Orange & Rockland

Climate Change Vulnerability Study

September 2023

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Abbreviations

ASCE	American Society of Civil Engineers
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BFE	Base Flood Elevation
CCIP	Climate Change Implementation Plan
CRREC	Climate Resilience and Resilience Executive Committee
CCRP	Climate Change Resilience Plan
CCVS	Climate Change Vulnerability Study
CDD	Cooling Degree Days
CERC	Corporate Emergency Response Center
CJWG	New York State Climate Justice Working Group
CMIP5/6	Coupled Model Intercomparison Project Phase 5 or 6
CSRP	Commercial System Relief Program
DAC	Disadvantaged Communities
DEM	Digital Elevation Models
DLCP	Direct Load Control Program
FERC	Federal Energy Regulatory Commission
FEMA	Federal Emergency Management Agency
GCM	Global Climate Model
HDD	Heating Degree Days
HVAC	Heating, Ventilation, and Air Conditioning
IDF	Intensity-duration-frequency
kV	kilovolt
MIT	Massachusetts Institute of Technology
NERC	North American Electric Reliability Corporation
NESC	National Electric Safety Code
NYC	New York City

NYSERDA	New York State Energy Research & Development Authority
PC2FM	Physical Chemistry Fire Frequency Model
p.u.	per unit
PSL	Public Service Law
PSC	Public Service Commission
RCP	Representative Concentration Pathway
ROW	Right-of-way
SME	Subject matter expert
SSP	Shared Socioeconomic Pathway
TV	Temperature Variable
TVMP	Transmission Vegetation Management Plan

Executive Summary

Orange and Rockland Utilities, Inc. ("O&R" or "the Company"), has been committed to increasing the resilience of the electric system for decades. In the face of climate change, it has become increasingly important to understand the impact that different weather events and climate hazards have on the electric system as it will continue to shape the Company's actions and investment priorities to support enhanced system resiliency and restoration capabilities.

O&R performed the Climate Change Vulnerability ("Study") with support from ICF's climate resilience experts ("the Study Team"). The Study incorporates climate data provided by the New York State Energy Research and Development Authority ("NYSERDA") in partnership with Columbia University. In November 2023, O&R will file a Climate Change Resilience Plan ("CCRP"), which will discuss climate adaptation measures the Company will implement over the next 10, and 20 years, with more details for the first 5 years.

As an affiliate of Consolidated Edison Company of New York, Inc. ("CECONY"),[i] O&R also benefits from the extensive work that CECONY has undertaken to date related to climate change. In particular, in 2019, CECONY published a Climate Change Vulnerability Study[ii] that explored a wide suite of potential adaptation solutions and a subsequent Climate Change Implementation Plan ("CCIP")[iii] that committed the Company to updating its planning, design, and operations

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[i] O&R and CECONY are referred to collectively as "the Companies."
[ii] To view the full 2019 Con Edison CCVS see https://www.coned.com/-/media/files/ConEd/documents/our-energy-future/our-energy-projects/climate-change-resiliency-plan/climate-change-vulnerability-study.pdf?la=en
[iii] To view the full 2020 CCIP see https://www.coned.com/-/media/files/coned/documents/our-energy-future/our-energy-projects/climate-change-resiliency-plan/climate-change-resilience-adaptation-2020.pdf

process to incorporate climate change. O&R has integrated the findings from past CECONY reports into the Study, as appropriate.[iv]

The Study provides:

- A presentation of projected changes in climate affecting the O&R service territory based on recent studies;
- A prioritization of specific climate changes that may impact the O&R electric system; and
- A suite of potential adaptation strategies that O&R will evaluate and consider further in the Company's CCRP.

Short summaries of these items are set forth below.

Climate Science

Climate science and advanced climate models are used to develop forward-looking projections that aid in the evaluation of potential vulnerabilities to assets, operations, and systems. Climate models are periodically updated and revised by scientists to account for observed conditions and improved modeling techniques (see Figure 1 below). O&R is committed to using the best available climate science to inform its planning decisions as relevant new data becomes available.

The Study leverages several data sources to develop a full understanding of the climate risks facing the Company. These sources include:

- New statistically downscaled global climate projections developed by Columbia University and supported by NYSERDA in 2022;[v]
- Sea-level rise projections from Columbia University and NYSERDA;
- Updated rainfall projections from the Cornell University intensity-duration-frequency ("IDF") curves;
- Prior analysis from a Massachusetts Institute of Technology ("MIT") study[1,vi] for National Grid with informational wind and ice projections;[2] and
- Numerous research papers and academic studies.

Future climate change is uncertain, and climate model projections account for a range of possible futures based on different emissions scenarios. The Study used statistically downscaled

[iv] For background information on climate science and energy systems view the 2019 Con Edison Report https://www.coned.com/-/media/files/ConEd/documents/our-energy-future/our-energy-projects/climate-change-resiliency-plan/climate-change-vulnerability-study.pdf?la=en

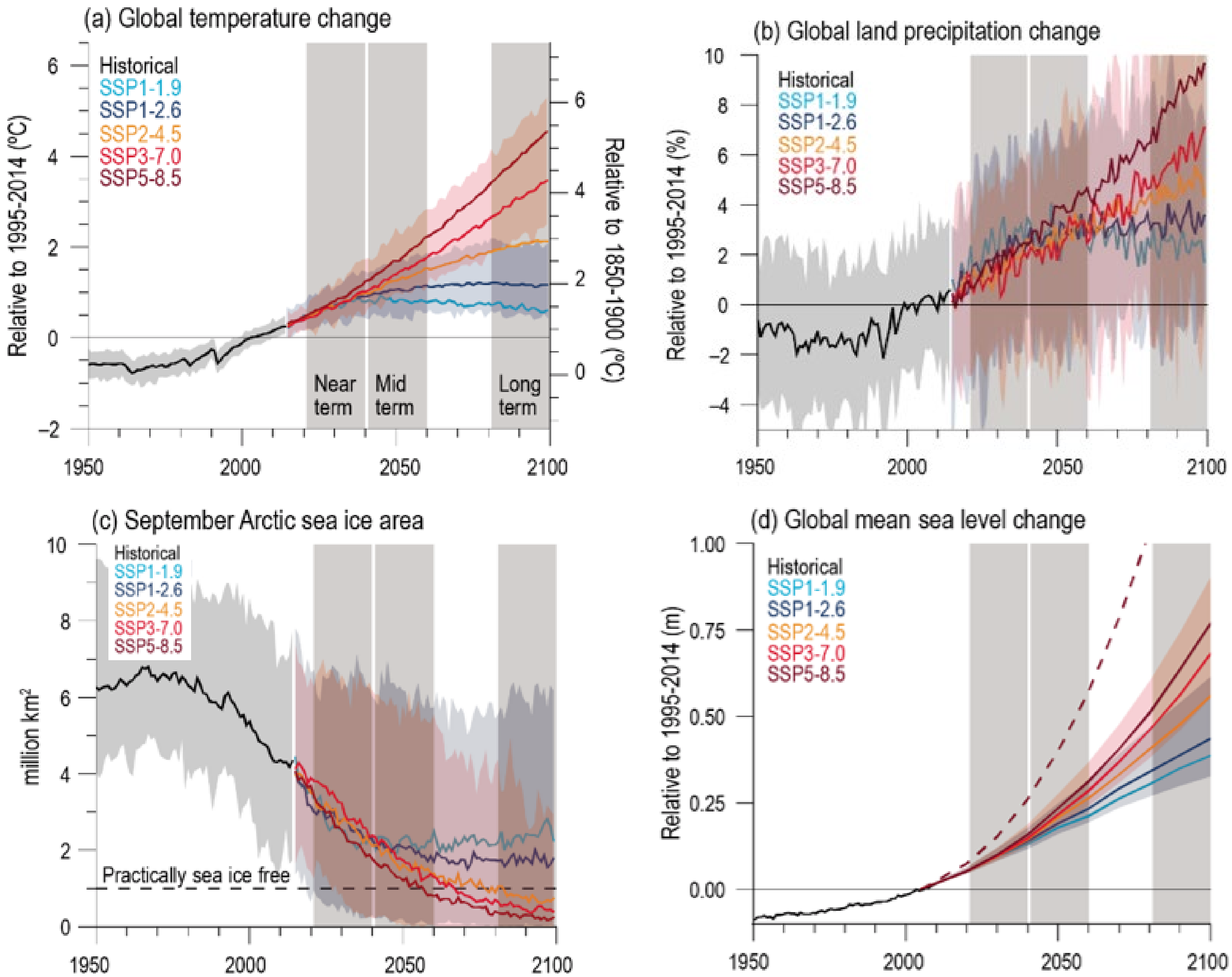
[v] Downscaled from the Coupled Model Intercomparison Project 6 dataset.

