

CLIMATE CHANGE IMPACTS ON HUMAN HEALTH & COMMUNITIES

September 2022

**ADDENDUM TO THE
2020 NEW JERSEY
SCIENTIFIC REPORT
ON CLIMATE CHANGE**





September 2022

Dear Fellow New Jersey Residents,

The New Jersey Departments of Health and Environmental Protection are pleased to share important information with you about the *Climate Change Impacts on Human Health and Communities*.


This is the first supplement to the [2020 New Jersey Scientific Report on Climate Change](#), which presented the latest and most reliable scientific information on the current and predicted future impacts of climate change specific to New Jersey's natural and built environments. This supplement adds important human health context to our climate science to better inform and prepare New Jersey for the health impacts associated with our changing climate.

As explained in the 2020 report, anthropogenic global atmospheric warming due primarily to the burning of fossil fuels is causing significant changes in climate patterns. New Jersey is uniquely vulnerable to these climate changes, which are projected only to worsen in the years ahead. These include increasing temperatures that further impair air quality, threats to water supplies and agriculture yield, rising sea levels adding more non-storm tidal flooding along the coast, increased dry spells interrupted by intense rainfalls that lead to more extreme inland flooding, and greater risks of major storms, such as those the state experienced with Superstorm Sandy and the remnants of Tropic Storm Ida.


This addendum explains how human health is likely to be directly and indirectly impacted by climate change. Heat waves and worsening air quality will likely increase the risk of cardiovascular disease, respiratory illness, and cancers. The risk of infectious diseases spread by pests or insects, as well microorganism contamination of food and water supplies, are likely to become more prevalent. Increasing extreme weather events will also present long-term challenges to the health and wellbeing of New Jersey residents and their communities. For example, rising sea-levels and increasing flood events will cause more residents to be displaced from their homes, contributing to the adverse impacts of climate change upon mental health. The impacts of climate change on human health and communities are anticipated to exacerbate existing environmental and public health disparities. Children, the elderly, and people with chronic health problems are most vulnerable to these impacts, which will also disproportionately burden underserved communities and those already overburdened by pollution and other stressors.

Raising awareness of these risks, while daunting, will position New Jersey to better confront the reality of climate change with solutions that create opportunity, promote inclusive and sustainable growth, and build vibrant, healthy communities for all people. Our Departments will continue to monitor the evolving science of climate change and update these materials so that, together, we may make the wise choices that build a more resilient New Jersey.

Sincerely,


Judith M. Persichilli, RN, BSN, MA
Commissioner of Health




Shawn M. LaTourette
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KEY FINDINGS

- 1** The extreme weather events predicted for New Jersey, including heat waves and heavy precipitation, can lead to both immediate and long-term effects on cardiovascular, respiratory, gastrointestinal, and mental health.
- 2** Climate change is anticipated to worsen air quality from both natural and human-made sources, which may lead to greater instances of cardiovascular disease, respiratory illnesses, and cancers in vulnerable populations.
- 3** Infectious diseases spread by arthropods, insects, and microbial contamination of food and water supplies are expected to become more prevalent as climate change increases the environmental conditions that are more favorable for pathogens and their hosts.
- 4** Population displacement as a result of sea-level rise, flooding events, and resource insecurity may add to the cumulative detrimental effects of climate change on mental health as individuals cope with the environmental and personal consequences of climate change.
- 5** Climate change will act as a threat multiplier for Environmental Justice communities, exacerbating existing stressors such as air pollution while adding new threats such as infectious diseases. These communities are also more vulnerable to the effects of extreme weather events, as they may lack adequate infrastructure, health, income, and resources to prepare for and recover from natural disasters. Food insecurity is worsened by climate injustices, which increase the already high frequency of chronic illnesses in impoverished areas.

ACKNOWLEDGMENTS

Thank you to the Department of Environmental Protection's (DEP's) Scientific Advisory Board and to the Department of Health's Consumer, Environmental and Occupational Health Service, who both provided thorough and insightful peer reviews of this addendum.

This work was made possible with financial assistance from the Coastal Zone Management Act of 1972, as amended, as administered by the Office of Coastal Management, National Oceanic and Atmospheric Administration's Program through the New Jersey Department of Environmental Protection, Coastal Management Program, Bureau of Climate Resilience Planning.

Any errors found within this report are the responsibility of the editors.

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Recommended Citation:

New Jersey Department of Environmental Protection. 2022. Climate Change Impacts on Human Health & Communities: Addendum to the 2020 New Jersey Scientific Report on Climate Change. Version 1.0. (Eds. J.A. Bonventre, L.A. Lester). Trenton, NJ. 54 pp.

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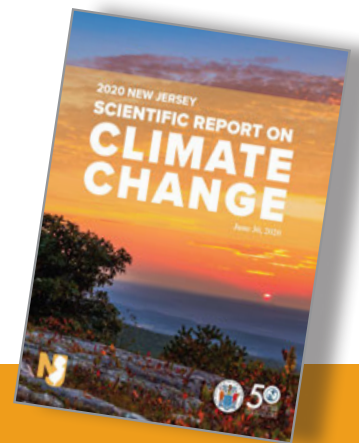
SECTION 1

INTRODUCTION

HIGH POINT STATE PARK, NEW JERSEY

This addendum to the 2020 New Jersey Scientific Report on Climate Change focuses on the ways in which human health is impacted by both the direct and indirect threats of global climate change.

Since the middle of the twentieth century, the changes in weather patterns in combination with global population growth have led to an increase in human exposure to more severe heat waves, forest fires, severe storms, droughts, and infectious disease vectors, with dire consequences to human health and communities. From a greater incidence of cardiovascular and respiratory dysfunction associated with extreme weather, to population displacement caused by rising sea-levels and increased flooding events, to the often-overlooked mental health toll that climate change has on individuals and communities, the vulnerability of the human population to climate change is tangible. The following sections describe how the impacts of climate change described in the *2020 New Jersey Scientific Report on Climate Change* may affect the human health and communities of New Jersey residents.



The *2020 New Jersey Scientific Report on Climate Change* is available here:

<https://www.nj.gov/dep/climatechange/data.html>



SECTION 2

EXTREME WEATHER



The extreme weather conditions brought about by climate change are largely the result of warming temperatures, anomalous precipitation, and air pollution, driven by human activities such as increases in atmospheric carbon dioxide (CO₂) and other greenhouse gases. Together, increased heat and precipitation promote the occurrence of more intense and severe weather events (e.g., hurricanes). These disturbances to the natural climate cycle influence human health in a variety of ways, particularly in individuals with chronic illnesses.

2.1 Temperature and Humidity

Climate change, as discussed in the *2020 New Jersey Scientific Report on Climate Change*, is fueling more frequent, more intense, and longer-lasting heat waves [see [Chapter 4.1, 4.1-4](#)]. Excessive heat events are increasing globally and the ten warmest years on record have occurred since 2005 (Lindsey and Dahlman 2021). Extreme heat is a natural hazard, with an upper limit to survivability; under prolonged exposure, the body's innate mechanisms for thermoregulation are rendered ineffective, especially in patients with chronic health conditions. Excessive heat can lead to increased heat-related mortality and morbidity, including illnesses such as heat exhaustion, heat cramps, heat edema (swelling in the legs and hands), heat syncope (fainting), and heat stroke (USGCRP 2016, CDC 2021a, Cissé et al. 2022). Mortality due to heat related deaths in warmer seasons are increasing globally, with 37% attributable to anthropogenic climate change (Vicedo-Cabrera et al. 2021). From 2006-2010, over 3,000 deaths in the United States were attributable to excessive heat, likely an underestimation as diagnostic criteria for heat-related mortality are inconsistent (Berko et al. 2014). In New Jersey alone, heat-related hospital admissions during the warm season (May to September) increased approximately 156% from 2004 to 2013 (Moran et al. 2017). The more frequent, elevated temperatures and prolonged heat waves predicted for New Jersey could lead to a significant increase in summer heat-

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related mortalities, more than a doubling in number from the mid-twentieth century to the middle of the twenty-first century (Kinney et al. 2004, Dupigny-Giroux et al. 2018).

"In New Jersey alone, heat-related hospital admissions during the warm season increased approximately 156% over a ten year period."

Humidity is an exacerbating factor contributing to the hazard of extreme heat, and global increases in heat and humidity can have deadly consequences (Raymond et al. 2020, Li et al. 2020). In a model evaluating climate variables to identify which were most likely to contribute to lethal heat conditions, daily surface air temperature and relative humidity were the most predictive pair (Mora et al. 2017). Above a certain combination of temperature and humidity, sweat will no longer evaporate from the surface of the skin, limiting the body's natural cooling mechanism. Prolonged exposure to such conditions can be fatal, and the higher the humidity, the lower the temperature at which heat stress can be fatal (Smith et al. 2014, Mora et al. 2017). While this is a greater threat to the equatorial regions of the globe, the Northeastern United States and New Jersey are prone to periods of high heat and humidity, and expected to have greater periods of such weather in the future (Moran et al. 2017, Dupigny-Giroux et al. 2018).

The combination of high heat with high humidity may compromise both outdoor occupational and recreational activities as humans reach thermal tolerance, meaning it will be uncomfortable and inadvisable to engage in heavy labor and other physically taxing outdoor activities. One study suggests that heat stress has already led to a 10% reduction in labor capacity globally in peak months in the past few decades, and projects that by 2050, that reduction will be 20%, particularly in the eastern mid-latitudes region of the United

States, such as New Jersey (Dunne et al. 2013). Temperatures above 85°F led to a 5-7% increase in injuries, in both indoor and outdoor settings, compared with temperatures in the 60s°F, with injuries not necessarily strictly heat-related, including falling from heights, being struck by a moving vehicle, or mishandling dangerous machinery (Jisung Park et al. 2021). Lower wage workers also tended to experience greater instances of injury due to the nature of the jobs they perform, which was documented over 20 years ago to highlight the growing inequality in the workplace (Hamermesh 1998). The effects of climate change can be expected to exacerbate workplace disparity, not only through oppressive temperature conditions, but through other mechanisms discussed throughout this section.

People who are the most vulnerable to extreme temperatures include children, elderly, and individuals in low-income communities and communities of color (Berko et al. 2014, CDC 2021a, Cissé et al. 2022). Urban communities are more susceptible to high temperatures, because the 'built environment' (e.g., buildings, roads, and sidewalks) absorbs and re-emits the sun's heat more readily than natural landscapes, a concept known as the heat-island effect [See [Chapter 4.1](#)]. In New York City, daily mortality spiked after a city-wide power failure in August 2003, due in part to increased exposure to heat (Anderson and Bell 2012). Further, in urbanized areas, the exposure to extreme heat is disproportionately experienced by people of color compared to non-Hispanic Whites, and by households below the poverty line relative to those at more than two times the poverty line (Hsu et al. 2021).

Extremes in temperature can worsen chronic health conditions, including cardiovascular and respiratory diseases, diabetes, and kidney disease (Cissé et al. 2022). Dehydration, from excessive perspiration, can lead to increased blood viscosity, and therefore strain the heart and increase the risk of blood clots (Näyhä 2005). More recently, the rise in chronic kidney disease in Central and South American farmers, generally associated

EXTREME WEATHER
PRECIPITATION ANOMALIES

with severe dehydration from laboring in extreme heat and humidity (Wesseling et al. 2013), serves as a cautionary tale for the Mid-Atlantic region of the United States as it prepares to experience more intense and prolonged heat waves. High temperatures also increase the likely formation of ground-level ozone in the air, the health consequences of which will be discussed in 3. Diminished Air Quality. Individuals with chronic health conditions are also more vulnerable to heat-related illness, and should take extra care to stay hydrated, avoid strenuous activity, and keep cool (e.g., have access to air conditioning) during extreme heat events (CDC 2022a). As the climate continues to change, more frequent and longer heat waves with rising temperatures can be expected to increase heat-related illness, resulting in surges of hospitalizations and deaths.

2.2 Precipitation Anomalies

The more frequent and intense rainfall events projected for certain regions of the globe, including in New Jersey [[Chapter 4.2-4](#)], will likely lead to increased flooding, increased erosion, and compromised human health (DeGaetano 2021). Of the greater than 10,600 deaths in the United States attributable to weather-related events from 2006-2010, over 6% were due to flooding, storms, or lightning, as a direct or associated cause of death (Berko et al. 2014). Males were twice as likely to die than females from such conditions, either directly from drowning during a flood or because of exacerbated preexisting medical conditions (e.g., cardiovascular disease). The Centers for Disease Control and Prevention (CDC) estimates that floods account for, on average, nearly 100 deaths annually in the United States (CDC 2021a). Flooding events are a hazard for drowning, injury, and hypothermia, and can lead to sanitation issues, as local wastewater treatment facilities can become overwhelmed (Cissé et al. 2022). Acute and chronic health effects secondary to a flooding event, such as respiratory illnesses from mold exposure and infectious disease spread from microorganism contamination of clean

water, are discussed in 3. *Diminished Air Quality* and 4. *Increases in Infectious Disease Transmission Patterns*, respectively.

