer systems and basements by providing more pervious surfaces during heavy rainfall.[473] A network of sensors, starting with 50 and expanding to 500 by 2026, will help populate a publicly available map of flooded areas for monitoring.

In 2023, the city further renewed its green roof tax rebate program, which provides incentives for the addition of pervious surfaces throughout the city. To further research what can be done during cloudburst events like Ida, a Cloudburst Resiliency Planning Study is running two pilot projects in Southeast Queens as well as a check valve study, which could prevent sewage from backing up into homes when the sewage system overflows during a storm. DEP's *Wait* campaign tries to spread messaging about delaying water-intensive activities such as laundry until after a storm passes.[499]

The topics of relocation from flood prone areas, such as through buyouts of property owners, and the risk of basement apartment flooding is considered in NPCC4, Rosenzweig et al.,[210] NPCC4, Balk et al.,[7] and in the *NYC Climate Vulnerability, Impact, and Adaptation Analysis* (*VIA*).[46]

4.6 | Occupational health protections

Although most deaths and admissions for heat-related illness in NYC occur in residential settings, heat-related illnesses can occur in a variety of occupational settings—both indoors and outdoors—as described above. There are no specific federal policies to address worker safety from heat exposure. The Occupational Safety and Health Administration does not require employers to provide air-conditioned (or, in the winter, heated) workplaces, though they recommend that employers implement heat safety plans.[500] In 2021, the agency began a process to create heat safety standards but has not completed the process. In the absence of federal protections, a handful of states, including California, Oregon, Minnesota, Colorado, and Washington have instituted worker protections, including mandating that water, shade, and rest breaks be provided, and that extreme heat response plans be developed and implemented for outdoor workers.[501] The National Institute for Occupational Safety and Health (NIOSH) has guidelines for working in heat and also recommends that workers be provided with water, shade, rest, and safety training, among other measures.[66]

Advocates have noted, however, that enforceable national safety rules are lacking and while these state-level policies are important, most of them still have large gaps, including a need for indoor safety standards, adequate enforcement and penalties, and heat-health safety trainings for workers.[501] In addition, including clothing

absorptivity in the WBGT equation for outdoor workers could improve workplace heat protections by establishing more realistic standards, if WBGT workplace guidelines such as those created by the International Standardization Organization, were enforced.[502] As noted above, though, even those workplace standards that exist are rarely enforced.[503] Undocumented workers are at increased risk of abusive workplace practices and may not report workplace safety issues for fear of immigration-related retaliation by employers.[504]

4.7 | Interventions for the public realm and shared environments

Controlling mosquito-borne illness: The NYC Department of Health and Mental Hygiene takes numerous measures to prevent WNV transmission in the city. Standing water sources are removed, larvae are treated with biological agents to prevent them from growing into adult mosquitos, and public education outreach programs are implemented to increase awareness about the risks of standing water and WNV.[386] Through surveillance data, the NYC Health Department can identify high transmission risk a few weeks in advance by testing traps for WNV a few weeks before it presents a risk to the public. If more serious measures are needed, such as the use of insecticides to reduce adult mosquito populations (adulticiding) then these can be identified and deployed. Requiring window screens in residential buildings may prevent human infections and appear to prevent sustained local transmission of mosquito-borne illnesses that depend on human hosts, such as dengue, chikungunya, and Zika viruses, and are not currently endemic in the NYC area.[380,405]

Public realm, flooding, and heat exposure: There are now smartphone applications to provide insights on flooded streets and offer alternative and accessible routes to move about safely before and during a flood.[505,506] Cloudburst strategies with priorities to provide accessible pathways in critical areas could be a next step. Recognizing that all buildings and open spaces will not offer the same level of adaptive capacity, a complementary retrofit tactic is to develop accessible pathways that enable safe pedestrian movement between locations.[499] As an example, in Yalding, the United Kingdom, a raised walkway provides a mode of egress/access in the event of a flood, which could be a helpful solution in areas with many older buildings or where flooding retrofits are infeasible due to costs or other practical reasons.[507]

Messaging to alert residents to these strategies and how to manage during flood events is a critical health contribution, as is coastal and riverine flood management in parks, at the rivers, and at the beaches to reduce floodwater exposure and associated messaging to keep community members informed of their risks. Continued focus on CSO prevention is needed as these are amplified with flooding and impact respite areas throughout the coastal and riverine parks of New York. In the Futures and Transitions chapter of this assessment, repurposing space in the public right of way is considered as a strategy for increasing green space to mitigate the UHI, prevent flooding, and provide cooler, shaded places for healthy active mobility and outdoor socializing.