[vi] Note that the Arabic numbered notes may be found in the References section below

climate projections developed by Columbia University and NYSERDA in 2022.[vii] These projections draw on an ensemble of Coupled Model Intercomparison Project Phase 6 ("CMIP6") Global Climate Models ("GCMs")[viii] and two future greenhouse gas emissions trajectories based on Shared Socioeconomic Pathways ("SSPs"), aligning with the latest climate science developed for the Intergovernmental Panel on Climate Change Sixth Assessment Report.[3] Climate change pathways provide an understanding of projected climate change in the O&R service territory and benchmark values for design parameters to plan to and make O&R's electric system more resilient to potential climate change risks. The pathways are based on the downscaled climate projections for variables related to a range of climate hazards, including temperature, precipitation, and sea-level rise. With input from internal and external stakeholders, O&R selected the climate change pathway of SSP5-8.5, 75th percentile, to use in the evaluation of asset vulnerability. SSP5-8.5 represents high, largely unmitigated future greenhouse gas emissions and therefore addresses the potential for worse-case climate change outcomes. See Climate Data Methods for a more detailed overview of the methodology.

[vii] For information on the prior NYSERDA report, see https://www.nyserda.ny.gov/About/Publications/Energy-Analysis-Reports-and-Studies/Environmental-Research-and-Development-Technical-Reports/Response-to-Climate-Change-in-New-York

[viii] Projections for daily temperature and precipitation variables are drawn on an ensemble of 16 GCMs and projections for hourly temperature and humidity variables are drawn on an ensemble of 14 GCMs.



Source: IPCC 6th Assessment Report.

Figure 1. Climate change projections for several hazards

Physical and Operational Vulnerabilities

In the Study, O&R develops an understanding of the electric system's key physical and operational vulnerabilities to climate change. Developing this detailed understanding of key vulnerabilities is an important step toward identifying priority adaptation measures for inclusion in the CCRP. The final prioritization of physical risks is shown in Table 1 as high (red), moderate (yellow), or low (green).

	Temperature and Temperature Variable (TV)	Flooding	Wind & Ice
Substations	Moderate	High	Low
Overhead Transmission	Moderate	Moderate	Moderate
Overhead Distribution	Moderate	Low	High
Underground Transmission	Moderate	Moderate	Low
Underground Distribution	Moderate	Moderate	Low
Company Facilities	Moderate	Moderate	Low

Green: Asset/system has low vulnerability to the given climate hazard.

Yellow: Asset/system is moderately vulnerable to the given climate hazard. Vulnerability is typically driven by assets' propensity to experience degradation from exposure to hazard overtime.

Red: Asset/system is highly vulnerable to the given climate hazard. Vulnerability is typically driven by asset's high sensitivity or a significant expected increase in magnitude of given climate hazard, resulting in a high risk of major failure or severe degradation of service.

Table 1. **Summary of Vulnerabilities.**

Additional information on the physical and operational impacts for each hazard is provided below.

Temperature and Humidity

Temperature and humidity represent a moderate concern for O&R's physical assets, as shown in Table 1 above. Higher temperatures can cause reductions in capacity for certain equipment, accelerated degradation (potentially leading to failures and decreased system reliability), as well as physical impacts such as increased line sag.[4, 5] When high temperatures coincide with high humidity, O&R typically experiences a spike in electric demand due to increased air conditioning use. In extreme situations, reduced capacity and increased demand could lead to capacity shortfalls or equipment failure. Increasing temperature and humidity have the potential to cause an increase in frequency of customer outages and higher repair costs.

Higher temperatures and temperature variable ("TV") also represent a risk to O&R's operational processes:

- Load forecasting and load relief planning calculations are heavily influenced by temperature, as high temperature increases demand;
- Higher average temperatures can accelerate vegetation growth, increasing the risk of vegetation contact with power lines; and
- Higher temperatures can also pose a risk to O&R staff who work in the field.

The above risks are somewhat moderate because projected temperature changes in the O&R service territory are relatively gradual through 2050 and beyond.

Flooding

Flooding represents a high priority hazard for O&R, especially for several specific substations. The O&R service territory is expected to experience increased flooding due to sea-level rise in the Hudson River and increasing heavy precipitation, which increases the risk of inland and riverine flooding. Tidal flooding is driven by a combination of tidal factors and wind-driven storm surge, both of which can be exacerbated by sea level rise and more intense tropical or extratropical cyclones. Extreme storms, such as hurricanes, are likely to increase in frequency and intensity, bringing with them potential increases in the frequency and intensity of storm surge.

The latest climate science finds that a 16-inch rise in sea level by 2050 (relative to 1995–2014 sea levels) and higher precipitation could expose three Company substations to flooding in a 1-in-100-year (1% annual chance) flood. The O&R service territory has experienced recent extreme rainfall events that underscore the risk of flooding. In July 2023, for example, the service territory experienced a 1-in-1,000-year (0.01% annual chance) rainfall event (see Figure 2 below). Events like these are projected to occur more frequently due to climate change, posing a greater risk of equipment damage, ongoing corrosion issues, and reduced access if surrounding roads are flooded. These impacts could result in more frequent outages with longer repair times and higher costs of recovery.

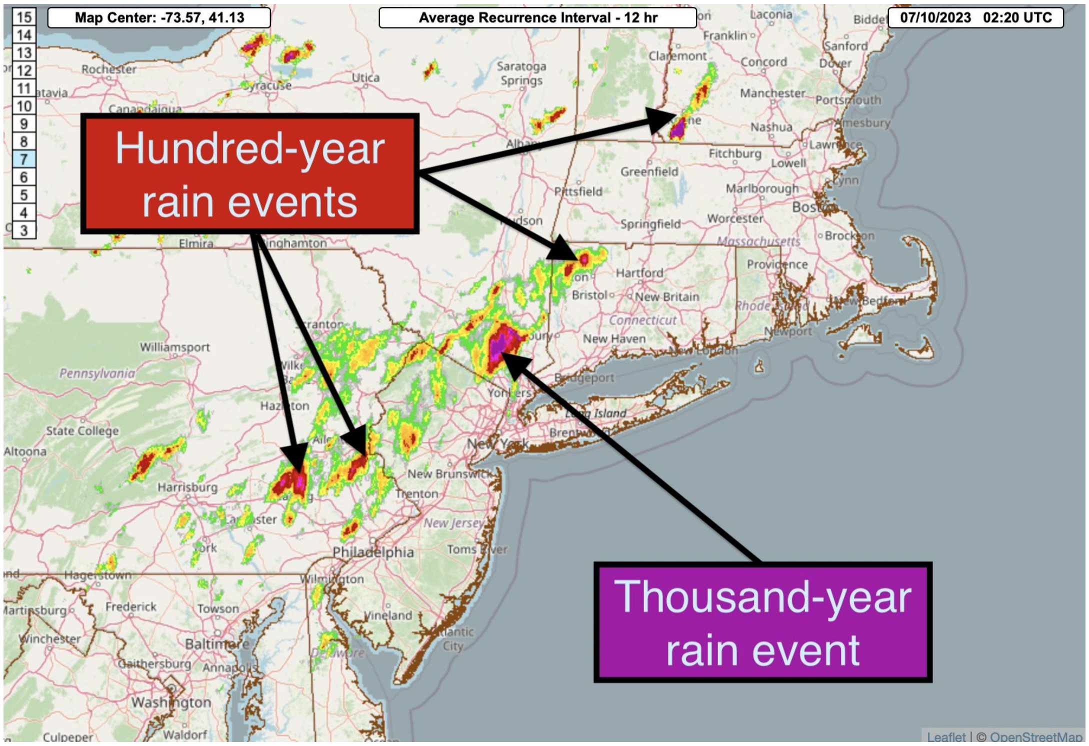


Figure 2. **1-in-100 and 1-in-1000, year rainfall events on July 9–10, 2023.**

An increase in flooding due to sea-level rise, precipitation, or storm surge will also likely result in more frequent activations of O&R's emergency response procedures, as well as additional hinderances (*e.g.*, blocked roadways) to system repairs. Although the Company has developed a robust emergency management framework, an increase in extreme events could still impact the Company's resources and delay recovery.

Wind and Ice

Wind and ice have historically been difficult to model due to their highly localized nature. To inform the Study, O&R acquired an additional data set from MIT that provides informational insight into future wind speeds and radial icing potential. This data set and other studies summarized in the Wind and Ice discussion demonstrate that wind speeds will likely increase, and there will remain a risk of radial icing. Extreme storms such as hurricanes can cause wind speeds to increase far beyond typical average speeds, and the wind speeds of the most intense hurricanes are projected to increase. The frequency of freezing rain and radial icing are projected to decrease as the atmosphere warms, but there could be larger snowfall totals for the largest snow events and increased radial ice accumulation. The magnitude of this trend remains highly uncertain due to the specific atmospheric conditions required for ice storms to occur.

These potential changes in wind and ice present an especially large risk to overhead distribution equipment. Although overhead distribution assets, including conductors, attachments, and cross-arms, are built to withstand defined design tolerances for combined wind and ice loading, they are frequently adjacent to neighboring vegetation that may be downed during these events caused by off right-of-way trees. Tree contact can cause lines to disconnect and fall, and can even lead to pole collapse, especially older poles or those with existing damage. This would result in asset failure, leading to outages and restoration costs.