As discussed in [Chapter 5.3](#), heavy rainfalls will negatively impact agriculture in a variety of ways, from planting delays to overly wet soils prone to root disease and limiting animal access to pastures (Hristov et al. 2018). Warmer, wetter winters, such as those predicted for New Jersey, can lead to increased weed and pest growth, prompting farmers and homeowners to utilize more pesticides, resulting in a greater exposure to potentially harmful chemicals for agricultural workers and local communities. Increased soil erosion and agricultural runoff may result in contaminated surface and groundwater sources posing a public health concern, as the increased manure, fertilizers, and pesticides enter local waterways (US EPA 2005, USGCRP 2016). In a controlled study, anthropogenic waste products containing household and industrial products were distributed as biosolids along an agricultural field, and contaminants were detected in surface waters and terrestrial sites far from the original point of application throughout the duration of the experiment (Gray et al. 2017). These waste streams contain many unidentified substances or bioactive substances that may impact health, requiring further study.

Heavy rainfall can also mobilize contaminants from urban environments as well (Tran et al. 2019). Following the flooding that occurred with Hurricane Sandy, contaminated soils from Superfund sites around the NY-NJ region were found inland from the sites of origin (Marcantonio et al. 2019). Drinking water sources contaminated by heavy storm runoff have been associated with increased hospitalization in New Jersey for gastrointestinal effects, specifically from increased microbiological contaminants in raw water (Gleason and Fagliano 2017), and exposure to pollutants is also likely to increase with heavy rainfall. In addition, human exposure to pollutants would increase during recreational activities (e.g., swimming in lakes) in areas where nutrients from run-off of agricultural fields or combined sewer overflows (CSOs) enter

EXTREME WEATHER *PRECIPITATION ANOMALIES*

waterways. In New Jersey, there are 212 CSOs located in 21 municipalities (NJDEP 2022a). This can also result in increased harmful algal blooms (HAB) in surface waters [see [Chapter 5.10](#)]. Further health consequences of HABs will be discussed in [4.2 Food and Waterborne Diseases](#).

In contrast to the consequences of heavy rainfall, lack of precipitation leads to its own myriad of human health complications. Droughts may affect water-storage, land-use and irrigation practices,

and human population distribution [see [Chapter 4.2-5](#)]. Drought conditions intensify extreme heat events, leave the environment more prone to flash floods, promote dust storm conditions, and strain water supplies (CDC 2021a). The combination of reduced precipitation and increased evaporation of surface waters (from extreme heat) may lead to unreplenished groundwater supplies, resulting in regional water-insecurities (Stanke et al. 2013, CDC 2021a). For regions dependent on surface water as a drinking water source, evaporation can decrease



"New Jersey's aging coastal infrastructure and ecosystems are vulnerable to the more intense and frequent hurricanes, precipitation, and storm surges that are predicted for the region."

JERSEY CITY, NEW JERSEY

EXTREME WEATHER
WEATHER-RELATED NATURAL DISASTERS

the overall water quality of surface water where the concentrations of chemical pollutants (e.g., pharmaceuticals, endocrine disrupting compounds, nitrates) increase as a result of decreased volume. An example of this was observed in Lake Mead, the major drinking water source for southern Nevada, following several years of drought (Benotti et al. 2010). The increased concentrations of contaminants in ground and surface waters can increase human exposure to pollutants through drinking water and recreational activities (e.g., swimming). For agricultural communities, decreased crop yields or overall crop failures are exacerbated under drought conditions, leading to both economic stress for farmers and resource strain for the food supply chain regionally and nationally [see [Chapter 5.3](#)].

"Extreme weather events, be they excessive heat and humidity, heavy rainfalls, drought, or natural weather-related disasters, lead to both immediate and long-term effects on human health."

Another health hazard from drought conditions is the increased likelihood of wildfires [see [Chapter 5.4-5](#)]. Increased wildfires will likely lead to excess mortality and morbidity from burns and the release of inhalable particulate matter and other toxic substances into the environment (Cissé et al. 2022). The Centers for Disease Control (CDC) reports that over 400 firefighters died in the United States from heat (e.g., collisions from low visibility) and sudden cardiac events while fighting wildfires from 2000-2019 (CDC 2021a). The general public can also be impacted in the aftermath of a wildfire event, experiencing eye irritation and corneal abrasions, heart attacks, asthma attacks, bronchitis, chronic obstructive pulmonary diseases (COPD), and premature death (Casco 2018, Xu et al. 2020). The impact of particulate matter and other toxic substances from wildfires and biomass combustion on air quality is discussed in 3. *Diminished Air*

Quality section. As droughts are predicted to occur more frequently in New Jersey due to changes in precipitation patterns, a greater portion of the population may be subjected to stress from increased exposure to smoke and particulate matter from wildfires or through decreased food and water security. The loss of life, homes, valuables, and neighbors leads to stress and depression.

2.3 Weather-Related Natural Disasters

Globally, weather-related natural disasters (e.g., storms and flooding) have risen since the middle of the twentieth century, with tropical storms and hurricanes being major weather-related threats to the Mid-Atlantic coast (Marquardt Collow et al. 2016, Broccoli et al. 2020). New Jersey’s coastal infrastructure and ecosystems are sensitive to the changing environmental conditions brought on by the more intense and frequent hurricanes, precipitation, and storm surges that are predicted for the region [[Chapter 4.3-3](#)]. The 2020 hurricane season was the worst on record, with 30 named storms, 12 of which made landfall in the United States, and was the fifth consecutive year with above-normal Atlantic hurricanes, where “normal” is 12 named storms, with six designated hurricanes (NOAA 2020). Further, hurricanes are getting stronger, as evidence suggests that climate change is increasing the chance of storms reaching Category 3 or higher (Kossin et al. 2020). Damage to the coastline directly impacts commercial and residential areas, and the communities therein, especially as storm surges coupled with sea-level rise increases the chance of severe flooding events (USGCRP 2016, Cissé et al. 2022). In many regions, the increased sea-levels will also lead to increased risk of population displacement (Cissé et al. 2022).

Power outages from extreme weather events can lead to a range of public health crises, including the negative outcomes related to a taxed health care system, food and drinking water safety concerns, and secondary impacts, such as carbon monoxide (CO) poisoning and electrical shock (CDC 2017).

EXTREME WEATHER

SUMMARY: EXTREME WEATHER AND HUMAN HEALTH EFFECTS

Infrastructure failure following devastating weather events may cause health care system failures, including a loss of access to essential medical equipment or devices and medicine for patients (Burger and Gochfeld 2017), resulting in increased mortality that otherwise could have been avoided, particularly for the elderly and those of low-socioeconomic status (Moran et al. 2017, Bates 2019). Such was the case in New Jersey post-Hurricane Sandy in 2012, where there was an increase in calls to emergency services, visits to hospital emergency departments, and hospital admissions (Moran et al. 2017). Powerful storms with heavy precipitation and hurricanes will cause roadway blockages (Burger et al. 2017), increases in drowning and other flood related injuries, exposure to contaminated drinking water and sewage disposal, and a host of additional public health concerns, including gastrointestinal illnesses and mental health impacts (Burger and Gochfeld 2017).

“Heavy rainfall events contaminate drinking water sources leading to increased hospitalizations in New Jersey.”

Beyond the immediate emergencies following dangerous storms are the long-lasting drastic effects from infrastructure recovery (e.g., poor management of diseases and mental health stress), particularly to health care services, and the community consequences from possible population displacement (Bates 2019). Health losses caused by storms and floods will likely increase over the century, particularly in coastal populations, unless mitigating measures are enacted (Cissé et al. 2022). The immediate and long-lasting consequences of extreme weather are more problematic for overburdened communities, which already suffer the cumulative effects of poor infrastructure and reduced health outcomes.

Overburdened communities are defined as areas where (1) at least 35 percent of the households qualify as low-income households; (2) at least 40 percent of the residents identify as minority or as members of a State recognized tribal community; or (3) at least 40 percent of the households have limited English proficiency (NJDEP 2022b).

2.4 Summary: Extreme Weather and Human Health Effects

Extreme weather events, be they excessive heat and humidity, heavy rainfalls, drought, or natural weather-related disasters, lead to both immediate and long-term effects on human health. Factors such as medical conditions (e.g., chronic diseases), age, race, and economic status as well as community and social support systems all play a role in individual resilience to environmental threats. Furthermore, these threats are often not isolated events, as was observed in the summer of 2020 when parts of the United States dealt with extreme heat waves, droughts, wildfires, hurricanes and a global pandemic (Salas et al. 2020). The effects of extreme weather influence can compound the health effects discussed in the subsequent sections.



LONG BEACH ISLAND, NEW JERSEY



SECTION 3

DIMINISHED AIR QUALITY



Climate change and air quality are in a destructive feedback loop. Air pollution not only contributes to climate change but is also exacerbated by it. Excess CO₂ and methane raise the earth's temperature, which in combination with ultraviolet radiation, leads to the formation of other air pollutants [see [Chapters 3 and 5.1-1](#)]. Additionally, increasing global temperatures and frequent flooding events will increase the production of allergenic air pollutants including mold (in houses and agricultural areas) and pollen due to a longer pollen season and more pollen production. The impact of climate change on air quality and how that affects human health is discussed in this section.

3.1 Exacerbated Air Pollution

Air pollution has both anthropogenic and natural sources, and the relationship between climate change and air pollution is discussed in [Chapter 5.1](#). Human-caused sources of air pollution include burning of fossil fuels (e.g., gasoline and diesel emissions, coal and natural gas, electricity production including higher energy demand in hotter summers) and agricultural emissions from livestock (methane and ammonia), while natural sources include smoke from wildfires, dust from dry conditions, and pollen. As is the case with excessive heat, increased air pollution can aggravate chronic conditions, such as asthma, COPD, and cardiovascular diseases, and increase the incidence of lung cancer (USGCRP 2016, CDC 2021a). Asthma is a condition of chronic airway inflammation, which characteristically leads to wheezing, shortness of breath, chest tightness, and coughing in symptomatic patients that afflicts 34 million Americans and accounts for about 4,000 deaths each year (CDC 2010). There are more than 600,000 adults and 167,000 children with asthma in New Jersey, with almost 40% of the 50,000 annual emergency department visits for asthma related symptoms for children (NJDHSS 2013, NJ DOH 2022a). In 2019 alone, approximately 6.67 million deaths globally were attributed to air pollution from ambient particulate matter pollution (e.g., PM_{2.5}),

DIMINISHED AIR QUALITY
EXACERBATED AIR POLLUTION

household air pollution from solid fuel for cooking (e.g., wood, charcoal, coal), and ground level ozone pollution (IHME 2020). Children are generally more vulnerable to air pollutants because they inhale a higher volume of air per body weight than adults and have immature defense mechanisms (Salvi 2007). Ozone, PM_{2.5}, and pollen were associated with increased pediatric asthma emergency department visits in New Jersey (Gleason et al. 2014). Warmer temperatures increase the concentration of air pollutants, further emphasizing that global climate change is a multifactorial problem (Cissé et al. 2022).

The United States Environmental Protection Agency (EPA) monitors key air pollutants regularly under the Clean Air Act in order to maintain nationwide air quality standards designed to meet health-based guidelines for common air pollutants (US EPA 2020). As discussed in [Chapter 5.1](#), significant outdoor air pollutants include carbon monoxide (CO), airborne lead, sulfur dioxide (SO₂), nitrogen dioxide (NO₂), particulate matter, and ground-level ozone pollution. Due to the motor vehicle emission standards and the removal of lead from gasoline,

both carbon monoxide and lead levels meet air quality standards nationwide, with the exception of areas surrounding lead-emitting industrial facilities (US EPA 2020). In contrast, SO₂ and NO₂ dioxide levels both reach unhealthy levels in several states near New Jersey (e.g., SO₂ levels in Pennsylvania and Maryland) throughout the year (US EPA 2020). While particulate matter and ground-level ozone have decreased over recent years in part due to the regulation and controls implemented to reduce levels to achieve the National Ambient Air Quality Standards, they remain a concern in many areas of the country as they result from a myriad of different sources (Lioy and Georgopoulos 2011, US EPA 2020). These air pollutants, among others, can cause serious health problems, particularly in populations that already have higher rates of heart and lung conditions. In New Jersey, for example, from 2011-2018, Black populations had higher prevalence of COPD on average compared to White, Hispanic, and Asian populations (NJ DOH 2019). Therefore, constant monitoring of the air quality is imperative to determining the effectiveness of federal and state efforts in maintaining healthy and clean air in the country.

Table 1. Daily Air Quality Index (AQI) Values and Outdoor Activity Guidance for PM_{2.5}.

Table was modified from www.airnow.gov/aqi/aqi-basics/ with information from US EPA 2012, and aligns with DEP's new flag program (<https://dep.nj.gov/njaqflagprogram/>).

AQI Color	Levels of Concern	Breakpoints (µg/m ³ , 24-hr avg)	Index Value	Description of Air Quality and Outdoor Activity Guidance
Green	Good	0.0 to 12.0	0 to 50	Air quality is satisfactory. No health impacts are expected.
Yellow	Moderate	12.1 to 35.4	51 to 100	Air quality is acceptable. Individuals who are unusually sensitive to air pollution may be at risk for affects.
Orange	Unhealthy for Sensitive Groups	35.5 to 55.4	101 to 150	Members of sensitive groups may experience health effects and should limit outdoor exposure. The general public is less likely to be affected.
Red	Unhealthy	55.5 to 150.4	151 to 200	Members of sensitive groups may experience more serious health effects and should avoid outdoor exertion. Some members of the general public may experience health effects.
Purple	Very Unhealthy	150.5 to 250.4	201 to 300	Health alert: The risk of health effects is increased for everyone. Outdoor exertion should be limited or avoided.
Maroon	Hazardous	250.5 to 500	301 and higher	Health warning of emergency conditions: everyone is more likely to be affected. Outdoor exertion should be avoided.