Climate adapted street trees: NYC Parks has developed an approved tree species list[508] for new and replacement street trees that are well-adapted to NYC climate and urban conditions and do not add to levels of the most allergenic tree pollen.

5 | OPPORTUNITIES FOR FUTURE RESEARCH

5.1 | Summary of knowledge gaps

5.1.1 | Heat and health

The effects of hot weather on mortality and other health outcomes have been extensively studied in New York and other cities with similar climates. Important knowledge gaps and research opportunities remain, however, and include a need to better understand:

- The projected relationships among higher temperatures, humidity, and other heat metrics under a changing climate.
- Occupational heat exposure and health impacts in NYC, including impacts on food vendors and delivery workers.
- Exposure and health benefits of UHI mitigation measures, such as green space.
- Improved data on indoor temperatures and health risks in different types of dwellings and structures.
- The impact of heat exposure on populations experiencing homelessness, both sheltered and unsheltered.

5.1.2 | Flooding

Economic costs of health impacts from climate sensitive events in NYC

As part of an ongoing Climate Vulnerability, Impact, and Adaptation Analysis (VIA) to study climate change's impacts on decision-making in NYC, a research team is reviewing published reports on the impacts of climate-sensitive events in NY from 2000 to 2020, then evaluating their health-related costs.[46] Health-related costs are not typically estimated and are largely absent from climate change damage estimates.[509] The evaluation of health-related costs will inform analyses of associated past, current, and future health costs under plausible climate change scenarios, which will be published in forthcoming work[46] (also see Section 4.2.1 in NPCC4, Balk et al.[7]).

Location information about compound flooding impacts and areas

As with coastal storm surges, the risk of death from cloudburst flooding during storms like the Ida Remnants Cloudburst and its long-term consequences for survivors were shaped by both geographic location and dwelling characteristics. Most obvious and tragic were drowning deaths in basement apartments. Although recent city administrations have undertaken apartment improvement programs, and issued studies relating to basement apartments and subways, the deadly combination of scant affordable housing, illegal basement apartments, and climate change-fueled increases in extreme rainfall events

merits further study to inform sustained, effective, and widespread action.

Residents and policymakers could benefit from more information about the vulnerability and resilience of residential buildings at risk of flooding from storm surge, cloudburst events, or sea level rise. Critically important for protecting health is data on the locations of basement dwellings in relation to pluvial and coastal flood hazards. Data on multi-family dwellings that have flood hardened building mechanical systems would be useful for both designing resilience strategies and planning for flood response. For existing renters and owners, having greater flood risk awareness can inform negotiations with landlords and co-op or condo boards and management companies, and help in developing strategies to reduce exposure. This is particularly pertinent for basement and ground floor apartment dwellers who may be unaware of their risks. The *NYC SRP* includes initiatives to ensure that relevant stakeholders know how to interpret and understand flood maps and preventative measures, as well as targeted messaging for people living in basement apartments prior to a storm. Also, recent NYS legislation[442] guarantees "right to know" for prospective buyers and complements 2021 legislation that does the same for renters.[510] However, for those already occupying residential buildings, there is no other mandate to provide information on flood-related health risks and existing residential building capacity to manage those risks.

In addition to improving understanding of risk awareness, an important knowledge gap is the capacity of households living in basement dwellings to receive and respond to timely evacuation warnings, given the relatively limited lead time and spatial uncertainty of cloudburst forecasts, the possibility that warnings will arrive will residents are asleep, that they may have mobility impairments, and may suffer stress, warning fatigue, and other adverse effects from false positive alerts. As the city improves its capacity for understanding the impact of cloudburst events[511] and weather forecasting improves, residents could benefit from receiving such information, helping to raise risk awareness and connect the types of rainfall events and their local weather announcements to household decision-making and, where applicable, the need to shelter elsewhere.