Changes in storm frequency and intensity also present a risk to O&R's emergency response capabilities. More frequent activations could impact the Company's available staff and spare equipment resources.

Extreme and Coincident Events

GCMs are limited in their ability to resolve extreme weather events due to the small spatial and time scales at which these events occur, the shortness of the historical record relative to the rarity of the events, and the complex and rare environmental and meteorological conditions that promote their formation. This necessitates an evaluation of extreme events using historical analogs and projections from scientific literature. This assessment supplements the projections developed by Columbia University to provide a broader understanding of potential future extreme events under the influence of climate change in the O&R service territory. Each extreme event characterizes the differing projected future changes in terms of frequency and intensity across the O&R service territory.

- Hurricanes and tropical cyclones are projected to increase in maximum sustained wind speed and wind gust intensity but will likely experience no change in overall frequency.
- Snow and ice events will likely decrease in frequency as the atmosphere warms, but there could be larger snowfall totals for the largest snow events and increased radial ice accumulation.
- Cold snaps and polar vortex events will likely decrease in frequency, but complex processes amplified by climate change, such as Arctic amplification, could worsen some cold snaps and polar vortex events.
- Drought and wildfire are projected to increase in both frequency and intensity, due to projected increases in temperature, dry conditions, and the occurrence of lightning strikes.
- Lightning and tornadoes could potentially increase in frequency and intensity due to projected changes in atmospheric conditions that facilitate thunderstorms and their associated severe weather, such as projected increases in temperature coupled with increases in atmospheric water vapor.

Looking Ahead

In November 2023, O&R will file a CCRP with the Public Service Commission ("PSC"), as required by Public Service Law ("PSL") §66(29). The CCRP will include an investment plan with adaptation measures to address physical and operational vulnerabilities identified in the Study, reflecting the latest climate data.

The CCRP will incorporate the overarching resilience framework developed as part of Con Edison's 2019 CCVS and jointly adopted by the Companies. The benefit of this framework is that it encourages holistic thinking about the types of measures that help build a more resilient system. The framework encompasses investments to:

- **Prevent** climate change impacts by hardening infrastructure;
- **Mitigate** the impacts from outage-inducing events by minimizing disruptions; and
- **Respond** rapidly to disruptions by reducing recovery times and costs.

O&R will update the Study every five years.[6] Doing so will help the Company to account for observed events, stay apprised of the latest advancements in climate change projections, and allow the Company to re-assess its priority vulnerabilities as it learns from its investments in resilience. The Company will also continue to engage stakeholders and improve communication with customers and municipal officials.

Introduction

Background

O&R is an investor-owned utility serving Orange, Rockland, and Sullivan Counties in New York State. O&R provides electric service to over 234,000 customers in New York[ix] and more than 130,000 natural gas customers in New York. The O&R electric system includes over 500 miles of electric transmission lines, almost 4,000 miles of overhead electric distribution lines, and over 1,800 miles of underground electric distribution lines.

New York State has experienced detrimental climate events that have caused damage to many of its communities and infrastructure. Temperatures in the State have increased almost 2.5°F since the beginning of the 20th century, and heavy precipitation events are occurring more frequently and with greater intensity.[7] Much of New York, including Orange and Rockland Counties, experienced intense flash floods during a rainstorm event in July 2023. The storm caused severe damage to homes and infrastructure. The area has also experienced intense wind events that have led to service interruptions across the O&R service territory as recently as July 2023. Research shows that a range of climate hazards, including temperature, precipitation, and winter storms, will continue to affect the State and are projected to increase in severity due to climate change.[8] Without investment in storm hardening and resilience measures, the impacts from climate hazards will make it increasingly difficult for energy utilities to provide reliable and safe power to their customers.

As a result of the Tropical Storm Isaias experience in 2020 and other mounting threats, the New York State Senate passed a new subdivision law[9] that requires New York electric utilities to develop a CCVS and CCRP for their transmission and distribution systems. The goal is to better

[ix] As of 12/15/23.

prepare utilities for the adverse effects of climate change and identify opportunities for improving system resilience. Soon after the law was passed, the PSC initiated a proceeding, Case 22-E-0222,[10] which will implement the legislative requirements. O&R, along with other electric utility companies subject to the PSL §25-a,[11] are required to submit a CCVS to the PSC by September 22, 2023.

To fulfill this requirement, the Company prepared the Study with support from ICF's climate resilience experts and NYSERDA (in partnership with Columbia University's Lamont-Doherty Earth Observatory).

Baseline Assumptions

The Study summarizes O&R's vulnerabilities to climate change hazards. In doing so, it relies upon the following two baseline assumptions.

O&R's system as it exists today. Over the next 20+ years, there will be changes in technology and policy that will alter O&R's electric system. Some of these changes may be relatively clear today, while others have not even been considered. To focus the analysis, the Study considers O&R's system as it exists today, not as it may evolve in the future. This assumption makes it easier and clearer to discern the potential impacts of climate change on the Company's electric system.

Climate consistency across the O&R service territory. O&R is committed to using the best available climate science to evaluate potential risks. As discussed in more detail below, this meant partnering with Columbia University and NYSERDA to access the most recent climate data available for the region. Two weather stations, near the O&R service territory, were used to provide climate projections: Mohonk and Dobbs Ferry. These weather stations provide useful data to evaluate risks but do not capture more granular nuances that may exist within the O&R service territory. Based on this limitation, for the purposes of the Study, the Company has assumed that projections of temperature, humidity, wind, and precipitation at these weather stations are applicable across the entire O&R service territory. Flooding, however, is highly geographically dependent and has been evaluated against specific asset locations.

Summary of Priority Hazards

While climate change will impact a number of weather events, the scope of the Study analyzes the following three key hazard categories: **temperature and humidity, flooding (including sea-level rise and changes in precipitation), and wind and ice**. The Study Team selected these hazards based on their potential to impact the Company's assets, as well as their potential future magnitude and frequency as a result of climate change. The Study Team found that while all climate hazards have the potential to impact O&R's assets and operations, the three selected hazards pose a much larger risk than others.

Temperature and Humidity. The majority of the O&R system will see impacts due to rising temperatures, and those impacts will be amplified during intense heat waves. Increasing temperature variable will cause an increase in electric loading and slight equipment degradation.

Flooding. O&R has already experienced inland and coastal flooding events that have impacted the Company's assets, and that risk is expected to worsen. Specific O&R substation sites have been identified to be especially vulnerable to flooding.

Wind and Ice. Projections indicate a potential for higher wind speeds and stronger icing events in the future. Vegetation contact during high wind events represent a high risk to the overhead distribution system, especially when combined with snow or icing events.

Importance of Equity

O&R recognizes the increasingly important role that equity plays in resilience planning efforts and has been deliberate about incorporating equity considerations into the planning process for investments, including the CCRP. It is critical to consider how disadvantaged communities ("DACs") may be disproportionately affected by climate change and what O&R can do to provide reliable and resilient service to those communities.

On March 27, 2023, the New York Climate Justice Working Group ("CJWG")[12] voted to approve and adopt a comprehensive list of criteria that defines disadvantaged communities based on socioeconomic data (*e.g.*, energy burden, poverty rate). Figure 3 below shows the CJWG map of DACs in the O&R service territory. Spatial comparisons can be drawn between DAC and climate hazard data to help distribute and prioritize benefits associated with resilience strategies.

As O&R advances through the climate change resilience planning and implementation process, there will be a need to prioritize adaptation projects for implementation, and equity will be an important consideration in that process. As such, equity will appear as a topic of more detailed discussion in the CCRP.