DIMINISHED AIR QUALITY
EXACERBATED AIR POLLUTION

Even healthy individuals, who may be less susceptible to the aggravated respiratory and cardiovascular effects of chronic disease, may experience a disruption of normal work and recreational outdoor activities when air quality diminishes due to increase levels of pollutants. Table 1 outlines the outdoor recreation recommendations for PM_{2.5} based on the EPA’s Air Quality Index (AQI). The AQI is an averaged measure of the pollutants in the air (e.g., CO, SO₂, NO₂, particulate matter, and ground-level ozone) in a 24-hr period relative to their National Ambient Air Quality Standards. The AQI ranges from 0-500, where values below 50 are considered good air quality and healthy for all persons to be outdoors, whereas values greater than 300 describe hazardous conditions where everyone is likely to be affected (US EPA 2012). An AQI of 51-100 is considered moderate, but still acceptable to be outside for all activities, with the exception of individuals who are “unusually sensitive” to air pollution. During instances of higher than acceptable AQI levels, individuals with asthma may experience coughing, wheezing, difficulty breathing, and chest tightness. In extreme conditions (>150 AQI), even individuals who do not have asthma may experience these symptoms. Such guidance values are generally applied to protect school-aged children who are more sensitive to air pollution than adults, but these values can also be used as a loose indication of climate change conditions by following trends within a certain area because just as climate change can impact air quality, air quality can impact climate change.

3.1-1.1 Air Pollution from Biomass Combustion

Prescribed burning is commonly utilized as a tool to reduce wildfire hazards in New Jersey, and there are also many ecological benefits to forest fires including wildlife habitat management, ecological plant and animal management, forest disease and pest control, nutrient recycling, and others (NJDEP 2020a). However, combustion of products from wildland fires (wild and controlled forest, grass, and peat fires) and other agricultural burning pollutes

the air, soil, and waterways of the surrounding area. In addition to producing greenhouse gases and climate pollutants [see [Chapter 3](#)], including carbon dioxide (CO₂), methane (CH₄), black carbon, and nitrous oxide (N₂O), fires also produce ozone precursors (e.g., nonmethane volatile organic compounds (NMVOCs), nitrogen oxides (NO_x) and particulate matter, both fine (PM_{2.5}) and coarse (PM₁₀) (Urbanski et al. 2008). Primary pollutants from burning biomass, such as CO, remain a local burden, restricted to the immediate region, while PM_{2.5} and ozone will be more broadly dispersed (Tao et al. 2020). The atmospheric transport of combustion products from wildland fire can reach far beyond the immediate location of the burn depending on meteorological conditions, plume dynamics (movement of the column of smoke and all that it contains through the air), the amount and chemical composition of the emissions, and the atmosphere into which the emissions are dispersed (Urbanski et al. 2008, Smith et al. 2014). As a result, particulate matter and ozone produced by combustion events have become the predominant pollutants for quantifying air quality. These pollutants form mainly through atmospheric chemical reactions following the release of precursor emissions (Dedoussi et al. 2020). The unusually high organic carbon content recorded at an air quality monitoring site located in Brigantine, New Jersey on July 7, 2002 was known to be attributable to a large wildfire in Quebec, Canada in that week (GFMC 2002). As more than 250,000 acres of forests burned, much of the northeastern United States was covered in smoke and haze that reached as far south as Washington, D.C., and air traffic was affected as far south as New York State (GFMC 2002). Similar occurrences following eastern Canadian wildfires took place in 2015, where air quality was impacted by smoke moving into the United States and south to Baltimore, Maryland and in 2016, where multiple New Jersey air-quality monitors noted exceedances of health-based ozone standards (NJDEP 2017, Dupigny-Giroux et al. 2018).

Exposure to fire emission pollutants is a growing global public health concern, as observed with

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increases in the incidence of acute cardiovascular events and the potential of such emissions to trigger respiratory conditions, such as asthmatic episodes and acute bronchitis; prolonged exposure to air pollutants could cause asthma and chronic bronchitis and further result in COPD (Cascio 2018, Anenberg et al. 2020). As a result, the risk of premature death due to exposure to fire emissions is also increased. Globally, fire emissions are estimated to be responsible for 339,000 deaths annually (Johnston et al. 2012). Individuals with respiratory and cardiovascular diseases, older adults, children, those who are pregnant, and fetuses are more sensitive to the adverse health effects of smoke exposure (USGCRP 2016). Excess hospitalizations were observed in areas downwind of wildfires, in a pattern following the distribution of smoke plumes (Deflorio-Barker et al. 2019). More specifically, increased exposure to elevated PM10 levels was associated with a higher incidence of acute coronary syndrome and hospitalization of elderly patients for several days following fire-related air quality exceedances (Kollanus et al. 2016, Kuźma et al. 2020). Admissions of both pediatric and adult asthma patients also increased with exposure to primary fire emissions PM2.5, PM10, or ozone, individually or in combination

(Pope et al. 2017, Baek et al. 2020). Pre-term birth has been associated with exposure to CO and PM2.5 early in pregnancy (Padula et al. 2019). The risk of hospitalization and pre-term birth is greater to vulnerable communities in areas prone to seasonal droughts, such as the western United States and Northeast (Dupigny-Giroux et al. 2018, Cascio 2018, Anenberg et al. 2020).

As the frequency and severity of wildfires are expected to increase in the western United States and Canada [Chapter 5.4-5], the air quality in New Jersey could be negatively impacted and the incidences of respiratory illness, reduced visibility, and disruption of outdoor activities will likely increase. For example, during the devastating 2020 wildfire season in the western United States, several populated cities, including Seattle, Washington, Portland, Oregon, and Sacramento, California, sustained “Unhealthy” and “Very Unhealthy” AQI values for several days. Many areas in the region experienced instances of “Hazardous” AQI conditions, including Portland, which recorded 8 days above 200, and a maximum AQI of 509 that year. Cities of neighboring states Idaho and Nevada also experienced several “Unhealthy” and “Very Unhealthy” days with AQIs in the 200s. In



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comparison, New Jersey, which experienced less of an impact from the fires, experienced state-wide AQIs that were never above “Unhealthy” in 2020, with the maximum AQI recorded as 143 for the Philadelphia-Camden-Wilmington, PA-NJ-DE-MD region (US EPA 2019). However, the severity of 2021 wildfire season led to multiple days of hazy skies and a characteristic red sun across the country and all the way to eastern cities, including the New York/New Jersey metropolitan area, due directly to a convergence of smoke plumes from several fires in the western United States and Canada (Popovich and Katz 2021). The resulting diminished air quality in the region led state officials to encourage vulnerable individuals to avoid outdoor activities to minimize exposure to the air pollution (primarily PM_{2.5}), a call that may become more common as western wildfires continue to rage in the drought stricken west coast. The fine particulate (PM_{2.5}) levels in the Mid-Atlantic and New England states increased to “Unhealthy” because of wildfire smoke from the western United States and Canada on July 20 and 21, 2021. Although emissions from cars, trucks, and industry contribute to PM_{2.5} air quality, the elevated levels of PM_{2.5} on these days in 2021 were caused by the wildfire smoke from upwind regions and resulted in concentrations exceeding the 24-hour average National Ambient Air Quality Standard for PM_{2.5} throughout the Northeast.

In 2021, nearly 2,000 acres of forests were burned in approximately 1,000 wildfires in New Jersey (NJDEP 2022c). While the scale of wildfires in New Jersey does not compare to regions in the western United States, a significant portion of its homes are adjacent to forested areas, making even the small fires a concern for human health and property (Hurdle 2022).

Burning waste products, either by individuals or more broadly by a municipality, is another contributor to air pollution that can drive climate change. The combustion of refuse produces not only the normal pollutants (e.g., CO, SO₂, NO₂, particulate matter, etc.), but can also release an abundance of toxic chemicals including, but not limited to polychlorinated dibenzo-p-dioxins

(PCDDs), polychlorinated dibenzofurans (PCDFs), and polychlorinated biphenyls (PCBs) (Ferronato and Torretta 2019) as well as metals. In addition to the toxic emissions from burning refuse, disposing of the ashes from such activity can result in high concentrations of heavy metals and other chemicals in soils of dumping areas (USGCRP 2016). Byproducts of waste burning can then be redistributed by wind in drought conditions or by heavy precipitation, expanding the contamination area and increasing exposures to a larger population. However, New Jersey residents are prohibited from open burning of rubbish, garbage, trade waste, fallen leaves, or any kind of plant material (N.J.A.C. 7:27-2.3), and New Jersey’s Air Quality Permitting Program regulates air toxic output from municipal and industrial incineration through a combination of state-of-the-art control technology requirements and risk assessments.

3.1-1.2 Particulate Matter Pollution

Particulate matter consists of particles and liquid droplets that are formed from gaseous precursor emissions of NO_x, sulfur oxides (SO_x), ammonia (NH₃), and other airborne compounds. Particulate matter can also be emitted directly, as in the case of black carbon [see [Chapter 3.5](#)] (Dedoussi et al. 2020). While wildfires may pollute the air in acute episodes, by producing various particulate materials (PM), such as PM₁₀, PM_{2.5}, and ultrafine particles (<0.1 μm, PM_{0.1}), there are other more chronic sources including power plants, automobile exhaust, and some household cooking [see [Chapter 5.1-1.2](#)]. Short-term particle exposure (hours or days) can cause eye, nose, throat and lung irritation, coughing, sneezing, runny nose, shortness of breath, asthmatic attacks, acute bronchitis, and increased susceptibility to respiratory infections. Long-term exposure (years) has been associated with reduced lung function, chronic bronchitis, and increased mortality from lung cancer and heart disease (US EPA 2003). Particulate matter vary in composition, containing sulfate, nitrate, ammonium, carbon, metal fragments, liquid, sea salt, or dust, and their toxicity is inversely related to their size (Smith et al. 2014, USGCRP 2016).

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The smaller the particle size, the larger the relative surface area of individual particles, which in turn means a greater surface area on which to absorb materials (e.g., toxic chemicals). Smaller particles are also capable of penetrating deeper into the respiratory tract than larger particles and may carry along pollutants adhered to them. $PM_{2.5}$ are known to cause pulmonary inflammation to a greater extent than PM_{10} , whereas $PM_{0.1}$ have the potential to cause greater damage due to their ability to enter circulation via the lung vasculature (Schraufnagel 2020). Particulate matter nanoparticles are also capable of reaching the central nervous system directly via the olfactory nerve (a nose-to-brain route), in a size dependent manner. Exposure to airborne particles in general has been associated with neurotoxicity for some metals, such as manganese, however, the effects of other pollutants (in the form of particulate matter for instance) are still emerging (Lucchini et al. 2012). The health effects of $PM_{2.5}$ and $PM_{0.1}$ are thought to be driven by oxidative stress, an imbalance between cellular free radicals and antioxidants, and the triggered immune response in target tissues (e.g., lung, blood vessels, heart). Furthermore, particulate matter air pollution is a leading cause of cardiovascular morbidity and mortality, particularly in elderly patients (Rao et al. 2018).

3.1-1.3 Ozone Pollution

Ground-level ozone, a major component of smog, is formed by a natural chemical reaction between nitrogen oxides and volatile organic carbons in the presence of sunlight, but is accelerated by human activity (e.g., automobile emissions) [see [Chapter 5.1-1.1](#)]. Ground-level ozone is associated with reduced lung function, increased severity of asthma attacks requiring emergency department visits and admissions, as well as premature deaths (USGCRP 2016, Nuvolone et al. 2018). Modeling of ozone-related premature deaths from 2000 to 2030 showed that the northeastern United States had the second highest projected change of six geographic regions of the country, second only to the midwestern United States (USGCRP 2016). Children, elderly, and people with asthma, bronchitis, or emphysema

are most at risk, but healthy adults with outdoor occupations may also succumb to ozone air pollution (Nuvolone et al. 2018, CDC 2021a). An estimated tens to thousands of ozone-related illnesses and deaths occur yearly, with a projected economic burden ranging from hundreds of millions to tens of billions of U.S. dollars (Fann et al. 2015).

Exposure to ozone occurs via inhalation where it is mostly absorbed by the upper respiratory tract. Absorption rates vary with age, gender, and overall physical health. Vigorous physical activity generally leads to higher penetration of ozone into the lung. Ozone will react with components of the natural fluid lining in the lung, leading to oxidative stress, cell injury, and inflammation. Symptoms of ozone exposure are similar with other air pollutants, including lung and throat irritation, coughing, wheezing, and difficulty breathing during exercise or outdoor activities (Nuvolone et al. 2018, CDC 2021a).

Ozone concentrations are generally highest in the warmer months in the Northern Hemisphere (USGCRP 2016, Dupigny-Giroux et al. 2018). With the rate of atmospheric warming expected to increase, particularly in New Jersey, several models have attempted to estimate the deaths in the United States attributable to ozone-related illnesses for the years 2000 to 2050, with the largest increase in deaths predicted for the northeastern United States (Post et al. 2012). Climate change is threatening to offset the recent progress that the Northeast has made in improvements to air quality, due in part to the increases of ground-level ozone concentration, particularly in urban environments (Fann et al. 2015, Dupigny-Giroux et al. 2018).

A recently published model predicted ozone concentrations to worsen across much of the contiguous United States by 2051 (Ren et al. 2022). In New Jersey, the daily ozone concentrations during the warm season (May to September) in 2051 are predicted to exceed the daily ozone concentrations measured in 2011 (Figure 1; pers. comm. with Panos Georgopoulos; April 2022).