With the latest information in PlaNYC regarding voluntary mobility[236], New Yorkers could also benefit from additional research on resettlement implications of the latest climate science (see NPCC4, Balk et al.[7]).

5.1.3 | Vector-borne disease

The influences on human risk of VBD are complex, involving climate, landcover, living conditions, ecosystems, and interactions among these and with humans and animals that can be infected and serve as hosts for further transmission. Further research is needed to understand these factors and better anticipate and control VBD risks in NYC and the metro area. Additionally, improved research and surveillance can help evaluate and improve control measures. For example, mosquito control strategies using IPM principles have been widely implemented in response to the spread of WNV in the United States. Although evidence supports effectiveness in reducing mosquito populations, few studies have used outcomes of reduced human cases or surrogates for WNV risk.[512]

5.1.4 | Mental health and social isolation

In addition to the well-established vulnerabilities to climate health risks among people with mental health conditions, climate anxiety is an emerging, but not well-studied phenomenon. It disproportionately affects younger people nationally and globally.[513] While not an NYC-specific phenomenon, studies on its causes, relation to news and messaging about climate change, and vulnerable subgroups are needed to inform effective prevention and care for those affected.[514] Recent research describes the effects of climate stressors on dementia risk and those living with cognitive decline.[266] Cities like NYC have an opportunity to shape municipal adaptation responses to better meet the needs of this population.

Social isolation at all ages is associated with worse health outcomes and often associated with mental health conditions. While distinct from living alone (which is fairly easy to measure), social isolation, which increases with age, is much harder to measure. As such, how social isolation influences health outcomes associated with vulnerability to heat, flooding and other climate stressors presents an important knowledge gap.

5.1.5 | Air pollution advisories and public health measures

As this assessment is being written, wildfire smoke has caused several days of poor air quality across much of the eastern United States and in NYC. Although the issuance of air quality health advisories and guidance based on the AQI is a long-established practice in the United States, important questions remain about the appropriateness of the AQI and advisory thresholds, the effectiveness of some recommended personal measures to reduce exposure, the ability of different populations to understand and implement recommended actions, and trade-offs between recommended activity restrictions and health benefits of regular physical activity.[449–451]

6 | SUSTAINED ASSESSMENT

Sustained assessment of NYC climate–health risks, impacts, and vulnerabilities should include monitoring quantitative indicators, city plans and actions to reduce them, and greater public and stakeholder awareness, feedback, and civic engagement to spur ongoing evidence-informed actions with continuity across mayoral and city council terms.

A comprehensive indicator and monitoring system for NYC has been recommended by NPCC in the past[515,516] but has not yet been

funded or implemented. For climate–health risks, a number of useful climate and health indicators and visualizations are available at the NYC Environment and Health Data Portal.[87] Drawing from these and other previously adopted indicators and coordinating reporting on those indicators alongside the climate change implications could be an early step. Another could be working within the existing Mayor's Management Report and expanding the Health and Human Services component to be inclusive of climate change impacts on health.[517,518] Public web portals provide the possibility of soliciting input and ideas from a much greater range of public stakeholders and organizations than those able to attend scheduled meetings. An example is the interactive Vision Zero Input Map, rolled out at the launch of that initiative,.[519] The public, journalists and advocacy groups can now access and visualize safety intervention, crash, injury, and fatality data to assess changes over time.[520]

Future sustained assessment efforts could be enhanced by implementing the roles, communications functions, and regular interactions among the NPCC, the Climate Change Adaptation Task Force (CCATF), and the NYC Mayor's office envisioned in the local law that established the NPCC.[521] This, in addition to NPCC engagement with the Environmental Justice Advisory Board (EJAB), the Sustainability Advisory Board, and the Climate Knowledge Exchange (CKE) can enhance the reflection of diverse stakeholders and technical expertise in the NPCC work products. This NPCC has also prioritized sustained assessment through the publication of a public NPCC website, which hosts up-to-date information on NPCC projects, and the production of public- and policymaker-facing, plain-language summaries of their research products.