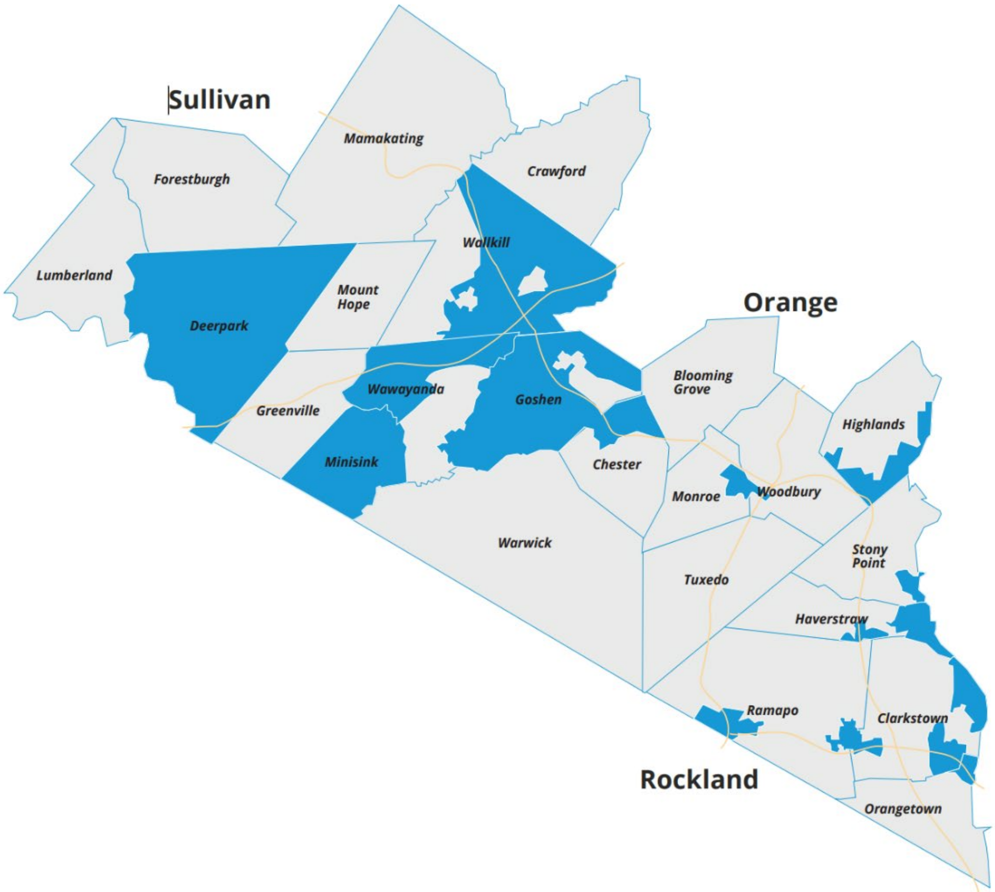


Figure 3. **Map of DAC areas in the O&R service territory (shown in blue).**

The Company has formed an Environmental Justice Working Group and Executive Steering Committee and plans to release a finalized Company Environmental Justice Policy Statement in 2023 to apply an equity lens to investments. Key components of the upcoming policy statement include commitments that:

- Operations will not disproportionately burden DACs;
- O&R will work to understand DAC concerns;
- Clean energy investments will benefit DACs; and
- O&R will provide opportunities for employment in its clean energy future.

These considerations will inform the application of resilience measures identified in the CCRP and help direct investments with the achievement of equity as an objective.

Climate Data and Future Projections

Earth's climate is changing in response to both natural and human-caused drivers. The past decade was the warmest on record, and global atmospheric warming has increased at a faster rate since the 1970s than in any other 50-year period, based on reconstructions from paleoclimate archives and direct observations.[13] Furthermore, the global climate science community attributes recent accelerated warming to corresponding increases in human-caused greenhouse gas emissions.[14]

A growing body of research reveals that a range of climate hazards will likely increase in frequency and intensity due to climate change.[15, 16] A warmer atmosphere will increase the frequency, intensity, and duration of heat waves; hold more water vapor for heavy precipitation events; and accelerate ice loss from large ice sheets, exacerbating sea-level rise and coastal storm surge. Extreme weather, such as heatwave and heavy precipitation events has already become more frequent and intense across most land regions since the 1950s.[17] As a result, climate change presents the potential for worsening climate hazards and challenges in the O&R service territory.

Climate Data Methods

Data Sources

The Company is committed to using the best available science to understand the impacts of future climate change in the O&R service territory. Climate science models project changes in Earth's climate for future decades using different scenarios of human actions, greenhouse gas emissions and concentrations, and global temperatures. Projections from the Cornell intensity-duration-frequency ("IDF") curves supplement the precipitation projections and provide information on the 4% annual chance (*i.e.*, 25-year) 24-hour precipitation totals in the O&R service area for the CMIP5 Relative Concentration Pathway ("RCP") 8.5 emissions scenario.[x, xi]

The **baseline time period** for the climate projections for temperature and precipitation variables used in this assessment is 1981-2010. It is important to note that this does not include recent events such as the heat waves experienced in the O&R service territory over the past several summers, including the July 2023 heat wave and flash flooding events that impacted the O&R service territory, along with much of the Northeastern US.

Projections are relative to a baseline corresponding to observations from 1981–2010[xii] at the Dobbs Ferry and Mohonk weather stations (see Figure 4 below) to represent Orange County, Rockland County, Sullivan County, and surrounding areas. The Mohonk weather station was found to be the closest match to Spring Valley, while the Dobbs Ferry weather station better captures the warmer urban environment. The Mohonk weather station has previously been used for O&R planning, as the historical conditions at the Mohonk weather station best match conditions at the Spring Valley weather station. While the recent historical period of 2011–2023 is not part of the baseline calculation for temperature and precipitation variables[xiii], recent trends toward warmer temperature extremes in line with model projections have been observed. Forward-looking projections are developed at decadal time horizons from the 2030s to the 2080s.

The SSPs represent scenarios of projected socio-economic and technological changes and are used to develop emissions scenarios.[18] Climate projections provide a range of plausible climate futures, reflecting uncertainty in future greenhouse gas concentrations, climate sensitivity to greenhouse gas increases, natural climate variability, and other factors. The range of projections can be evaluated quasi-probabilistically using percentiles, where the 10th, 50th, and 90th percentiles represent the low end, median, and high end of the projection range, respectively.

The Study also uses sea-level rise projections developed by Columbia University and NYSERDA. The sea-level rise projections use a combined ensemble of SSP2-4.5 and SSP5-8.5 projections for a statewide composite of local projections at Montauk Point, the Battery tide gauge, and Troy

[x] Historical heavy rainfall is provided by the NOAA Atlas-14 for the entire U.S. A point-and-click map interface with historical heavy rainfall amounts based on IDF estimates and 90% confidence intervals can be found on their website (https://hdsc.nws.noaa.gov/pfds/pfds_map_cont.html?bkmrk=ny).

[xi] Rainfall return period projections use the ensemble mean rather than the 75th percentile because they use a different methodology than other climate projections used in this guidance and cataloged in the lifecycle tables. This information is publicly available through Cornell University (http://ny-idf- projections.nrcc.cornell.edu/index.html).

[xii] The baseline represents a period centered on the 1990s and was used in the most recent CMIP6 projections. It does not include the recent period of 2011–2023, during which weather and climate events (*e.g.,* heat waves) may have occurred.

[xiii] The most recent historical period of 2015-2023 is not part of the baseline calculation for sea level rise.

Dam.[xiv] Sea-level rise projections draw from an ensemble of GCMs and are relative to a 1995–2014 baseline time period.

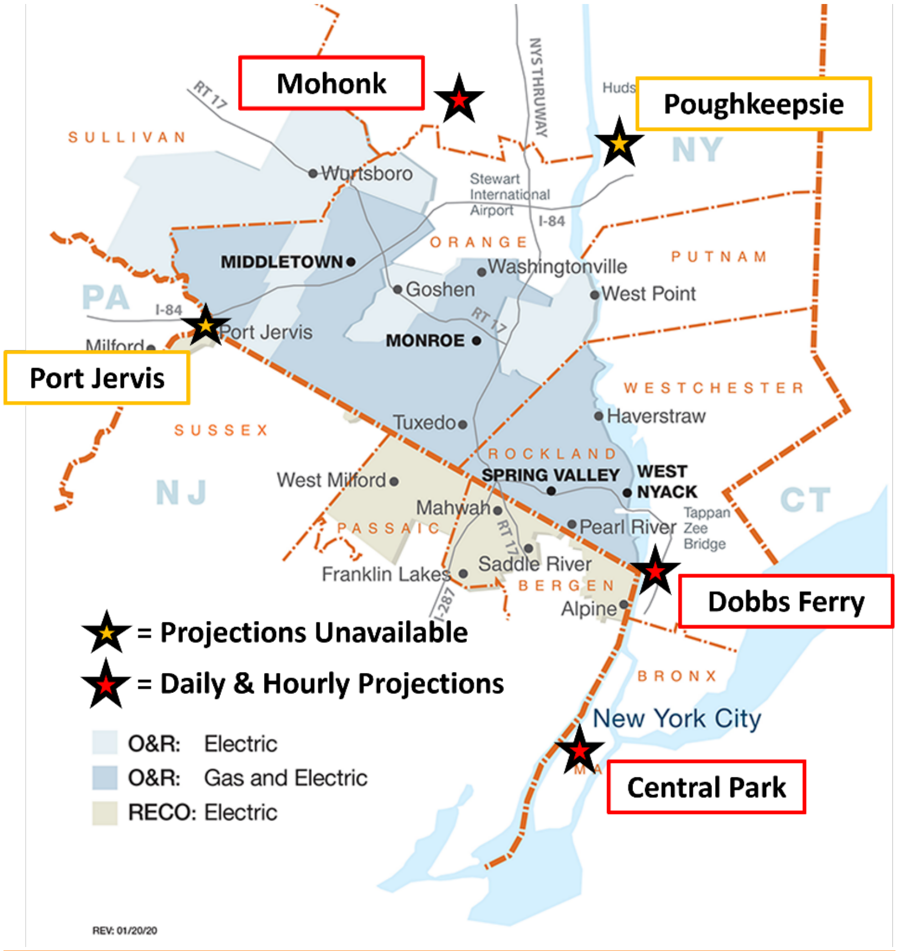


Figure 4. Columbia Dataset Weather Station Locations Relevant to the O&R's Service Area.