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 INCREASED AEROALLERGENS**

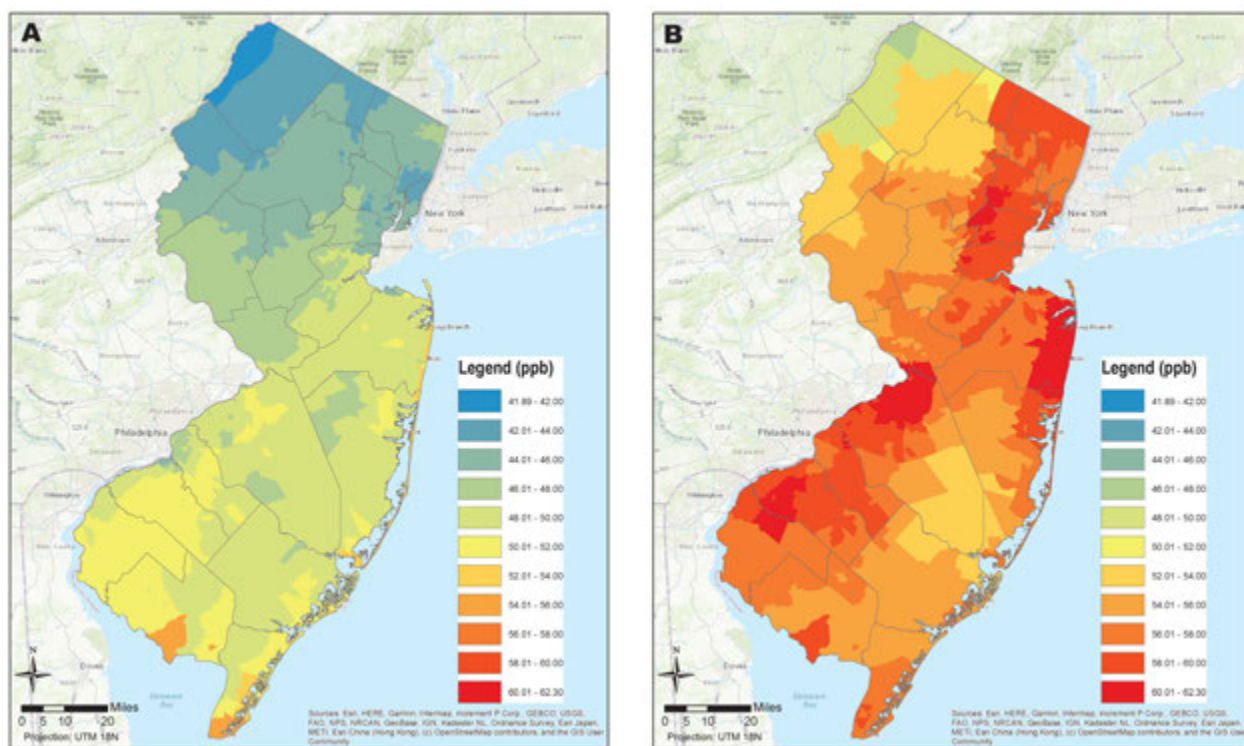


Figure 1. Maps of 2011 and model estimates for 2051 levels of ozone across New Jersey.

The maps show means of Daily Maximum 8-Hour Running Average values of ozone concentrations during the warm season (May to September) in 2011 (A) and predicted for 2051 (B). The 2051 estimates have been calculated for the "worst case" scenario, using the method described in (Ren et al. 2022).

3.2 Increased Aeroallergens

Climate change driven increases in CO₂, temperature and humidity, and precipitation have secondary consequences beyond those discussed previously [see [Chapter 3](#)]. CO₂ increases plant growth; combined with the predicted lengthier warmer weather seasons makes for a longer growing season that is likely to increase exposure to pollen, increasing the prevalence of allergy and asthma. Indoor environments are similarly negatively impacted from secondary effects of severe storms and flooding including the growth of mildew and mold, increasing the likelihood of respiratory illnesses from exposure. Additionally, the severity and prevalence of asthma and other allergic diseases, as well as respiratory infections, worsens due to prolonged and widely distributed over-production of “natural” threats (e.g., pollen)

which alter the immune system response to the allergens (USGCRP 2016) [see [Chapter 5.3-1.3](#)].

3.2-2.1 Pollen

Climate change is expected to impart regionally specific effects on the start, duration, and intensity of the pollen season (Ziska and Beggs 2012, Anderegg et al. 2021). In the northeastern United States, shorter, milder winters will likely lead to a longer and more intense pollen season (Dupigny-Giroux et al. 2018). The quantity of pollen produced, the amount that becomes airborne, and the kinds of pollen produced from changes in vegetation, are all variables that contribute to human sensitivity to aeroallergen. The increase in pollen has led to a greater prevalence of allergic airway diseases (Seth

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and Bielory 2021). Aeroallergen exposures trigger respiratory effects such as asthmatic episodes, allergic rhinitis or hay fever, and sinusitis, but may also contribute to the occurrence of conjunctivitis (i.e., pink eye), hives, atopic dermatitis or eczema, and life-threatening anaphylaxis (USGCRP 2016). Seasonal allergic rhinitis may range in severity depending on individual susceptibility and concentration of allergen exposure. Pollen allergens trigger inflammatory cells to release histamine and other immune-stimulating molecules in the body. Together, asthma and allergic rhinitis are two manifestations of the common allergic respiratory syndrome (Xie et al. 2019). There is also evidence to suggest that pollen may suppress the body's innate defense against respiratory viruses, making outdoor activities more hazardous to at-risk populations, including children and the elderly (Gilles et al. 2020).

As discussed in [Chapter 5.3-1.3](#), prevalence of aeroallergenic responses has increased in the United States from 1970 to 2000, with hay fever increasing from 10% to 30% of the population and asthma

rates raising from 55 per 1,000 persons to up to 90 per 1,000 persons (USGCRP 2016). While the most significant changes in temporal pollen increases have been observed in Texas and the Midwest (Anderegg et al. 2021), pollen season for birch and oak was observed to start earlier and last longer in Newark, New Jersey in 2011 compared to 1994, an observation attributed to regional warming (Zhang et al. 2013). Increases in sales of allergy medicine, emergency medical service calls, and hospital visits for asthma and rhinitis symptoms have occurred with increasing pollen counts (Gleason et al. 2014, Dupigny-Giroux et al. 2018, Cissé et al. 2022). While plant pollen is the most abundant aeroallergen, respiratory allergies are more prevalent among urban residents than rural residents, perhaps due to the interaction between chemical air pollutants and pollen grains, especially particulate matter (Sedghy et al. 2018). Storms can bring on an outbreak of asthma, as the meteorological event is thought to induce the release of pollen *en masse* (Xie et al. 2019). Storms can also lead to damp conditions, ideal for the release of fungi allergens (e.g., spores), as discussed in the next section.



"Indoor dampness and mold growth have been linked to millions of cases of worsened asthma, up to 20% of common respiratory infections in the United States alone, and are associated with increased risk of developing asthma in young children."

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3.2-2.2 Fungi/Mold

In addition to the immediate health hazards associated with extreme precipitation events, other hazards follow in the wake of storms and flooding events. Damp conditions, particularly in indoor environments, can create the ideal climate for mold and other fungi to propagate, at the detriment of human health (USGCRP 2016, Dupigny-Giroux et al. 2018). Reactions to fungal toxins induce symptoms akin to other aeroallergens (e.g., nasal congestion, sneezing, coughing) and may aggravate asthma symptoms. In fact, populations living in damp indoor environments, such as buildings damaged by hurricanes, experience increased prevalence of asthma and other upper respiratory tract symptoms, as well as infections in the lower respiratory tract, including pneumonia, respiratory syncytial virus (RSV), and RSV pneumonia (CDC 2021a). Indoor dampness and mold growth have been linked to millions of cases of worsened asthma, up to 20% of common respiratory infections in the United States alone, and are associated with increased risk of developing asthma in young children (USGCRP 2016, Baxi et al. 2016). For this reason, school and home environments with chronic or consistent water damage should be considered sources of exposure (Baxi et al. 2013, 2016). Fungi allergens are also associated with other respiratory illnesses, including allergic bronchopulmonary mycoses, allergic fungal sinusitis, and hypersensitivity pneumonitis (WHO 2009).

Mold and other fungal colonies can start to grow on damp surfaces within 48 hours of deposition from spores that circulate through the air and are an even greater concern when power outages compound the ability to dry out damp areas. In indoor air, humans may be exposed to a variety of fungal spores, metabolites, and other compounds (e.g., mycotoxins) produced by this diverse class of organisms (WHO 2009). Visible mold may indicate higher mold spore counts in a particular microenvironment, suggesting that if the mold is visible then exposure to fungal products is likely (Baxi et al. 2013). The human respiratory system, including the lungs, is a primary target organ for fungal products, and multiple mechanisms of

immuno-activation can be triggered by the complex mixtures released by fungi, resulting in respiratory illnesses (WHO 2009, Baxi et al. 2016).

The prediction of more frequent and severe storms for New Jersey and the Northeastern United States, as well as the high temperatures and humidity, suggests that mold- and fungal-induced respiratory illnesses will likely be on the rise in the coming decades (Moran et al. 2017, Dupigny-Giroux et al. 2018).

3.3 Summary: Diminished Air Quality and Human Health Effects

Climate change will likely worsen air pollution from a myriad of sources, both natural and anthropogenic. This may lead to greater instances of respiratory illnesses in vulnerable populations, including people of color, people experiencing poverty, children, elderly, and communities regionally located near sources of pollution (e.g., urban areas), wildfire vulnerable woodlands, and areas prone to heavy storms and flooding (American Lung Association 2021). Further consideration should be made for how climate change-driven warmer weather affects human adaptive behaviors (e.g., increased demand for air conditioning to cool buildings in the summer), which could in turn exacerbate air pollution (USGCRP 2016). Much of our energy currently comes from burning fossil fuels, meaning the prevalence and use of air conditioning undoubtedly increases emissions of air pollutants from power plants, further diminishing air quality and worsening human health impacts. One study estimated that approximately 9% of air-pollution-related mortality could be attributed to increases in emissions from power plants in an attempt to sustain the demand on electricity (Abel et al. 2018). Overall, though the EPA and DEP have made strides in meeting health-based national standards of air quality since the 1970s, climate change factors pose an increasing threat to dampening of that progress.



SECTION 4

INCREASES IN INFECTIOUS DISEASE TRANSMISSION PATTERNS

In addition to the likely increase in acute and chronic cardiovascular and respiratory illnesses caused by extreme weather and diminished air quality conditions, the human health impacts of climate change also include challenges from other diseases, such as those brought on by vector-borne diseases, microorganism contamination (food and waterborne diseases), and other related consequences. For example, the increased use of pesticides to mitigate vector exposure and the potential for novel pathogens. Associations between climate, infectious agents, and disease spread are apparent; however, the ability to accurately predict the distribution and prevalence of the myriad of vectors and pathogens is subject to a high degree of uncertainty (USGCRP 2016).

4.1 Vector-borne Diseases

Illnesses transmitted by arthropod and insect vectors, which include ticks, mosquitoes, and fleas, have historically afflicted humans throughout their existence. However, because weather and climate have direct impacts on the habitat and food sources of these arthropod and insect vectors, climate change is expected to influence many aspects of vector biology and behavior, and in doing so, alter the exposure paradigms for humans. Temperature [[Chapter 4.1](#)], precipitation [[Chapter 4.2](#)], and seasonal shifts can all play a role in altering geographic distribution, habitat availability and population dynamics of these species, and therefore may lead to spatial and temporal changes in the exposure window or to new human populations being exposed (USGCRP 2016, Ogden 2017, Dupigny-Giroux et al. 2018). Not all changes in vector-borne disease dynamics can be attributable to climate change. Anthropogenic influences, such as land use, agricultural practices, and pest-mitigation efforts, may also impact transmission (Dantas-Torres 2015, Ogden and Lindsay 2016). However, this section will focus on ways climate change is affecting vector transmitted disease spread.

Vector-borne diseases are a growing public health concern globally, with tropical and subtropical countries bearing the greatest burden of cases (WHO

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VECTOR-BORNE DISEASES

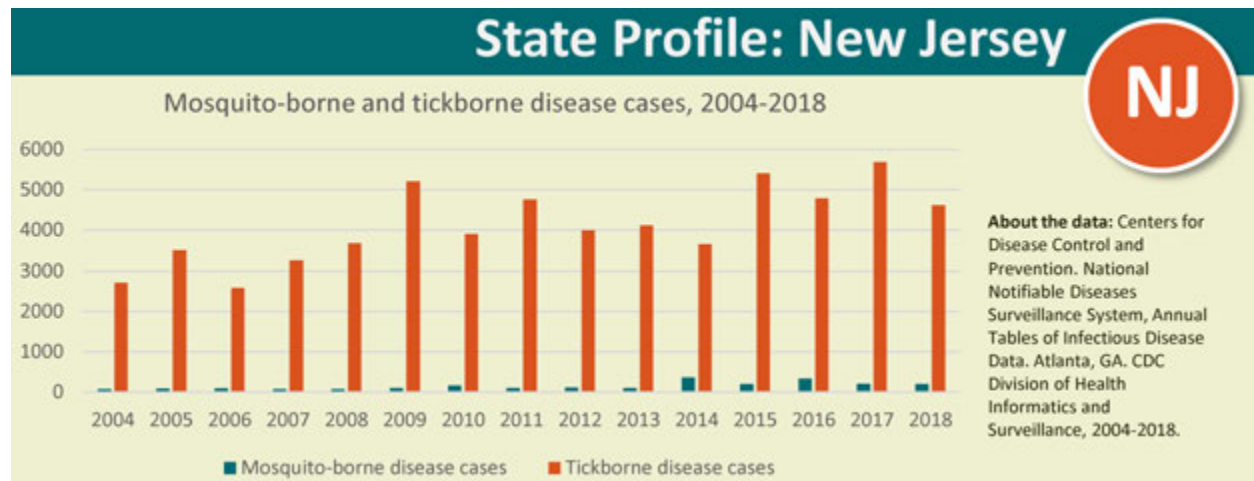


Figure 2. New Jersey: Vector-borne Diseases Profile (2004-2018).