Specific to the health sector, cultivating a community of health professionals in concert with community members in an ongoing knowledge exchange, deepening, or developing, ongoing relationships within communities to encourage climate and health conversations and to create supportive pathways to ask for help is an important shift. For example, a health ambassador program could offer a possible way forward. The Climate for Health Ambassador Training Program and the NextGen Climate and Health Ambassador Program are examples. To fairly compensate community members for their contributions,[522,523] the EPA's Water Ambassador Program offers another example.[524]

7 | TRACEABLE ACCOUNTS

Key Message 1: Climate change-related health risks are a threat to all New Yorkers, but especially those most vulnerable because of age, poor health, and racial and social inequities. Inequities in household and neighborhood physical environments also mediate vulnerability to climate–health impacts. Addressing key environmental and social drivers of vulnerability is an essential adaptation strategy. Many current NYC policies and strategies, (e.g., improving access to residential air conditioning, tree planting), aim to accomplish this. These efforts can be informed and evaluated using data on climate–health vulnerabilities, such as components of the HVI and a FVI under development.

- **Description of evidence**: Multiple studies in NYC and urban areas with similar climate show that climate change is increasing risks to health from exposure to heat, flooding, and other climate-sensitive exposures.[1,23,25,207,218,219,275] Evidence of greater vulnerability due to age, pre-existing health conditions, and racial and social inequities is also extensive.[39,65,87,89,103–106,120–123] Disparities in home and neighborhood physical environments have been demonstrated to modify health risks.[65,87,89]
- **Remaining uncertainties**: Uncertainties and knowledge gaps are summarized for each specific climate exposure below.
- **Assessment of confidence based on evidence**: There is high confidence that NYC climate-related health risks, especially from heat and flooding, will increase, that vulnerable populations have been identified, and that adaptation can reduce risks.

Key Message 2: Heat waves are, on average, the deadliest type of extreme weather in NYC and in much of the United States. Even hot, but not extreme, summer weather also causes serious illness, death, and other harms to wellbeing. Because of climate change, NYC will experience more dangerous hot weather. Most heat-related deaths are due to exacerbation of chronic health conditions, such as cardiovascular disease. Indoor exposures can be especially deadly for people without air conditioning who have one or more physical or mental health conditions, are energy insecure, or are older adults. Also vulnerable are those with jobs exposing them to unsafe temperatures. These risk factors can be consequences of structural racial, social, and economic inequities. Adaptive measures are needed that protect vulnerable populations from season-long heat-health risks, including from nonextreme but hot weather. Evidence-informed strategies include enhanced access to air conditioning, reducing energy insecurity, engaging community and health provider networks to reach vulnerable populations, and augmenting tree canopy cover.

- **Description of evidence**: Multiple assessments of the IPCC, US National Climate Assessment, and NPCC state that temperatures will rise, extreme heat events will worsen, and support the conclusion that temperature increases will have a negative impact on health.[9,525] Many epidemiologic studies focused on NYC, other parts of the United States, and internationally have described the large, negative effect heat currently has on human health, including morbidity and mortality.[23,29,35,38,39,70,71,72,74,75,80,109,110] These studies often identify groups at higher risk; other studies focus specifically on associations and risk factors for heat mortality and morbidity. In addition, several studies and assessments describe multiple pathways through which persistent racism can negatively affect health for people of color through multiple pathways, including through inequitable heat exposure.[65,84,90,120,197,526,527] Most heat-related deaths are caused by heat exacerbation of chronic conditions (excess mortality).[1,23,25] Comparisons of mortality burden across extreme weather types are limited because excess deaths from hurricanes have not been as well-documented, a field that is currently emerging.[220] Even so, existing and recent evidence contin-

ues to support the conclusion that heat is deadliest type of extreme weather in NYC and in the United States, on average.