The climate projections developed by Columbia University and NYSERDA do not address some extreme events such as tropical storms, wind gusts, and wildfire. This is due to the rarity of those types of events relative to the historical record and the limited ability of current GCMs to resolve the small space and time scales over which they occur. To address this, the Study uses a combination of literature review and supplementary dynamically downscaled climate projections to evaluate the potential for worsening extreme weather in the O&R service territory due to climate change. The extreme weather events literature review supplements the climate projections to illustrate expected changes and impacts in extreme events and provide a broader understanding of complex hazards in the O&R service territory.

[xiv] Projections for the Albany/Troy Dam are calculated using the data for the Battery and are adjusted for the appropriate rate of vertical land motion. The values for vertical land motion at the Battery are removed and then the local rate at the Albany/Troy Dam is added in. This is consistent with prior methods used in Horton et al., 2011;2014.

O&R's Selected Pathway and Climate Variables

Climate change pathways ("pathways") are a single set of climate projections based on an SSP and percentile that characterize how much and when climate hazards will change in the O&R service territory. O&R has selected a set of pathways to acknowledge uncertainty in future greenhouse gas emissions and to characterize future changes in temperature, humidity, precipitation, and sea-level rise. The selected pathways are based on a range of underlying considerations, including climate science, external benchmarking, high-level system sensitivity, and potential co-benefits. O&R sought pathways that would broadly align with regional benchmarks, including industry shifts in climate change risk tolerance and changes in external standards or codes (*e.g.*, New York State Community Risk and Resiliency Act).

The pathways the Company selected provide standardized climate change projections to inform the analysis of vulnerabilities and to guide adaptation efforts. O&R's pathways for temperature, precipitation, and related variables use upper-range climate projections based on a high emission scenario. Specifically, O&R will use the **75th percentile of the SSP5-8.5 projections** for temperature, precipitation, and related variables, representing the upper end of the middle range estimates for this. SSP5-8.5 represents largely unabated global greenhouse gas emissions through 2100 and provides a high risk-aversion lens through which to plan for potential climate change. O&R's pathway for sea-level rise will use the **50th percentile of the combined SSP2-4.5 and SSP5-8.5 projections**. SSP2-4.5 represents some actions taken to reduce global greenhouse gas emissions through 2100 and provides a lower risk aversion lens to plan for potential climate change. These pathway selections for O&R are in alignment with Con Edison's pathways.

Tailored Climate Data Analysis

> A Climate hazard is a climate related trend that may cause damage. Climate variables address a range of climate hazards through projections tailored to the sensitivities and constraints of O&R's system that relate plausible impacts of climate change.

The Company identified in Table 2 below a list of prioritized climate variables that could present outsized impacts to operations, planning, and infrastructure.[xv] The variables include both gradual and extreme impacts of climate change. Gradual impacts are those that evolve slowly over time and extend to larger geographic areas, such as changes in cooling degree-days or sea levels relative to baseline. Extreme impacts (*i.e.*, extreme events) are outsized risks compared to gradual hazards and may demand larger emergency response efforts than those experienced historically, such as a hurricane with

[xv] Ice and winter precipitation were not included as a hazard because such events are expected to decrease in frequency as temperatures warm. In addition, O&R has historically experienced these events and therefore has a robust response system in place.

extreme wind gusts and storm surge. The prioritized variables, categorized by hazard, include the following:

Hazard	Prioritized Variables
Extreme Heat	Days per year with maximum daily temperature above 95°F
	Days per year with average daily ambient temperature above 86°F
	Number of heat waves per year with 3 or more consecutive days over 90°F
	Maximum duration of heat waves per year with maximum temperatures over 95°F
	Maximum duration of heat waves per year with maximum temperatures over 90°F
	Maximum duration of heat waves per year with average temperatures over 90°F
	Highest annual maximum daily temperature
Heat Index	Days per year with heat index exceeding 91°F
	Days per year with heat index exceeding 95°F
	Days per year with heat index exceeding 103°F
	Days per year with heat index exceeding 115°F
Extreme Cold	Annual coldest daily temperature
Heavy Precipitation	5-day maximum precipitation
	Days per year with >2 inches of precipitation
Return period precipitation	25-year, 24-hour precipitation event
Energy Demand	Cooling Degree Days
	Heating Degree Days
Temperature Variable (TV)	Days per summer with TV >85°F
	Summer daily TV
Coastal Flooding	Projected sea level rise
	Inundation extent and depth
Inland Flooding	100- and 500-year floodplain extent
Wind	MIT projections of maximum hourly wind speeds
	Review of scientific literature for wind gusts

Hazard	Prioritized Variables
Extreme Events	Hurricanes and tropical cyclones
	Snow and ice
	Cold snaps and polar vortex events
	Drought
	Wildfire
	Lightning and tornadoes
	Multiple extreme weather events

Note: See the Study Appendix for all prioritized variables.

Table 2. Prioritized climate variables used in this Study, categorized by climate hazard.

Climate Data Results

The Study Team characterized historical and future changes in temperature, humidity, precipitation, sea-level rise, and extreme events within the O&R service territory. The sections below provide an overview of projected climate changes relevant to the O&R service territory, using projections for Mohonk and Dobbs Ferry as primary reference points.

Temperature

Columbia and NYSERDA projections show that climate change could increase both average air temperatures and extreme heat throughout the rest of the 21st century, relative to historical conditions (see Figure 5 below). Warmer temperatures are projected to lead to overall drier local conditions by increasing surface evapotranspiration.[xvi] This can lead to increasing frequency and intensity of droughts, particularly during the summer. Climate projections reveal increases in temperature as shown by the following sample temperature variables:

The maximum duration of heat waves over 95°F could reach 14 days and the hottest maximum temperature could reach up to 112°F in Dobbs Ferry by the 2080s.

- Projections show that, by 2050, the number of days per year when average temperatures exceed 86°F could reach up to 20 days per year from a baseline of 1 day in Dobbs Ferry, and up to 8 days per year from a baseline of 0 days in Mohonk.

[xvi] The process by which water is transferred from the soil to the atmosphere by evaporation and from plants to the atmosphere by transpiration.

- Projections show that, by 2050, maximum temperatures could exceed 95°F for up to 35 days per year from a baseline of 4 days in Dobbs Ferry, and up to 13 days per year from a baseline of 1 day in Mohonk (see Figure 5 (a) below).

Multi-day heat events, known as heat waves, can impact the electric system because they drive demand for air conditioning and stress the electric infrastructure. Projections show that the number of heat waves, defined here as 3 or more consecutive days when average temperatures exceed 90°F, could reach up to 3 events per year by 2080 in Dobbs Ferry, relative to a baseline of 0 events, and up to 2 events per year by 2080 in Mohonk, relative to a baseline of 0 events (see Figure 5 (b) below). Additionally, the maximum heat wave duration with maximum temperatures exceeding 95°F could reach up to 14 days per year by 2080 in Dobbs Ferry, relative to a baseline of 2 days, and up to 10 days per year by 2080 in Mohonk, relative to a baseline of 1 day (see Figure 4 (c) above). Furthermore, projections show that maximum temperatures could reach up to 112°F by 2080 in Dobbs Ferry and up to 108°F in Mohonk by 2080 (see Figure 5 (d) below).

Applying the Science to Vulnerability Assessment: Temperature

To use temperature projections in the vulnerability assessment, the Study Team selected the most relevant temperature variable for each asset group and evaluated exposure based on that variable. For example, knowing the number of days over 104°F per year is important for substations because transformers are designed with a reference temperature of 104°F, but for underground conductors, it is more useful to know how the average ambient temperature will change.