2003, CDC 2020a, Rocklöv and Dubrow 2020). In the United States, at least 17 vector-borne diseases are reported by states to the CDC annually, and the numbers of vector-borne infections have doubled from 2004 to 2018 (CDC 2020a). Diseases carried by ticks and mosquitoes are the most common in the United States, with infections caused by a tick bite at an all-time high (CDC 2020a). In New Jersey, infections transmitted by ticks surpass those transmitted by mosquitoes significantly as seen in Figure 2, and show a persistent increase in recent years (CDC 2020b, NJ DOH 2020).

4.1-1 Tickborne Diseases

Ticks are obligate parasitic arachnids (meaning they require a host to complete their life cycle) that can carry bacteria, viruses, or protozoa, which when transmitted to humans through a bite, cause a number of diseases. The most common tickborne disease, Lyme disease, is caused predominantly by the bacterium *Borrelia burgdorferi*, and afflicts an estimated 476,000 people in the United States annually (CDC 2021b). Despite the decreasing trend in Lyme disease (Table 2), New Jersey had the highest reported number of cases in the nation in 2019 (CDC 2021b). Typically, symptoms of infection include fever, headache, fatigue, and a characteristic skin rash at the site of the bite wound. However, an untreated infection may spread to the joints, the heart, and the nervous system (CDC 2021b). In New Jersey, in addition to Lyme

disease, other tickborne diseases are less frequently diagnosed such as Anaplasmosis, Babesiosis, Ehrlichiosis, Powassan, and Spotted Fever Group Rickettsioses (Table 2). As the anticipated changes to our regional climate take place, including increasing temperatures, precipitation, and humidity, tick activity is expected to start earlier, last longer, and perhaps more concerningly, expand in geographical range (USGCRP 2016, Dupigny-Giroux et al. 2018). The result of this change in activity is a likely increase in the chance of human exposure to the pathogens carried by the arthropods.

Ticks survive inclement weather by remaining in the protective soil layer of temperate woodland surfaces, and they rely primarily on humidity to rehydrate and survive from one life stage to the next (Ogden and Lindsay 2016). Warmer winters and more humid summers will promote tick survival, while prolonged heavy rains and persistent flooding will have a negative impact on tick mortality (Ogden and Lindsay 2016). Multiple studies have shown the northward migration of certain tick species, attributed mostly to the milder winters and extended growing seasons (Dantas-Torres 2015). Conversely, high temperatures in lower latitudes, particularly under dry conditions, may adversely affect tick survival. Different life stages of the various tick species are not equally sensitive to climate conditions, leading to further variations in the activity of these insects. Typically,



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ticks go through four life stages: egg, six-legged larva, eight-legged nymph, and adult. This life cycle lasts months to years (Ogden and Lindsay 2016). Ticks require a blood meal upon hatching to survive to each successive stage, and may feed on mammals, birds, reptiles, or amphibians. Their ability to find a host is dependent on proximity to a host, as ticks are only capable of moving a few meters on their own. While a tick is feeding, which can last for several days, small amounts of tick saliva may enter the host, thereby transmitting the pathogen (if the tick is infected). If their host carries the pathogen, the tick will ingest the pathogen and then it will be able to pass it along to a new host in the subsequent life stage (CDC 2020c). Humans are “dead-end” hosts because while they may be infected by the pathogen, they do not transmit the pathogen themselves (Baum 2008).

Tick reproduction rate is dependent on both host density and habitat, and varies by tick species (Ogden et al. 2013). The likelihood of a tick surviving to the subsequent stage is also related to their ability to find a blood host. Therefore, climate has both direct and indirect effects on tickborne disease transmission; specifically, increased temperatures and humidity accelerate development and reduce mortality, while increased rainfall and flooding inhibit survival and activity (Ogden and Lindsay 2016). Seasonally dependent activities of hosts are weather dependent and will alter accessibility, thereby indirectly impacting tick survival. While the transmission of tickborne diseases is expected to continue to rise in the Mid-Atlantic region, particularly in New Jersey (USGCRP 2016, Dupigny-Giroux et al. 2018), multiple factors determine the prevalence and are likely regionally specific.

Table 2. Human Cases of Tickborne Pathogens and Diseases Detected in New Jersey.
 Data from the NJDOH <https://www.nj.gov/health/cd/statistics/reportable-disease-stats/> and <https://www.nj.gov/health/cd/statistics/arboviral-stats/index.shtml>

Pathogen	Disease	2016	2017	2018	2019	2020	2021
<i>Anaplasma phagocytophilum</i>	Anaplasmosis	109	154	118	142	115	202
<i>Babesia</i> species	Babesiosis	174	193	249	236	238	258
<i>Borrelia miyamotoi</i>	Tickborne Relapsing Fever	-	-	8	16	9	16
<i>Borrelia burgdorferi</i>	Lyme disease	4,350	5,092	4,000	3,619	2,566	3,518
<i>Ehrlichia</i> species	Ehrlichiosis	76	88	94	146	81	77
Powassan virus (Flavivirus)	Powassan	0	4	1	4	1	-
<i>Rickettsia</i> species	Spotted Fever Group Rickettsiosis	64	137	147	209	35	39

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Changes in climate patterns may raise the risk of human interaction with ticks and thus causes more tick bites. Shifting climate patterns leading to warmer winters and longer, hotter summers have already been implicated in the expanded domain of where Lyme disease carrying ticks have been previously reported (Beard et al. 2016). Specifically, a warming climate changes environmental characteristics like vegetation and temperature to be more suited for ticks in all life stages, raising the prevalence of tickborne diseases (Leighton et al. 2012).

4.1-2 Mosquito-borne Diseases

Mosquitoes are insects that can infect humans and animals with the viruses and parasites they harbor through a bite. Unlike ticks, the only parasitic life-stage of a mosquito is the adult female; other life stages (eggs, multiple larval stages, and pupae) do not require a blood host (Ogden and Lindsay 2016). Like ticks, climate change is predicted to have a direct impact on mosquito-borne disease dynamics (USGCRP 2016).

The life cycle of mosquitoes is such that eggs are laid in water, the sides of artificial containers, or on soil, and once they hatch, it takes approximately 7-10 days for larvae to develop into adults. Although mosquito eggs require water to survive, eggs from certain mosquito species, such as *Aedes aegypti* (yellow fever mosquito), can withstand dry periods for up to 8 months (Schraufnagel

2020). The preferred feeding source (e.g., human, animal), habitat (e.g., indoors, outdoors), and their ability to fly distances are all species dependent characteristics (CDC 2020d). However, water is crucial to the life cycle of a mosquito, and therefore these insects are vulnerable to changes in climate that will increase or decrease water availability.

There are at least 16 different diseases caused by the viruses and parasites carried by mosquitoes. In the United States, West Nile Virus (WNV) is the most common mosquito-borne disease transmitted, with a total of 2,445 cases reported in 2021 (CDC 2020e). Most (80%) individuals infected with WNV are asymptomatic; those who do develop symptoms (20%) can exhibit fever, headaches, body aches, joint pain, vomiting, diarrhea, rash, and fatigue. A smaller portion of infected individuals (~0.7%) develop serious neuro-invasive symptoms, including encephalitis, meningitis, acute flaccid paralysis, or other acute signs of central or peripheral neurologic dysfunction that may require hospitalization (CDC 2020e). The virus itself requires a bird host, and it is spread between birds and mosquitoes readily (Baum 2008). The first case of WNV in humans was reported in 1999 in New York State (Queens, NY) (Baum 2008), and between 2010-2020, the CDC has recorded an average of 2,077 cases of WNV per year nationwide (CDC 2020c). The incidence of WNV in the northeastern United States has declined in recent years. It is unclear, however, whether this decline



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Table 3. Positive Cases [Fatalities] of West Nile Virus in New Jersey.

Data from the NJDOH <https://www.nj.gov/health/cd/statistics/arboviral-stats/index.shtml>

Number in brackets represents the number of fatalities from reported infections.

Year	Human	Avian	Mosquito (Pools)
2006	5	43	253
2007	1	45	345
2008	10 [2]	53	644
2009	3	31	323
2010	30 [2]	129	846
2011	7	42	532
2012	48 [6]	132	1027
2013	12 [2]	36	658
2014	8	18	637
2015	26 [3]	28	904
2016	11 [2]	0	447
2017	8 [2]	0	861
2018	61 [3]	13	1331
2019	8	0	365
2020	3	1	241
2021	36 [5]	13	995

is due to mitigation efforts with applications of insecticides, or due to the prevalence of antibodies in hosts (Baum 2008). New Jersey monitors cases of WNV in humans, birds, animals, and mosquitoes annually, with the largest number of human cases, 61, reported in 2018 (Table 3) (NJ DOH 2022b).

Other important domestic mosquito-borne diseases and pathogens reported in the United States include, but are not limited to, Eastern equine encephalitis, Jamestown Canyon, La Crosse encephalitis, and St. Louis encephalitis viruses (CDC 2020b). Eastern equine encephalitis is detected annually in mosquito populations in New Jersey, with sporadic human cases reported as well. Eastern equine encephalitis is the most severe domestic arbovirus, resulting in death in approximately 30% of persons infected. Important travel-associated mosquito-borne diseases reported in the United States include malaria, dengue, chikungunya, and Zika. With the exception of malaria, which is caused by a

parasite, all other illnesses are caused by viruses. Human malaria, chikungunya, dengue, and Zika cases are generally associated with travelers or immigrants returning from countries with known high transmission rates; specifically, chikungunya, yellow fever, and Japanese encephalitis have not been found in domestic mosquito populations. Rarely, domestically acquired cases of chikungunya, dengue, and Zika viruses have been recorded, especially in Florida and Texas (CDC 2020d). Routine disease surveillance of mosquito populations in New Jersey have not indicated any NJ specific reservoirs of these diseases (NJ DOH 2020). There are approximately 2,000 cases of malaria in the United States each year, largely from immigrants or travelers from Central and South America, the Caribbean, sub-Saharan Africa, India, Southeast Asia, the Middle East and South Pacific (NJ DOH 2012, CDC 2020d). In New Jersey, malaria cases account for the greatest number of mosquito-borne diseases identified in the state

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(Table 4), but there is currently no evidence that malaria transmission has occurred from a local carrying population of mosquitoes (NJ DOH 2012). In contrast with ticks, mosquitoes are highly dependent on their habitat for reproduction, and therefore directly vulnerable to extreme weather (Ogden and Lindsay 2016). Viral transmission of the respective pathogens will also be sensitive to extremes in weather as a consequence of altered habitats and activities of their hosts (USGCRP 2016). Warmer winters will likely permit more adult mosquitoes to survive through the cold months, and wetter summers present more optimal conditions for the water dependent-mosquito life stages (Ogden and Lindsay 2016). Bird host availability may also be affected as migration patterns are climate-driven behaviors, but the extent to which this availability impacts the transmission rates or geographic locations of mosquito-borne diseases is unknown (USGCRP 2016). The projected changes to the regional temperature, precipitation rates, and humidity are expected to influence the distribution and abundance of mosquitoes, and therefore increase the potential for human exposure and the overall prevalence of mosquito-borne diseases (USGCRP 2016, Dupigny-Giroux et al. 2018).

4.2 Foodborne and Waterborne Diseases

Illnesses that result from food spoilage or contaminated water are yet another category of diseases that may increase as circumstances associated with climate change worsen. Generally, these include acute gastrointestinal illnesses caused by pathogens that thrive in warmer, wetter climates. Moreover, some pathogens that are predicted to flourish under projected climate conditions may inflict wound infections, neurotoxic effects, or organ damage, leading to more severe and sometimes fatal outcomes. The risk for increased infectious disease spread following a catastrophic weather event is great, as diarrheal illnesses contribute up to 40% of deaths following a flooding event (Liang and Messenger 2018). However, many gastrointestinal illnesses, particularly mild cases, go unreported

thereby making it more difficult to uncover a pattern between climate change and the extent to which food and waterborne illnesses are related.

4.2-1 Foodborne Illnesses

Foodborne illnesses are caused by viruses, bacteria, and parasites (Scallan et al. 2011). Climate can alter key drivers of pathogen survival thereby influencing food quality. For example, higher temperatures favor bacterial population growth on food and heavy precipitation may lead to contamination of water supplies used for irrigation. Additionally, rising ocean temperatures can increase the risk of pathogen exposure from ingestion of contaminated seafood as warmer temperatures lead to optimal conditions for pathogen survival (USGCRP 2016). The CDC estimates that each year there are 9.4 million episodes of foodborne illness in the United States, with 55,961 cases requiring hospitalization and 1,351 cases leading to deaths (Scallan et al. 2011). Of the 31 major pathogens identified annually, over 50% were cases of norovirus, with *Campylobacter* species (spp.) and nontyphoidal *Salmonella* spp., accounting for 9% and 11% of the remaining cases, respectively (Scallan et al. 2011).