- **Remaining uncertainties**: There is evidence about the indoor temperature in NYC and US urban areas demonstrating that it can be elevated in the absence of air conditioning during and after hot weather,[48,203] but there are few studies measuring indoor temperature in relation to health, and less available evidence about indoor temperature thresholds appropriate for vulnerable populations, for example those who are older adults or people with chronic or mental health conditions. However, heat stress and heat-exacerbated deaths are more frequent in NYC residences compared to other settings, underscoring the risk of indoor settings.[25,90,151] Some heat adaptation strategies have been assessed or evaluated,[431,432,458] but there have been no or limited evaluations of the implementation and effectiveness of many heat interventions. In addition, there are limited studies of long-term or chronic heat exposure effects as well as heat-health effects that do not result in interactions with the health care system, with most studies focused on acute and/or severe health effects.
- **Assessment of confidence based on evidence**: There is high confidence that hot weather causes serious illness and death among vulnerable New Yorkers exposed indoors, that the burden is cumulatively greater from hot, but nonextreme weather, and that air conditioning can reduce risk.

Key Message 3: Public health can be impacted before, during, and after flooding, which exposes New Yorkers to risks of drowning and other injuries, stressful evacuation, short- or long-term displacement from home, and exposures from clean up, repair, water contaminants, and mold from water damage. Climate projections for NYC anticipate an increase in extreme precipitation days and sea level rise contributing to more frequent flooding over wider areas. Socioeconomic disadvantage, pre-existing health conditions, and flood-vulnerable housing and infrastructure amplify health impacts of flooding. Adaptation strategies that modify these factors can reduce future flooding impacts on health.

- **Description of evidence**: National and northeast regional evidence supports the connections between climate change, flooding, and associated health risks.[9,206,528] The wide range of health risks and impacts associated with flooding includes premature mortality from drowning, physical injuries during flooding and from post-event cleanup, asphyxiation from improper use of space heaters, exposures to waterborne pathogens and chemical contaminants, increases in respiratory ailments from mold growth on water-damaged infrastructure, health care service disruption caused by flooding, increased risks of adverse pregnancy outcomes, and lasting mental health consequences, such as anxiety, depression, and PTSD among affected communities.[9,41,215,218,219,238,258,262,265,267,269,275,368,370] The array of strategies to address these risks now includes efforts to improve the power supply resiliency of buildings, developing ways to increase safe affordable housing outside of flood-prone areas, supporting home re-occupancy or alternative occupancies post-flood, developing more community awareness of long-term sea level rise risks, and use of new technologies like phone applications that can provide insights on safer access routes before and during flooding, among others.[247,278,279,293,505]
- **Remaining uncertainties**: Uncertainties exist around the interaction of sea level rise, coastal flooding, pluvial, fluvial, and groundwater flooding to create location-specific compound flooding risks, as these complex systems and events are challenging to simulate with computer modeling. Better predictive capacity regarding the impacts of cloudburst events will help in evaluating localized flooding risks. Furthermore, data on the economic costs associated with flooding-related health impacts are not routinely collected, creating uncertainties as to the full range of flooding-associated societal costs. Uncertainties also exist regarding the factors that can maximize voluntary, timely participation in flood evacuations, New Yorkers could also benefit from additional research on resettlement implications of the latest climate science.
- **Assessment of confidence based on evidence**: Given the evidence and remaining uncertainties, there is high confidence that without significant intervention and reduction of vulnerabilities, New Yorkers' health will be harmed by multiple types of flooding, including pluvial, fluvial, coastal, and groundwater flooding, and their compound flood hazards.

Key Message 4: Hotter weather can increase concentrations of harmful air pollutants, including fine particles and ground-level ozone, by increasing emissions of precursor pollutants and the formation of ozone on warm, sunny days. These pollutants are harmful to health for all New Yorkers, but especially for the very young and old, people with certain chronic health conditions, those without residential air conditioning, and those living where emissions from buildings and traffic are concentrated. Most of these vulnerability factors are more common among Black, Latino, and low-income households. Despite a warming climate, air quality has improved in NYC because of reduced local and regional emissions. Recent wildfire smoke plumes affecting much of the eastern United States indicate the potential to reverse a trend of improving air quality. Efforts to further reduce emissions and exposures of vulnerable populations can prevent or mitigate climate-related air quality impacts.