Additionally, projections show that the coldest minimum temperatures could increase to 15°F in Dobbs Ferry and 9°F in Mohonk by 2050, relative to baselines of 3°F and -5°F, respectively. However, these projections do not account for the possibility of future severe cold snaps, which are not fully captured by the climate models. Findings from the extreme weather events literature review show that complex processes amplified by climate change, such as Arctic amplification and a weakening of the polar vortex, could produce extreme cold snaps in the O&R service territory even though, on average winter temperatures are projected to be warmer.[19]

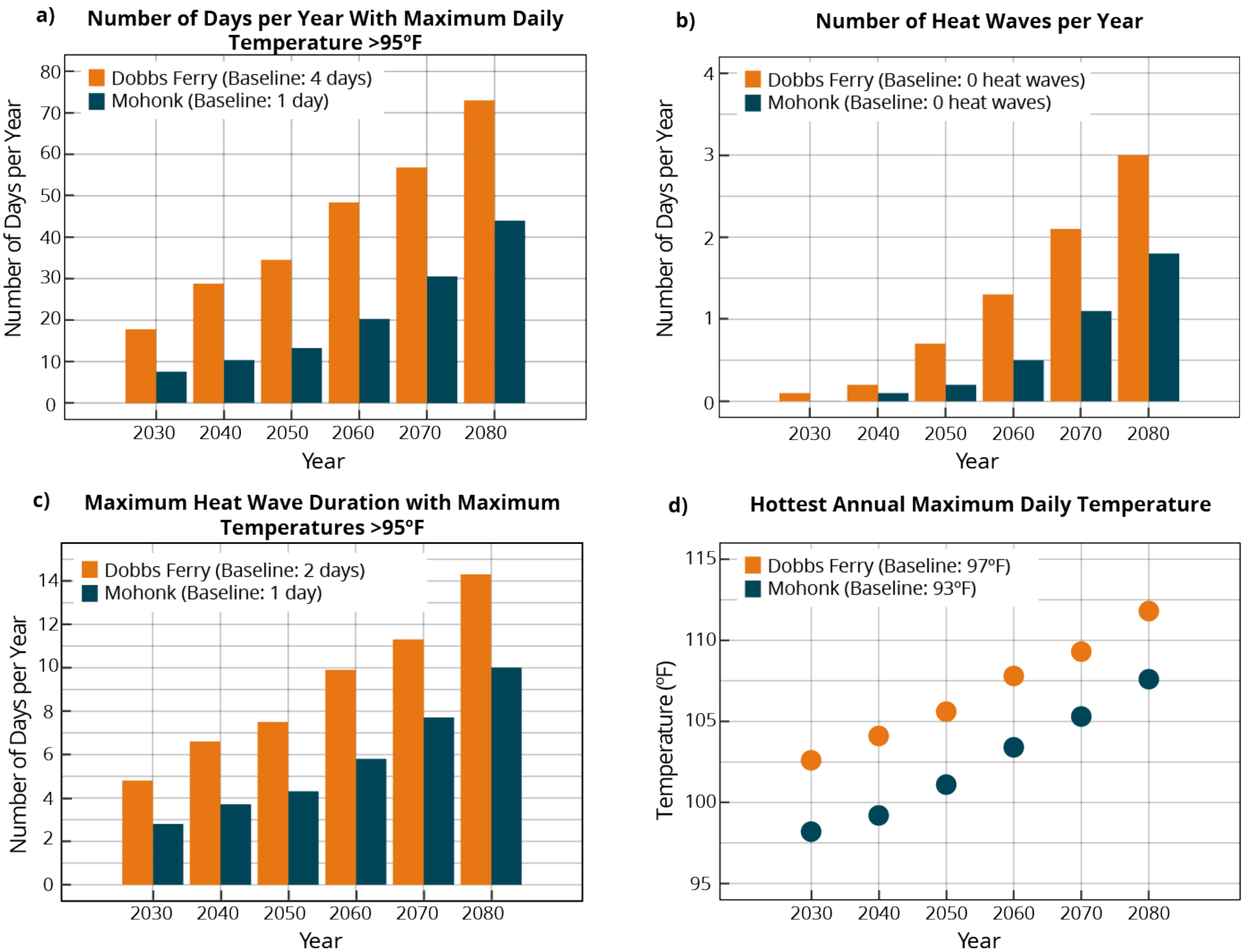


Figure 5. (a) Projected days with maximum daily temperatures exceeding 95°F in Dobbs Ferry and Mohonk, relative to a baseline of 4 days for Dobbs Ferry and 1 day for Mohonk. (b) Projected number of heat waves per year with ambient daily temperatures over 90°F in Dobbs Ferry and Mohonk, relative to a baseline of 0. (c) Projected annual maximum heat wave duration with maximum daily temperatures exceeding 95°F in Dobbs Ferry and Mohonk, relative to a baseline of 2 days for Dobbs Ferry and 1 day for Mohonk. (d) Projected hottest annual maximum daily temperatures in Dobbs Ferry and Mohonk, relative to a baseline of 97°F for Dobbs Ferry and 93°F for Mohonk.

Temperature, Humidity, and Peak Load

High heat and humidity make temperatures feel warmer, and, in turn, increase electric demand in a manner that cannot be captured by temperature alone. To address this, the Company currently evaluates the potential for high loads using an index referred to as TV,[xvii] which incorporates considerations of temperature and humidity.

Columbia and NYSERDA projections show that the average number of days per year with maximum summer daily TV exceeding 85°F at Mohonk and Dobbs Ferry could increase as early as 2030, relative to the historical baseline time period. Projections show that days with maximum summer TV exceeding 85°F could become more common (see Figure 6 below), relative to a baseline of 1 day per year in Dobbs Ferry and 0 days per year in Mohonk, occurring up to:

- **2050**:18 times per year in Dobbs Ferry and 14 times per year in Mohonk; and
- **2080**: 51 times per year in Dobbs Ferry and 43 times per year in Mohonk.

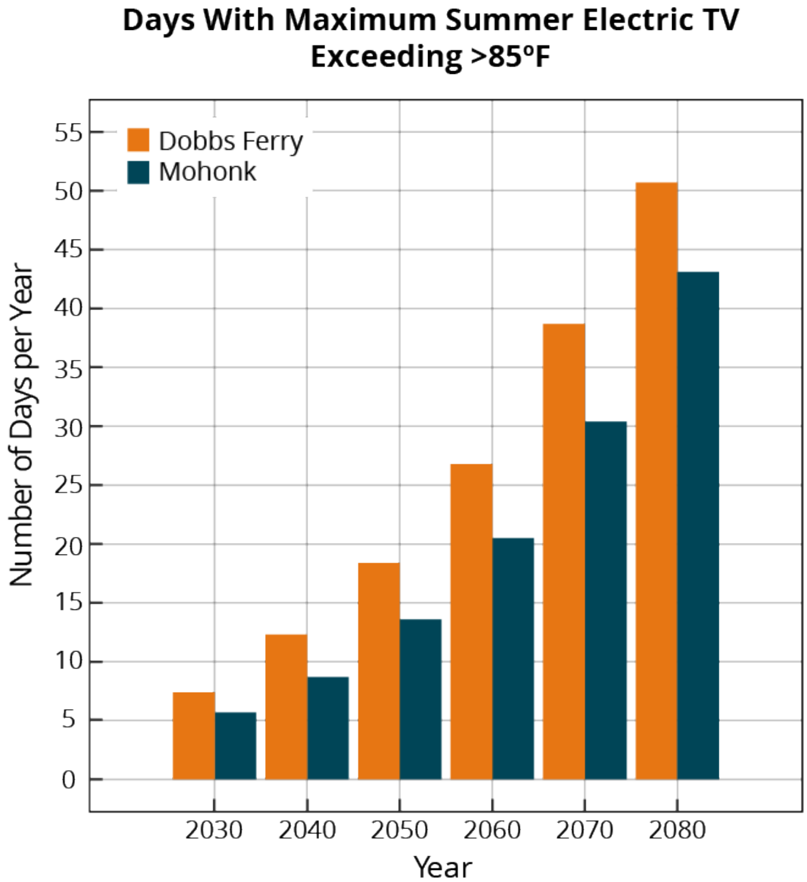


Figure 6. Projections for days with maximum summer TV exceeding 85°F in Dobbs Ferry and Mohonk, relative to a baseline of 1 day per year for Dobbs Ferry and 0 days per year for Mohonk.

[xvii] Temperature variable is calculated using the weighted time integration of the highest daily recorded 3-hour temperature and humidity over a 3-day period. The historical reference TV for O&R is 85°F, which approximates a heat index of 105°F.