Concerns have been raised over the potential for increased cases of norovirus, a highly contagious virus that induces symptoms such as diarrhea, abdominal cramping, nausea, vomiting, and low-grade fever. This virus is acquired by consuming contaminated food or water, inadequate handwashing after touching contaminated surfaces, and person to person contact (e.g., aerosols) (CDC 2021c). Norovirus favors colder, dryer conditions, but benefits from extreme weather events, such as heavy precipitation and flooding (Rohayem 2009, USGCRP 2016). The aerosol transmission potential of norovirus from person-to-person contact can be influenced by local humidity and temperature conditions, which also facilitate the persistence and virulence of the virus (Rohayem 2009). Norovirus transmission is greatest during periods of inclement weather and winter, underscoring a seasonality to this virus and therefore its sensitivity to climate change dynamics (Rohayem 2009).

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Table 4. Human Cases of Other Mosquito-borne Diseases in New Jersey.

Data from the NJDOH <https://www.nj.gov/health/cd/statistics/reportable-disease-stats/> and <https://www.nj.gov/health/cd/statistics/arboviral-stats/index.shtml>

Disease	2016	2017	2018	2019	2020	2021
Chikungunya	11	12	16	15	3	4
Dengue	50	25	20	73	2	12
Eastern Equine Encephalitis	1	0	0	4	-	-
Jamestown Canyon virus	-	-	-	-	-	2
Malaria	84	125	93	102	24	71
Zika	237	37	10	12	3	-

Salmonella spp. and *Campylobacter* spp., which also induce diarrhea, cramping, nausea, and fever as symptoms, are both susceptible to changes in the timing or length of seasons, precipitation and flooding, and extreme weather events (USGCRP 2016, Niedermeyer et al. 2020, Cissé et al. 2022). Unlike norovirus, *Salmonella* infections are observed to increase at higher temperatures (Akil et al. 2014). The United States averages about 5.7 salmonella outbreaks each year linked to contaminated food products (e.g., poultry, alfalfa sprouts, pre-cut melon) from predominantly six different species (CDC 2021d). As temperatures rise, salmonella outbreaks are expected to become more frequent. *Campylobacter* outbreaks, reported in poultry, raw milk, and untreated water, are also expected to rise with increasing temperatures and number of heavy precipitation events, particularly in the summer months (Kuhn et al. 2020).

The CDC monitors the incidence of some enteric (intestinal) pathogens via FoodNet, a population-based surveillance network for laboratory-diagnosed infections caused by *Campylobacter*, *Cyclospora*, *Listeria*, *Salmonella*, Shiga toxin-producing *Escherichia coli* (STEC), *Shigella*, *Vibrio*, and *Yersinia*. Preliminary data from 2019 indicate that the incidence of infections caused by pathogens transmitted commonly through food either increased (for *Campylobacter*, *Cyclospora*, STEC, *Vibrio*, *Yersinia*) or remained unchanged

(for *Listeria*, *Salmonella*, *Shigella*) compared to the previous three years, with the majority of cases being acquired domestically (Tack et al. 2020). As extreme weather events, such as hurricanes, challenge local infrastructure and cause power outages, food spoilage will likely be of increased concern (Dupigny-Giroux et al. 2018, Liang and Messenger 2018). An example of this followed the 2003 New York City black out that affected millions of people in the Northeast United States, where increased reports of diarrheal illnesses occurred due to the consumption of spoiled food (Dupigny-Giroux et al. 2018). Another example occurred when outbreaks of norovirus were reported in shelters following hurricane Katrina in 2005 and to a lesser extent in New York City shelters following Hurricane Sandy in 2012 (Liang and Messenger 2018).

Other non-microorganism driven foodborne illnesses may be caused by chemical contamination of food products in processing or packaging (e.g., overuse of pesticides, other agricultural products, heavy metals) (USGCRP 2016). Such threats to food safety are discussed further in Section 5. *Climate Change-driven Community Impacts.*

4.2-2 Waterborne Illnesses

Water contamination by pathogens, either of drinking water sources or recreational surface waters, is likely to increase with rising surface

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water temperatures and with greater frequency and intensity of precipitation. These climate change related factors will affect the growth, spread, and virulence of waterborne pathogens, and increase the risk of human exposure to them (USGCRP 2016). Individuals are exposed to waterborne pathogens via ingestion of water from contaminated sources, accidental ingestion during a recreational activity, or from eating contaminated fish or shellfish (Table 5).

As briefly mentioned in 2.2 *Precipitation Anomalies*, one of the secondary effects of flooding is the potential for microorganism contamination of clean water from sewers and wastewater treatment plant overflows, as well as from agricultural and storm water runoff (US EPA 2005, USGCRP 2016, Tran et al. 2019, Cissé et al. 2022). Infrastructure failures of water treatment plants following extreme weather events and storm surges are likely to increase, either from damage or capacity exceedances, as conditions of climate change worsen over time (USGCRP 2016).

As such, the risk of human exposure to waterborne pathogens will increase. For example, norovirus and other enteric pathogens which enter sewage as a result of human exposure to contaminated food (e.g.,

shellfish), can spread quickly in populated areas if sewage treatment plants experience flooding from heavy precipitation events (USGCRP 2016). In New Jersey, contamination of drinking water sources by storm runoff has previously been associated with an increase in hospitalization for gastrointestinal effects (Gleason and Fagliano 2017). Moderate flooding events projected to become more frequent in the Northeast United States will likely increase the risks of combined sewer overflows and storm-related power outages, which escalate the risk of both food and waterborne illness (Dupigny-Giroux et al. 2018). Furthermore, recreational activities, such as fishing and shellfish harvesting, will likely become less favorable, as the organisms become contaminated with waterborne pathogens.

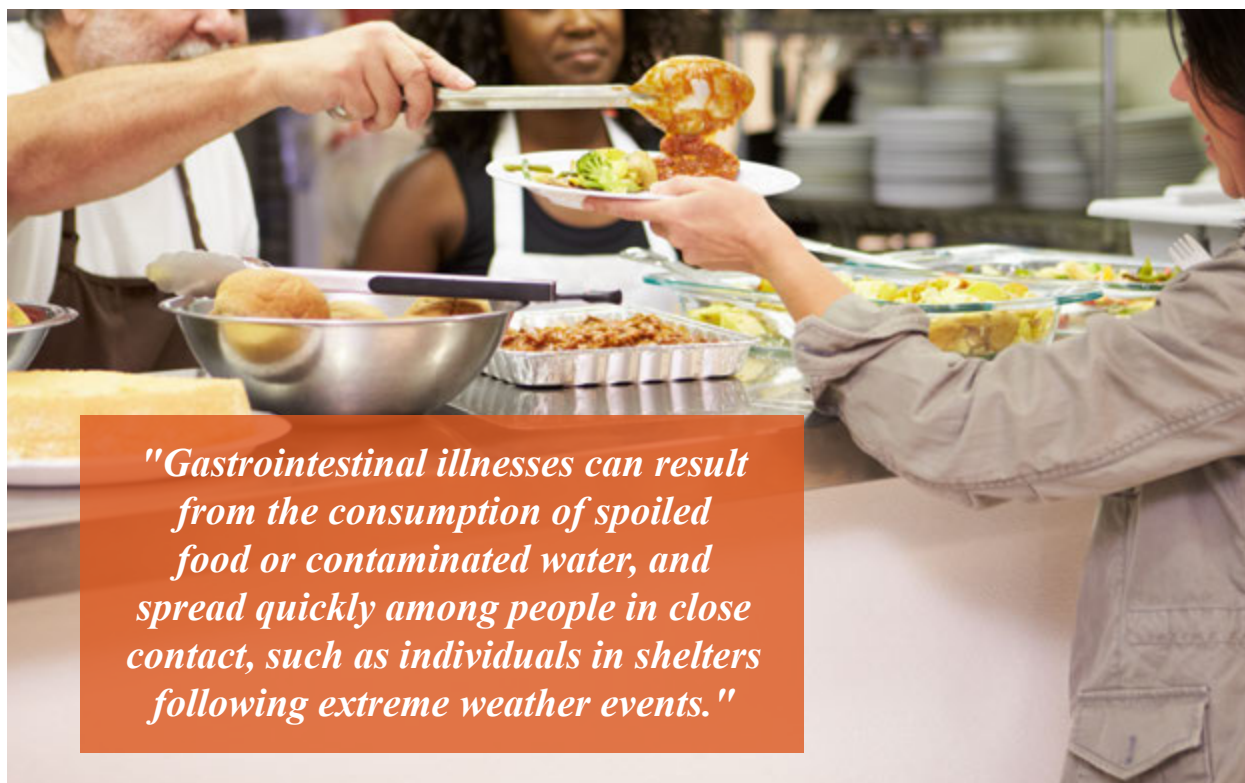
Enteric pathogens (viruses, bacteria, and parasites) are among the most common causes of diarrhea from contaminated water or food, and are a major factor in morbidity and mortality worldwide (Smith et al. 2014). Children are especially vulnerable to diarrheal diseases, with almost 500,000 deaths annually for children 5 years of age and younger, largely in developing countries (Troeger et al. 2018). Immunocompromised individuals and people who endure less sanitary living conditions are also more likely to be exposed to diarrheal causing pathogens

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Table 5. Agents of Waterborne Illnesses and Their Climate-Sensitive Drivers.
 (Adapted from USGCRP 2016 and NJDEP 2020)

Pathogen or Toxin Producer	Exposure Pathway	Symptoms & Health Outcomes	Major Climate Driver
Algae:			
Toxigenic marine species of <i>Alexandrium</i> , <i>Pseudo-nitzschia</i> , <i>Dinophysis</i> , <i>Gambierdiscus</i> spp., <i>Karenia brevis</i>	Shellfish, Fish	Shellfish and Fish poisoning: <ul style="list-style-type: none"> • Gastrointestinal illness • Neurological illness 	<ul style="list-style-type: none"> • Temperature (increased water temperature) • Ocean surface currents and acidification • Hurricanes
	Recreational water	<ul style="list-style-type: none"> • Aerosolized toxins may cause: • Asthma exacerbations 	
	Aerosolized toxins	<ul style="list-style-type: none"> • Eye irritations 	
Bacteria:			
Cyanobacteria (multiple freshwater species and their toxins)	Drinking water	<ul style="list-style-type: none"> • Gastroenteritis • Liver and kidney damage 	<ul style="list-style-type: none"> • Temperature • Precipitation patterns • Nutrient runoff
	Recreational water	<ul style="list-style-type: none"> • Neurological disorders • Respiratory arrest 	
	Fish	<ul style="list-style-type: none"> • Irritation (dermal, eyes, respiratory) 	
Enteric bacteria and protozoan parasites:			
<i>Salmonella enterica</i> ; <i>Campylobacter</i> spp.; Toxigenic <i>Escherichia coli</i> ; <i>Cryptosporidium</i> ; <i>Giardia</i>	Drinking water	<ul style="list-style-type: none"> • Enteric pathogens generally cause gastroenteritis 	<ul style="list-style-type: none"> • Temperature (air and water; both increase and decrease) • Heavy precipitation • Flooding
	Recreational water	<ul style="list-style-type: none"> • Severe cases may be associated with long-term and recurring effects 	
	Shellfish		
Enteric viruses:			
Enteroviruses; Rotaviruses; Noroviruses; Hepatitis A and E	Drinking water	<ul style="list-style-type: none"> • Gastrointestinal illness 	<ul style="list-style-type: none"> • Temperature (air and water; both increase and decrease) • Heavy precipitation • Flooding
	Recreational water	<ul style="list-style-type: none"> • Severe cases may include paralysis and infection of the heart or other organs 	
	Shellfish		
Bacteria:			
<i>Leptospira</i> and <i>Leptonema</i>	Recreational water	<ul style="list-style-type: none"> • Mild to severe flu-like illness • Severe cases may induce meningitis, kidney, and liver failure 	<ul style="list-style-type: none"> • Temperature (increased water temperature) • Heavy precipitation • Flooding
Bacteria:			
<i>Vibrio</i> spp.	Recreational water	Varies by species: <ul style="list-style-type: none"> • Gastroenteritis 	<ul style="list-style-type: none"> • Temperature (increased water temperature) • Sea-level rise • Precipitation patterns (as it affects coastal salinity)
	Shellfish	<ul style="list-style-type: none"> • (<i>V. cholerae</i> and <i>V. parahaemolyticus</i>) • Septicemia through ingestion or wounds (<i>V. vulnificus</i>) • Infections of the skin, eye, or ear (<i>V. alginolyticus</i>) 	

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(Troeger et al. 2018). Enteric pathogens are naturally present in aquatic environments but are more commonly introduced to waterways through leaking sewage and septic systems, urban runoff, agricultural runoff, sewage outfall, and wastewater discharge (Fong and Lipp 2005). While disease transmission for these organisms displays some seasonality, the exact climate factors contributing to pathogen survival are species dependent (USGCRP 2016). Diarrheal diseases are largely preventable, and maintaining proper hygiene and sanitation go a long way to mitigate the transmission of many of the pathogens.