- **Description of evidence**: The relation of weather to harmful air pollutant concentrations has been thoroughly studied, demonstrating the potential climate change to increase ambient concentrations health risks, especially for ozone.[1,300,305] The national and global body of evidence of health effects from $PM_{2.5}$ and ozone are extensive and robust.[317,320] Physiologic mechanisms and epidemiologic studies have demonstrated the influence of age and chronic health conditions.[321,340] Evidence for physical environment factors influencing vulnerability, including residential air conditioning and proximity to traffic emissions is also substantial[350–353] as are data showing Black, Latino, and low-income households having a greater burden of health and physical environment vulnerabilities.[107] Robust local data show improving air quality in NYC because of reduced emissions.[308,314,316,529]

- **Remaining uncertainties**: Air pollution epidemiology continues to identify additional health effects at levels well below regulatory standards and current health burdens are likely to be underestimated. Future risks of severe wildfire smoke episodes, like that impacting NYC in the summer of 2023 are yet to be quantified as is the potential for them to reverse decades of progress in reducing $PM_{2.5}$ exposure in NYC. Questions remain about the appropriateness of public health response strategies for acute air pollution episodes, including the AQI and advisory thresholds, the effectiveness of some recommended personal measures to reduce exposure, the ability of different populations to understand and implement recommended actions, and trade-offs between recommended activity restrictions and health benefits of regular physical activity.[449–451] The exposure-response relationship of indoor NO_2 pollution from gas stoves is uncertain and direct evidence of the health benefits of replacing gas stoves with electric ones is limited.
- **Assessment of confidence based on evidence**: Based on high-quality local and national studies, there is high confidence that: air pollution will continue to cause substantial public health impacts in NYC, especially among vulnerable populations and that reducing local emissions has and can continue to improve local air quality. There is moderate confidence that climate change will increase the risk of wildfires that can adversely affect NYC air quality. There is substantial uncertainty about the future frequency and severity of wildfire smoke episodes in NYC and the effectiveness of measures to reduce local exposures and health risks.

Key Message 5: Nationally, climate change is causing an earlier, longer, and possibly more intense plant pollen production season, but this trend is less evident in the northeast. Within NYC, pollen from several common tree species contribute to pollen exposure, seasonal allergic rhinitis, and asthma exacerbations. Communities with less access to health care, more household asthma triggers, and less well-managed asthma are more vulnerable. Air conditioning and filtration can reduce indoor pollen exposure. Attention to local tree cover density and species composition along with improved access to care, evidence-based asthma management, and patient education can reduce pollen exposure, vulnerability, and future allergic illness.

- **Description of evidence**: High-quality national and local studies published since NPCC2[1] add to the weight of evidence available for that assessment that the pollen season timing and intensity are being influenced by climate change and that pollen exposure and allergic illness is influenced by local land cover with plant species producing allergenic pollen.[359–362] Evidence has also grown that climate influences indoor and outdoor mold growth and that mold exposure can cause or exacerbate respiratory illness.[363–367]
- **Remaining uncertainties**: Local data on trends in pollen and mold exposure are limited and there are uncertainties in the relative influence of climate change versus trends in local landcover and housing construction and condition on these exposures. This adds uncertainty to knowledge of recent local trends and future projections of local allergic illness risk from these climate change sensitive aeroallergens.
- **Assessment of confidence based on evidence**: Confidence is high that climate change is influencing and increasing national aeroallergen exposure. Confidence is moderate that climate change will increase local health aeroallergen exposures and health risks, which are also influenced by multiple nonclimate factors.

Key Message 6: In the northeast, changes in climate, landcover, and ecosystems continue to shift the spatial and seasonal distribution of mosquitos and ticks that are current or potential vectors of human illness. Within NYC, the spatial distribution of these vectors and potential for human infection and serious illness varies with differences in the built environment, natural habitat and host animal abundance, human behaviors, and population vulnerability. Seniors, those with chronic illnesses, and people who are homeless are more susceptible to complications from WNV infection. Lyme disease risk among New Yorkers is increased among those engaged in outdoor activities mostly outside the city, but also in Staten Island and a limited area in the Bronx. VBD risk is also increased by international travel to and immigration from disease-endemic areas. Disease surveillance, vector monitoring and control, and public and clinician awareness can reduce future risks in a changing climate.