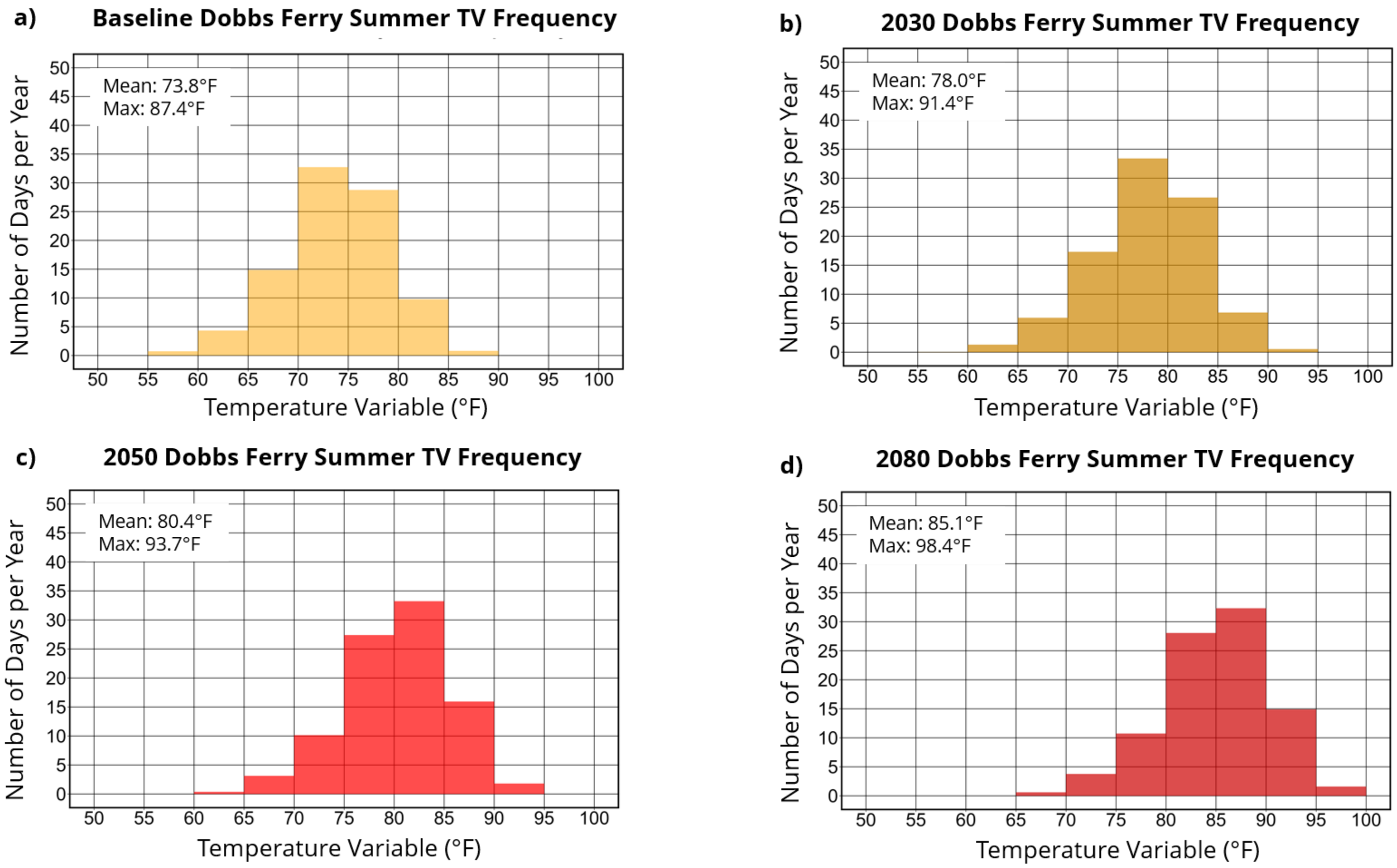


Figure 7. **(a) Distribution of historical summer daily TV at Dobbs Ferry. (b) Distribution of 2030 projected summer daily TV at Dobbs Ferry. (c) Distribution of 2050 projected summer daily TV at Dobbs Ferry (d) Distribution of 2080 projected summer daily TV at Dobbs Ferry. 2030,2050, and 2080 projections use the SSP5-8.5 75th percentile pathway.**

Figure 7 above and Figure 8 below show a positive (warming) shift in the Mohonk and Dobbs Ferry weather stations' summer daily TV distribution in 2030, 2050 and 2080 relative to historical baseline, leading to more days exceeding the historical maximum at both stations.

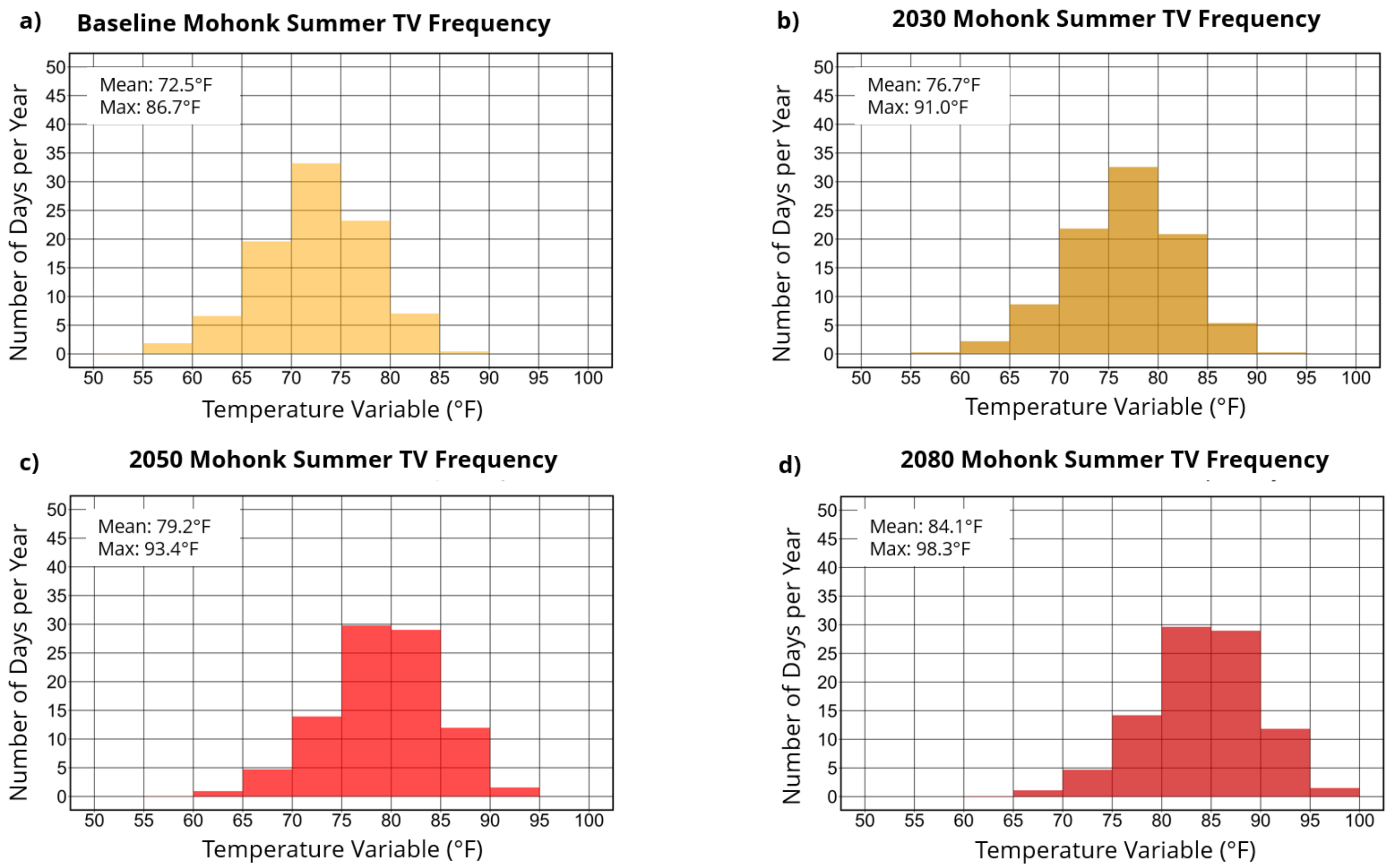


Figure 8. (a) Distribution of historical summer daily TV at Mohonk. (b) Distribution of 2030 projected summer daily TV at Mohonk. (c) Distribution of 2050 projected summer daily TV at Mohonk. (d) Distribution of 2080 projected summer daily TV at Mohonk. 2030, 2050, and 2080 projections use the SSP5-8.5 75th percentile pathway.

Cooling Degree Days ("CDD") and Heating Degree Days ("HDD") are defined as the cumulative sum of the difference between the average daily temperature and 63°F across the entire year (where a temperature above and below 63°F is considered 0 HDD and 0 CDD, respectively). HDD and CDD are used as indices for heating and cooling energy requirements, respectively, relative to outdoor air temperatures. At Dobbs Ferry, projections show that CDD could increase from a baseline of 1,602 per year up to 2,800 per year by 2050 and 3,785 per year by 2080. Projections show similar increases in CDD at Mohonk. Alternatively, projections show that HDD could decrease throughout the century as winters warm at both Dobbs Ferry and Mohonk, as shown in Table 3 below.

Applying the Science to Vulnerability Assessment: TV

To evaluate TV against O&R's assets, the Study Team looked at the number of days per year with summer daily TV exceeding 85°F.

Units	Location	Baseline	2030	2050	2080
CDD	Mohonk	1,402	2,078	2,542	3,598
	Dobbs Ferry	1,602	2,313	2,800	3,785
HDD	Mohonk	4,904	4,230	3,809	3,136
	Dobbs Ferry	4,230	3,576	3,181	2,552

Table 3. Projected number of CDD and HDD for Mohonk and Dobbs Ferry, relative to a baseline of 1,402 CDD and 4,904 HDD for Mohonk, and 1,602 CDD and 4,230 HDD for Dobbs Ferry.