Harmful Algal Blooms (HABs) are a global problem that can affect nearly all surface waters on the planet and are directly related to changes in climate [see [Chapter 5.10](#)]. Due to projected climate change factors, waters are becoming more conducive and hospitable to photosynthetic microbial growth (USGCRP 2016, Cissé et al. 2022). Large scale events in marine environments caused by the over proliferation of noxious organisms (e.g.,

Brown Tide, Red Tide) are well documented and increasing in frequency (USGCRP 2016). Bloom events on our inland rivers, lakes, and streams are increasing in frequency too; due in large part to shifting climate patterns and anthropogenic activities (NJDEP 2020b). These events have been marked by both true algae species, which can cause issues with delivery of potable drinking water, and cyanobacteria, which can cause both short- and long-term negative health effects to human and animal health upon exposure. Exposure to cyanobacteria can cause cytotoxic or endotoxic effects (toxicity relating to the cells or the protein on the surface of the cells) or, if being produced, several toxins formally known as cyanotoxins. These toxins can be harmful to the nervous system, liver, and skin. Human exposures to cyanobacteria and their toxins occur during recreational activities through accidental swallowing, skin contact, and breathing aerosols, and local and systemic toxic effects can lead to a range of adverse reactions from a mild skin rash to serious illness. Adverse reactions may occur in response to components of the cyanobacterial

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cells, regardless of whether the cells are producing cyanotoxins, and generally producing allergic-like irritation of the skin, eyes, respiratory tract, or gastrointestinal tract. Exposure to the primary cyanotoxins: microcystins, cylindrospermopsin, anatoxin-a group, and saxitoxin, can lead to severe health conditions, including gastroenteritis, liver inflammation, kidney damage, or muscular and respiratory paralysis (NJDEP 2020b). HAB events are expected to increase as changes to New Jersey’s climate becomes more favorable to the growth and survival of these organisms.

Leptospira spp. are zoonotic pathogens causing the disease Leptospirosis, transmitted primarily via the urine-oral route from animals infected with the bacterium. Leptospirosis causes a wide range of symptoms or none at all, but if left without treatment, can lead to kidney damage, meningitis, liver failure, respiratory distress, and death (CDC 2019). Humans are exposed to *Leptospira* spp. through water or food contaminated with animal urine, or from their household pets infected by contaminated water or food, and exposure is expected to increase with the projected frequency of heavy precipitation and flooding (Brown and Prescott 2008, Lau et al. 2010).

Vibrio spp. are the source of a number of freshwater and marine environment waterborne illnesses and are of a particular concern for New Jersey [see [Chapter 5.9-5](#)]. *Vibrio cholerae* is the pathogenic source of the acute diarrheal infection cholera, which is characterized by profuse watery diarrhea, vomiting, thirst, leg cramps, and, in severe cases, death due in part to dehydration (CDC 2020f). Cholera has historically plagued human populations with poor sanitation; but increases in disinfection practices of potable water as well as advances in wastewater treatment technology has led to a decrease in infection rates globally. However, while *Vibrio*-derived drinking water illnesses have decreased, exposure to *Vibrio* spp. through other routes, such as consumption of contaminated seafood or recreational swimming (e.g., accidental oral ingestion or through open wounds) continues or is on the rise (Dechet et al. 2008, Newton et al.

2014). In fact, climate change projections for the Northeast, such as increased warming patterns or severe weather events, are favorable for *Vibrio* survival and infection potential, indicating that a greater incidence of infection rates from *Vibrio* spp. will occur (Martinez-Urtaza et al. 2010, Baker-Austin et al. 2013).

Together, food and waterborne infections are a major public health issue, particularly in developing countries where infrastructure is often suboptimal, but also in the United States, where our aged infrastructure (e.g., CSOs) remains a persistent concern due to its vulnerability to extreme and severe weather events (USGCRP 2016, Dupigny-Giroux et al. 2018).

4.3 Other Concerns Related to Infectious Disease Transmission

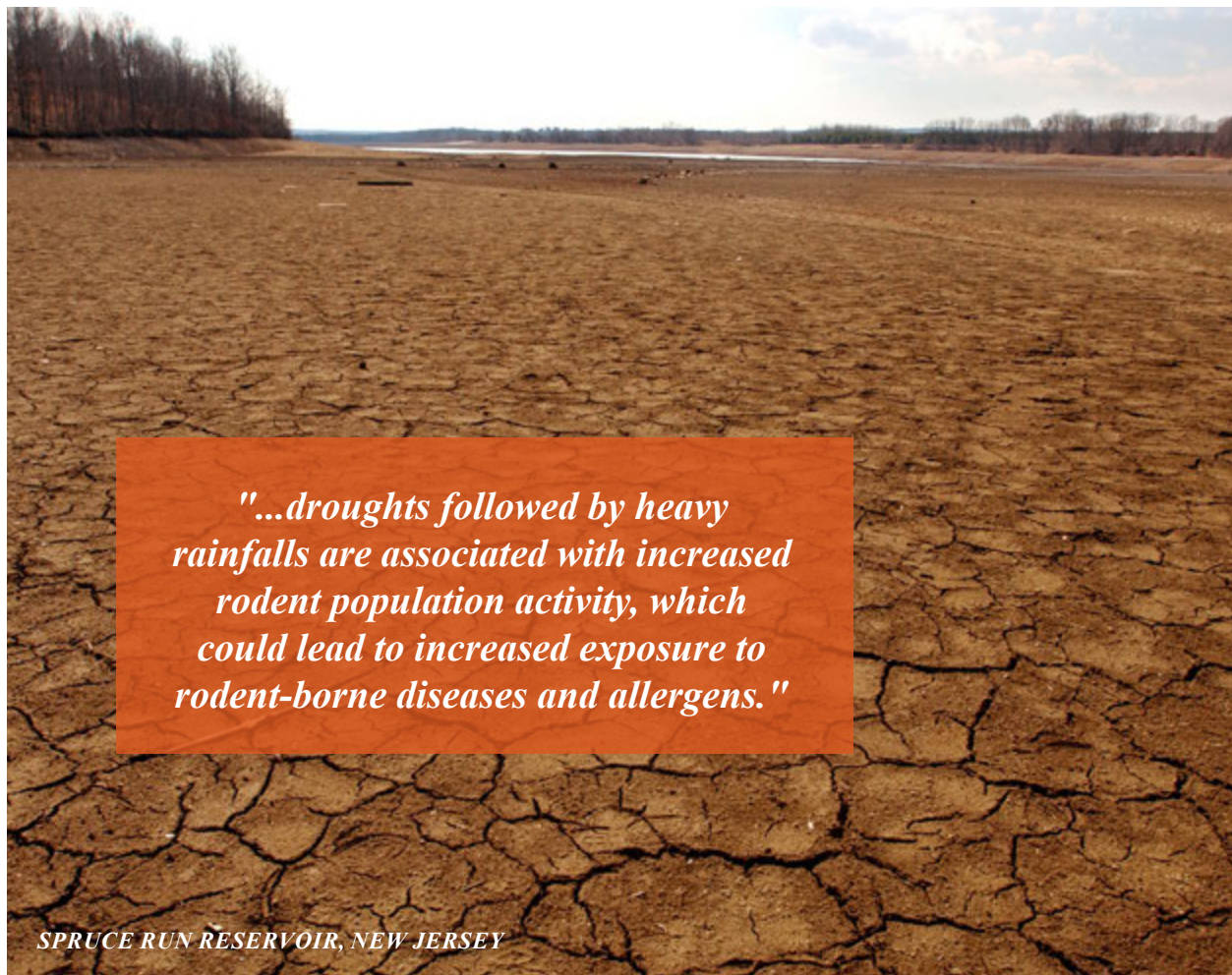
The continued progression of climate change dynamics brings with it the concern for emerging, novel types of pathogens with a greater frequency and endemic potential (Ogden and Lindsay 2016). Pathogens will encounter new hosts as loss of habitat leads to population migration of traditional hosts. These new encounters are predicted to be more frequent for mammals and are more likely to occur in areas that are projected to be human settled or agricultural lands (Carlson et al 2022). Extreme conditions may increase the potential for increased and novel contact between humans and other animals. For example, droughts followed by heavy rainfalls are associated with increased rodent population activity, which could lead to increased exposure to rodent-borne diseases and allergens (USGCRP 2016). Indirectly, human exposures to pesticides may increase, as mitigation efforts to combat pathogen containing vectors arise, but also contaminate the food supply (Dupigny-Giroux et al. 2018).

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4.4 Summary: Climate- change Driven Infectious Disease Transmission

Large uncertainties remain as to the direct effects of climate change factors on the future of pathogen transmission and impacts on human health. One of the challenges to linking the spread of infectious disease to climate change is the lack of complete reporting of infections. Mild cases of some illnesses may go unnoticed, misattributed, or unreported to the proper health authorities. With regards to vector-borne diseases, mitigation efforts to combat tick and mosquito populations, for example, come with additional challenges of how to protect the human population from

excessive exposure to pesticides. Furthermore, climate change factors may act synergistically on non-human hosts, vectors, pathogens, and humans, making it difficult to predict and mitigate the effects of climate change on infectious disease spread. One Health, by the CDC, is an initiative that recognizes the interconnection between humans and animals and strives to use an interdisciplinary approach to prevent outbreaks of zoonotic disease in animals and people, improve food safety and security, and other actions that improve health of humans and animals in our changing climate (CDC 2022b).







SECTION 5

CLIMATE CHANGE-DRIVEN COMMUNITY IMPACTS



Rising temperatures, anomalous precipitation, diminished air quality from pollution and natural allergens, and greater exposure to vector-, food-, or waterborne pathogens, are all climate change effects expected to adversely impact human health. The collective impacts of climate change on the health of communities are more nebulous to catalog and predict, particularly because these impacts will not be distributed uniformly among populations. Human health impacts are often felt most strongly by high-risk or vulnerable communities that are located in areas where the impacts of extreme conditions occur most often and have insufficient access to risk reduction strategies, such as funding, updated early warning systems, and resilient infrastructure (Cissé et al. 2022). Resource insecurity (e.g., energy usage, food production, interrupted supply chains), the economic and logistical challenges to population displacement, and the negative effects that the compounding changes may have on mental health, are disproportionately experienced across the world.

5.1 Human Adaptation to a Changing Climate

Climate change is likely to alter a number of human behaviors and activities as we learn to live under new environmental conditions. Hotter weather generally causes an increased reliance on air conditioning to off-set the heat, which in turn requires greater electricity consumption to meet the energy demands (Lundgren-Kownacki et al. 2018). Also, hotter weather may drive people to shower more often and launder their clothes more frequently, utilizing greater volumes of water and increasing usage of detergents, which may increase surface water pollution and distort nutrient loads, consequently favoring algal bloom conditions (Liu et al. 2012). Water consumption will increase to stave off dehydration during the increasingly hot summer months. Applications of personal care products (e.g., deodorants, sunscreens) and over-the-counter medicines to mitigate mild symptoms from environmental exposure to sun, pollen, and pests (e.g., analgesics, cortisone creams,

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RESOURCE INSECURITY ON THE RISE

and antihistamines) will likely see greater use. Pharmaceuticals used in the treatment of more chronic cardiovascular and respiratory diseases are also likely to increase, as may the use of antibiotics for treatment to combat certain vector-, food-, and waterborne infections. However, the ecological impacts and the economic implications of these indirect climate change effects in usage are unclear (Redshaw et al. 2013). Individually, these actions may not amount to much change; however, a more significant impact may be observed on a community-wide level.

5.2 Resource Insecurity on the Rise

Globally, climate change is expected to threaten food production and certain aspects of food quality. With the combined effects of rising temperatures, rainfall variability, and extreme weather events, many crop yields are expected to decline (Luber et al. 2014). The crop yield decline may occur through a variety of mechanisms, including saltwater intrusion in soil and groundwater, higher temperatures in summer, changes in frequency and intensity of droughts, flooding during extreme wet conditions, and expanding seasonal and regional distribution of insects [see [Chapter 5.3](#)] (Ray et al. 2019). Livestock and fish production are vulnerable to similar factors (Brown et al. 2015). Consequently, disruptions to supply chains and the distribution of food products are likely to be affected and prices may increase, which will have a direct impact on New Jersey residents, particularly in low-income communities. Even though food insecurity in New Jersey has decreased in the past decade, stabilizing at around 9% across all ages, around 10% of children under the age of 18 are considered food insecure (NJ DOH 2022c).

Climate change can affect all aspects of food supply chain, including production, transportation, trade, storage, processing and packaging, wholesale, retail, consumption, and disposal of food. As a result, access to the necessary resources may become increasingly more difficult, leading to, among other

things, food insecurity. Food insecurity occurs in situations where food is unavailable, inaccessible, or unusable to individuals or a group, and can happen in urban or rural populations, and in wealthy and poor nations alike (Brown et al. 2015). Low-income communities are less likely to be in close proximity to grocery stores that provide access to healthy and affordable food options; such communities are often designated food deserts or food swamps (Dutko et al. 2012). In such situations, people turn to calorie-rich, nutrient-poor, and often cheaper foods (e.g., highly processed, packaged food), the consequence of which range from malnutrition to obesity (Luber et al. 2014, Cooksey-Stowers et al. 2017, Tonumaïpe’a et al. 2021). Children are particularly vulnerable to the malnutrition that results from a poor diet due to their continued cognitive and physical development, the results of which may manifest as negative lifelong health and economic outcomes (Brown et al. 2015). In adults, food insecurity in the US is increasingly linked to obesity (Myers et al. 2020). The nutritional value of some foods (e.g., wheat, rice, soy) is also projected to decline due to climate change [see [Chapter 5.3](#)]. This change in nutritional value impacts not only plants for human consumption, but also plant-based feed for livestock, potentially reducing the quality and sustainability of livestock production (Godde et al. 2021).