- **Description of evidence**: High-quality local and national studies demonstrate sensitivity of the range and abundance of mosquitos and ticks to climate change and complex interactions among climate variables.[1,374–377,382] Evidence is also strong that nonclimate variables, including human settlement and behavior patterns, and their interactions with climate also influence exposure and health risks from vector-borne pathogens.[9,375,378,381] Robust local surveillance data show that TBDs are most often acquired by New Yorkers during travel outside NYC and that locally acquired infection occurs mostly in Staten Island.
- **Remaining uncertainties**: The influences of the complex, multiple climate and nonclimate factors influencing human risk of VBD make it difficult to project future risks of currently endemic VBD in NYC and the metro area. Even more uncertain are future risks of new or emergent VBD. Additionally, improved research and surveillance can help evaluate and improve control measures. For example, mosquito control strategies using IPM principles have been widely implemented in response to the spread of WNV in the United States. Although evidence supports effectiveness in reducing mosquito populations, few studies have used outcomes of reduced human cases or surrogates for WNV risk.[512]
- **Assessment of confidence based on evidence**: There is high confidence that locally endemic VBDs will continue to cause illness in New Yorkers, that the risk of exposure will vary spatially and with changes in weather, and that robust local surveillance of insect vectors and human infections is essential to early identification and control of outbreaks. There is moderate confidence that changes in climate, international migration, and habitat could cause cases of locally transmitted malaria or other VBD not currently endemic in

NYC but high uncertainty concerning the future risk of sustained local transmission.

Key Message 7: Climate change may increase the risk of exposure to waterborne pathogens in surface waters and wastewater in and around NYC and could threaten its drinking water sources and distribution system. Increased flooding can cause exposure to contaminants flood and surface waters from CSOs and sewer backups. Rising temperatures facilitate the growth and spread of pathogens such as bacteria that cause gastrointestinal illness, Legionnaire's disease, and a range of illnesses from HABs. Extreme weather and climate change impacts on NYC's source and distribution infrastructure could compromise water quality and quantity. Continued maintenance and adaptation of infrastructure along with coordinated surveillance of water quality, human, and animal health can help prevent and control quality impacts on health.

- **Description of evidence**: Global and national studies demonstrate the potential for flooding, higher temperatures and rising humidity caused by climate change to increase risk of waterborne gastrointestinal, respiratory, and other illnesses.[215,415,416,418,420,421,427] In New York State, HAB reports increased in frequency from 2012 to 2020.[428] Locally, climate risks to NYC's drinking water supply are more complex because of its protected upstate watershed.[295] Local data show the potential for flooding to exposure to water contaminants through sewage backups and CSOs that affect surface water quality around the city,[424] for legionella outbreaks from cooling towers,[422] and for HABs to affect local water bodies.[430]
- **Remaining uncertainties**: NYC's unique and complex drinking water infrastructure and behaviors influencing contact with surface water makes it difficult to quantify future waterborne illness risk caused by climate change.
- **Assessment of confidence based on evidence**: There is moderate confidence that, absent adaptation, climate change can increase the local risk of exposure to waterborne contaminants from flooding and to legionella aerosols from cooling towers.

Key Message 8: Climate risks can be compounded when they disrupt lifeline infrastructure systems or overlap with nonclimate public health emergencies. Examples include power outages during recent extreme heat events and the COVID-19 pandemic creating potential disease transmission risks in cooling centers and other publicly accessible indoor spaces. The health risks from compound hazards can be reduced through investing in lifeline and other critical infrastructure and building mechanical systems that are adapted to extreme weather, redundant, and flexible. Rapid, flexible, collaborative, multisectoral responses are needed to respond to pandemics and other unanticipated compound hazards.

- **Description of evidence**: In addition to compound risks caused by damage to lifeline infrastructure during extreme weather, covered earlier, local studies demonstrated the compound risks to health created by hot summer weather co-occurring with COVID-19 transmission[431–434] or wildfire smoke.[437]
- **Remaining uncertainties**: Currently available data do not allow for quantifying the local added burden of human illness caused by the co-occurrence of hot weather with COVID-19 or with wildfire smoke exposure.
- **Assessment of confidence based on evidence**: Confidence is high that compound hazards can amplify climate–health impacts but low concerning the burden of illness caused by the interaction of climate risks and recently emerging hazards of COVID-19 and wildfire smoke.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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