Water sustainability may also be challenged as future climate change projections become a reality. Scarcity of clean water threatens drinking water sources for humans and agricultural supplies to maintain plants and livestock (Brown et al. 2015). Storm surges and flooding brought about by extreme weather and sea-level rise can contaminate water supplies through run-off, sewage treatment failures, microbial pathogens, and saltwater contamination of groundwater (Brown et al. 2015, Cissé et al. 2022). Furthermore, the concentrations of contaminants in ground and surface waters may increase in responses to droughts (Benotti et al. 2010). The combined effects of compromised sanitation, poor hygiene, and crowded living situations are enhanced as supplies of clean water are limited, risking the spread of pathogens. Enteric

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POPULATION DISPLACEMENT, MIGRATION, AND THE NEGATIVE IMPLICATIONS ON TOURISM



pathogens, such as norovirus, are more likely to propagate in areas of dense human population (Rohayem 2009). This is a particular concern for the Northeast, where much of the sewage infrastructure is dated and more vulnerable to extreme weather events (Dupigny-Giroux et al. 2018).

Food and water are not the only community-important resources that will be impacted by climate change. Extreme weather events not only pose an immediate threat from the flooding caused by a storm but are also a concern for short- and long-term resiliency of available resources. For example, after Hurricane Sandy made landfall in October 2012, flooding and medical care were the immediate concern for coastal communities, followed by safe food and water (Moran et al. 2017). However, for inland residents, the predominant concern was resource availability. The storm shut down utilities, restricting access to electricity and running water, and many people, especially those without cars or with mobility issues, could not easily access food stores, public transit, community or social services, or personal support networks. There were also widespread gasoline shortages, further exacerbating the conditions. Storms such as Hurricane Sandy may disrupt transportation, delaying first responders and

access to medical treatment (USGCRP 2016). As the incidence of extreme weather events increases, sustainable and reliable access to resources in the long-term becomes a pressing concern.

5.3 Population Displacement, Migration, and the Negative Implications on Tourism

Many of the climate change factors described in this addendum focus on the health effects individuals may experience, such as cardiovascular and respiratory distress conditions or infection from various vector-, food-, or waterborne pathogens. An indirect effect of climate change that affects a society more broadly is population displacement. Population displacement occurs when a catastrophic event (e.g., hurricane, wildfire, sea-level rise, etc.) forces people to move away from their homes either for the short- or long-term (USGCRP 2016, Cissé et al. 2022). In 2017 alone, more than 18 million people worldwide were displaced as a result of weather-related disasters (Semenza and Ebi 2019). In the

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aftermath of Hurricane Sandy, around 1,200 people from Long Beach Island had to stay in shelters until roads were cleared and it was determined safe to return to their homes (Waxman 2012). One immediate concern to population displacement is the spread of illness among displaced individuals residing in cramped conditions in emergency shelters. Temporary shelters to house the displaced following severe weather events can become a breeding ground for infectious diseases, such that as much as 40% of deaths from natural disasters may be attributed to diarrheal illnesses (Liang and Messenger 2018). Population displacement strains food and other resources, which may lead to violent conflicts as competition over limited supplies, internal strife, and overcrowding reaches a tipping point.

Deteriorating infrastructure is another consequence of climate change that can lead to population displacement. In the Lower Manhattan Climate Resilience Study, a rise in the groundwater table was shown to have an adverse effect on Lower Manhattan's current infrastructure. In coastal areas, groundwater table rise, an impact of climate change, has the potential to destabilize building foundations, increase pressure and infiltrate underground utilities with saltwater, and uplift and unsettle buildings and underground utilities (New York City 2019). Coastal cities in New Jersey like Jersey City, Atlantic City, and Newark may face similar threats, and as the climate situation worsens, destabilized buildings will necessitate community displacement. Deteriorating infrastructure may be of particular concern in overburdened communities where resources may be unavailable to rebuild.

A reduction in land productivity and habitability are other indirect climate change-related factors that may result in population displacement, as people are driven away from regions heavily impacted by increasing ambient temperature, precipitation anomalies, frequent and intense extreme weather, and sea-level rise. Combined with economic and social factors, climate change is expected to give rise to increased migration (Semenza and Ebi 2019). The risk of disease may be higher for

migrants because of conditions in their country of origin, conditions in their destination country, or conditions that they encounter during migration (Semenza and Ebi 2019).

Similarly, areas dependent upon tourism may struggle as travel destinations change due to climate variability (USGCRP 2016, Semenza and Ebi 2019). Increased extreme weather or wildfires can threaten travel or properties in affected regions. Wastewater treatment facilities overwhelmed by heavy precipitation can lead to bacterial contamination of bathing waters leading to beach closures. Warm winters lead to less natural snow and less ability to create snow at New Jersey ski resorts. If climate changes effects on recreational areas become endemic, they will have a serious impact on the tourist economy of the state. Changes in migration or tourism can add to the strain on resources and challenge public health efforts designed to provide adequate living conditions, screening and vaccination programs, and other medical intervention practices (Semenza and Ebi 2019).

5.4 Climate Change and Mental Health

The mental health consequences of climate change can range from minimal stress responses to serious clinical disorders (USGCRP 2016). For example, property loss, displacement, and the related traumatic experience of living through a catastrophic climate event increase the potential for mental illnesses such as post-traumatic stress disorder, depression, and insomnia. Population displacement may result in the loss or destruction of communities as people are dispersed, which can have detrimental effects on mental health. Alternatively, individuals living in low-income communities with fewer resources and means to evacuate, may be forced to survive under inhospitable living conditions. Mental health problems increase following disasters among both individuals with no history of mental illness and individuals with pre-existing mental health conditions (Luber et al. 2014). In particular, children,

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DISPROPORTIONATE EFFECTS OF CLIMATE CHANGE

those who are pregnant and post-partum, the elderly, economically disadvantaged individuals, and first responders are especially prone to suffering mental health issues following exposure to climate change-related disasters (USGCRP 2016). For example, studies have shown that exposure to wildfires in childhood was associated with decreased academic performance and with an increased likelihood of mental illness in adulthood (Xu et al. 2020). Some medications for mental illness treatment (e.g., schizophrenia) are known to interfere with the body’s ability to self-regulate temperature, and may leave patients more susceptible to heat (USGCRP 2016). High levels of general anxiety and post-traumatic stress disorder have been identified among people affected by hurricanes, floods, and heat waves (Luber et al. 2014).

The connection between climate change and mental disorders is an emerging concern, with health effects described with novel terminology including: ecoanxiety, ecoguilt, ecopsychology, ecological grief, solastalgia (distress caused by environmental change), and biospheric concern (Cianconi et al. 2020, Comtesse et al. 2021). In particular, the mental and emotional strain on survivors and emergency responders experiencing extreme events, throughout and following an event, is of significant concern. Even individuals who may not yet be directly affected by climate change may develop anxiety over the climate crisis (Ingle and Mikulewicz 2020). In a recent Surgeon General’s report, climate anxiety was proposed as one of the reasons why feelings of sadness and hopelessness have increased by 40% over the last decade in United States high school students (US HSS 2021). Moreover, recently ecological grief and anxiety have been noted in relation to the experienced or anticipated loss of species, ecosystems, and meaningful landscapes (e.g., forests, coastal wetlands) due to projected environmental changes (Cunsolo and Ellis 2018). The beneficial effects of engaging or interacting with nature are well known to provide a benefit to mental health, therefore, the loss or impending loss of ecological features can understandably impact the mental health of some individuals (Dillman-Hasso 2021).

5.5 Disproportionate Effects of Climate Change

While climate change is a threat to everyone’s physical and mental health, socially and economically disadvantaged individuals are particularly vulnerable to the greatest impacts of climate change. A lack of physical mobility and resilience capacity due to structural or systems-level inequities puts vulnerable populations, such as the chronically ill and elderly, communities of color, urban and rural poor, and non-English speaking communities at greater risk from storms, floods, heat waves, and other extreme weather events. Further, individuals with pre-existing conditions are further at risk if crises lead to stressed healthcare systems.

Climate change is a significant threat to environmental justice. Environmental justice is defined as “the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies,” (US EPA 2022). Economically disadvantaged households and communities of color are disproportionately subjected to a greater number of environmental and public health stressors, and as a result, these communities experience asthma, cancer, elevated blood lead levels, cardiovascular disease, and other adverse health effects, at higher rates than richer and whiter communities (NJDEP 2022d). It is the poor and communities of color that have and will likely bear the largest burden of climate change effects because of their location’s inadequate infrastructure, health, income, and limited access to resources (Cissé et al. 2022). Some root causes of these climate injustices include structural racism, lack of power and political representation, and language barriers (Newell et al. 2021). Living in poverty and congested cities puts a significant population at risk due the environmental conditions such as greater heat island effects, poor air quality, the prevalence of chronic illnesses including asthma and obesity, a reliance on lower paying jobs, and decreased access to healthy food options (e.g., food

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deserts). It is a further challenge for communities and people for whom English is not the native language. The impact that socioeconomic status and racial disparities have on a population's vulnerability to climate change makes policies that strive to relieve overburdened communities from environmental and public health stressors, such as New Jersey's Environmental Justice Law (N.J.S.A. 13:1D-157), are all the more critical, especially as future climate change projections become a reality. To this end, New Jersey continues to make resources available to invest in clean energy, clean transportation, and equity programs via the Regional Greenhouse Gas Initiative (RGGI) that are aligned with objectives defined in the Global Warming Solutions Fund Act, one of which is to "be directly responsive to the negative effects on human health and the environment in communities that disproportionality impacted by the effects of environmental degradation and climate change" (NJ 2022).

5.6 Summary: Climate Change-driven Impacts on Communities

In combination, the anticipated climate change effects (e.g., heat stress, poor air quality, flooding) will pose a greater threat to vulnerable groups—including young children, elderly, socially or linguistically isolated, economically disadvantaged, and those with preexisting health conditions—because these groups are less likely to have the resources necessary to recover quickly (USGCRP 2016, Cissé et al. 2022). Individual vulnerability is likely to increase as infrastructure failures become more common, especially in the northeastern United States where infrastructure is generally older than other areas of the country (Dupigny-Giroux et al. 2018). The urbanization of large portions of New Jersey makes the state's residents particularly vulnerable to the impacts of increased temperatures, which are made worse by heat island effects. The large expanses of asphalt and concrete associated with urban and suburban sprawl and the

consequential loss of green spaces combined with traffic congestion, results in warmer temperatures in urban centers, particularly in the summer months (Carnahan and Larson 1990, Mohajerani et al. 2017). The challenges humans experience at the hand of climate change are not equitable nor are they easily quantified. In addition to the tragedy of lives lost, the economic disruption of climate change from losses in homes and/or businesses, from medical bills accrued, and from the destruction of structures and land is a growing concern for humans and their communities.

Multiple public health organizations and agencies have begun to outline potential surveillance opportunities surrounding climate change and human health (USGCRP 2016, CSTE 2017). The CDC has an online publication of climate change indicators including: community characteristics (housing units, internet access, land cover and land usage); historical drought; extreme heat (temperature and heat projections), historical temperature and heat-index; heat-related illnesses (deaths, emergency department visits, and hospitalizations); poor air quality related diseases (deaths, emergency department visits, and hospitalizations); population characteristics (demographics, health status, and socioeconomic status); precipitation & flooding (historical precipitation, precipitation and flooding projections); vulnerabilities and preparedness (flood hazard zones, heat vulnerability and preparedness, medical infrastructure); social vulnerability index; and wildfires. New Jersey Department of Health (NJDOH) has also begun to track selected climate change-related health indicators, including heat-related hospitalization and emergency department visits; asthma, COPD and heart attack hospitalization and emergency department visits; CO deaths, hospitalizations, and emergency department visits; CO detectors in the home; and ownership of portable generators (NJ DOH 2021).

An aerial photograph of a dense urban neighborhood, likely in New York City, showing a grid of streets and numerous multi-story buildings. The buildings are mostly light-colored, with some darker roofs. The streets are narrow and filled with cars. The overall scene is a typical city block.

"Climate change is a significant threat to environmental justice."



SECTION 6

CONCLUSIONS



This addendum summarizes how changes in temperature, precipitation, sea-level rise, and extreme weather can directly and indirectly lead to detrimental effects on human health. These effects include acute and chronic cardiovascular and respiratory conditions; vector-, food-, and waterborne diseases; community displacement; and can contribute to negative mental health and sometimes mental illness. In particular, the addendum focuses on how our understanding of the current and anticipated impacts on New Jersey’s environment, natural resources, and infrastructure, will affect individuals and communities therein. The climate crisis disproportionately harms vulnerable populations (e.g., children, elderly, and the chronically ill) and households that are economically and socially disadvantaged. It is anticipated that the effects on the human population will be significant, and the strain on existing infrastructure, including medical and public health services, will grow. Severe storms and extreme temperatures will affect agricultural production, threatening food supplies. Flooding and sea-level rise will decrease water quality. Pollution from wildfires and ground level ozone will diminish air quality. Pathogens, through various mechanisms, are anticipated to become a greater public health concern. Importantly, these factors will not be isolated, but rather, will be a collective challenge to our ways of living. Understanding how these challenges posed by climate change threaten human health and communities is essential to establishing strategies and environmental policies that can effectively and equitably protect and improve health outcomes.

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