Precipitation

Columbia and NYSERDA projections of maximum 5-day precipitation values provide insight into large, prolonged rainfall events that could swell rivers and streams, leading to adjacent flooding. Projections show that maximum 5-day precipitation could increase 13% (to 5.7 inches) by 2050 at Dobbs Ferry, relative to a baseline of approximately 5 inches. Similarly, maximum 5-day precipitation could increase 15% (to 6.0 inches) by 2050 at Mohonk, relative to a baseline of 5.2 inches. Days with more than 2 inches of rain in a 24-hour period, a relevant threshold for urban flooding and flash flooding after drainage systems are overwhelmed, are more closely related to flash flooding events, which can overwhelm drainage systems and cause urbanized flooding, as seen during Hurricane Ida in 2021. Projections show that the number of days per year with precipitation exceeding 2 inches could increase 44% (4 days) and 45% (5 days) by 2050 at Mohonk and Dobbs Ferry, respectively. The number of days per year with precipitation exceeding 2 inches could increase 78% (5 days) and 77% (6 days) by 2080 at Mohonk and Dobbs Ferry, respectively, relative to a baseline of 3 days. Overall, projections show that heavy precipitation in the O&R service territory could increase throughout the century, as shown in Figure 9 below.

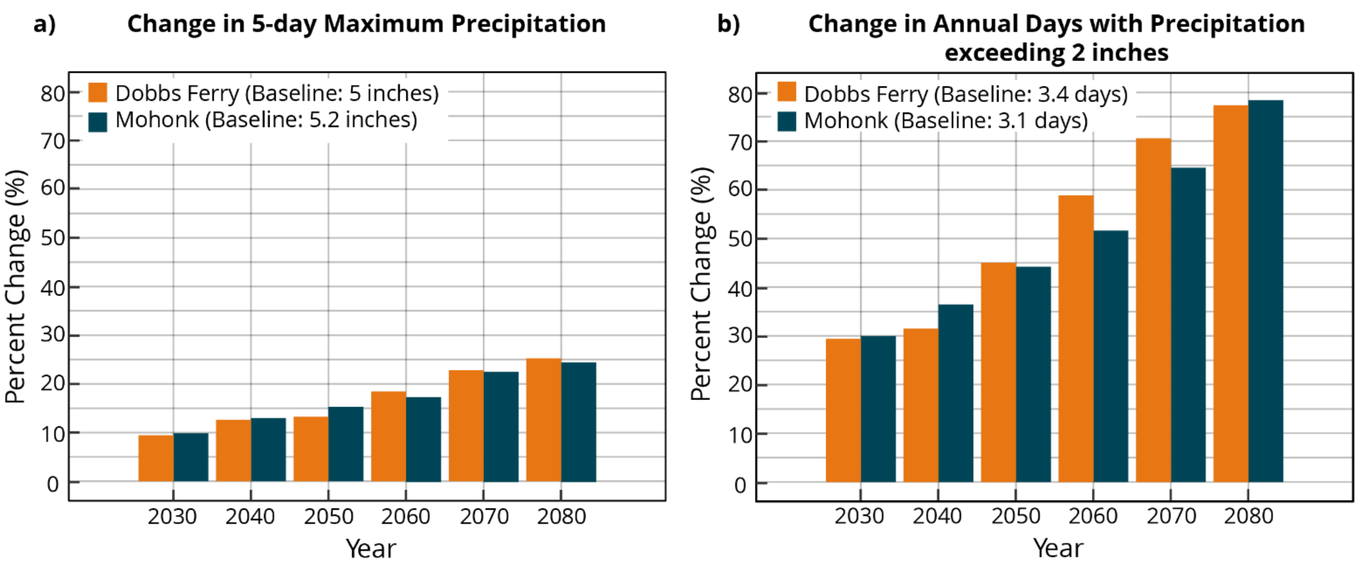


Figure 9. (a) Percent change in maximum 5-day precipitation at Dobbs Ferry (orange bars) and Mohonk (dark teal bars), relative to the baseline of 5 inches and 5.2 inches, respectively. (b) Percent change in annual days with precipitation exceeding 2 inches at Dobbs Ferry and Mohonk, relative to a baseline of 3.4 and 3.1 days, respectively.

The O&R service territory experiences different forms of precipitation, including rainfall and frozen precipitation (*e.g.*, snow, sleet, freezing rain). Climate change is projected to result in heavier precipitation because a warmer atmosphere holds more water vapor and provides more energy for storms, among other factors. Furthermore, studies agree that the O&R service territory is likely to see less snow in the future.[20, 21, 22] The Study Appendix provides supplemental information on historical data and future projections of snow, ice, cold snaps, and polar vortex events in the O&R service territory. Extreme Events also illustrate other extreme event hazards that could be impacted by future changes in precipitation in the O&R service territory, such as drought and wildfire.

Sea-Level Rise and Tidal Flooding

A range of underlying factors can result in sea-level rise, including the rate of ice loss from glaciers and ice sheets, thermal expansion of the ocean, atmosphere and ocean dynamics, and vertical coastline adjustments. Overall, sea-level rise is projected to increase the frequency and intensity of tidal flooding in the Company's service area (*i.e.*, along the Hudson River), even without the influence of changes in coastal storms. Projections show sea levels could rise 16 inches by the 2050s and 36 inches by 2100 relative to the historical baseline time period of 1995–2014 at the Battery tide gauge, as shown in Figure 10 below.[xviii]

Applying the Science to Vulnerability Assessment: Flooding

To evaluate vulnerability, the Study Team assessed precipitation, coastal flooding, and inland flooding together. Tidal flood risk was assessed using the Hudson River Sea Level Rise mapping tool, and inland flood risk was assessed using the Federal Emergency Management Agency's ("FEMA") flood insurance rate maps.

[xviii] Sea-level rise projections are relative to the Battery tide gauge in lower Manhattan, the closest tide gauge to the O&R service territory. The historical baseline time period is 1995–2014.

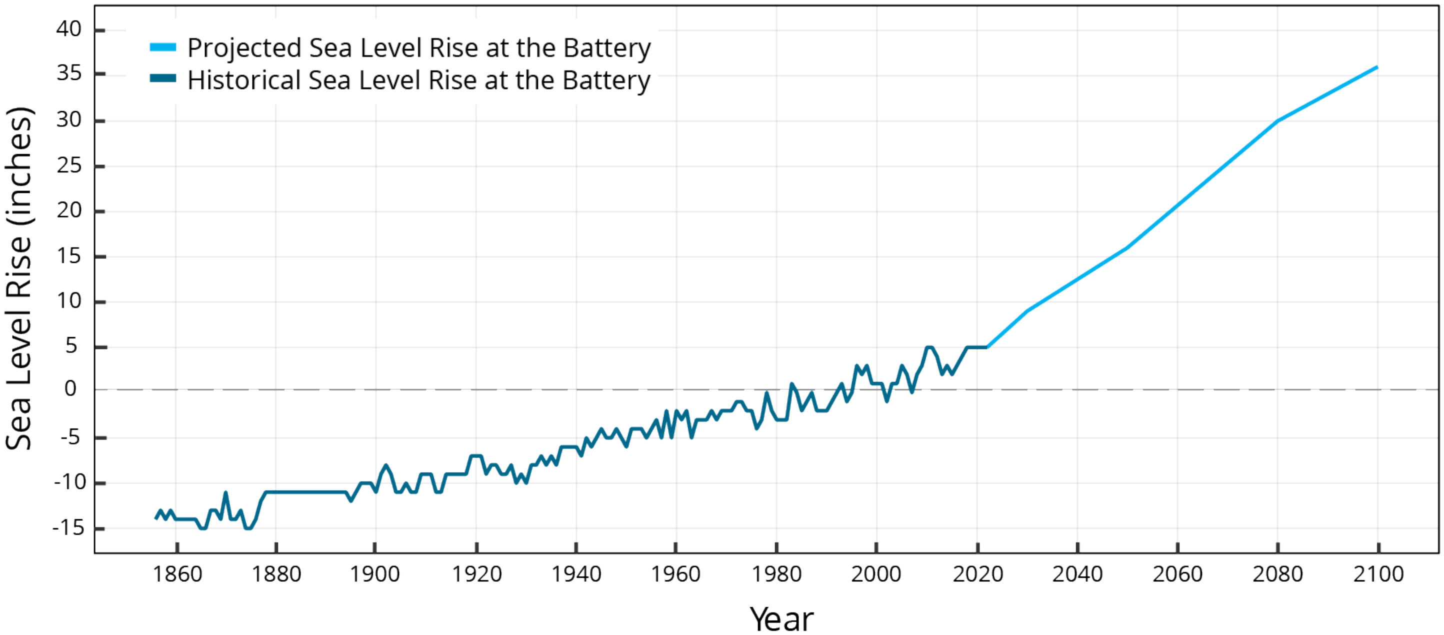


Figure 10. Historical and projected sea level rise at the Battery tide gauge in New York City ("NYC"). The dark blue line shows historical mean sea level at the Battery tide gauge (NOAA Tides & Currents).[23] The light blue line shows the 50th percentile of the merged SSP2-4.5 and SSP5-8.5 sea level rise projections relative to the Battery tide gauge, with a historical baseline time period of 1995-2014. Since 1992, the Battery tide gauge has experienced approximately 5 inches of sea-level rise.

Sea-level rise will result in heightened and more permanent flooding along the banks of the Hudson River, which may increase the perpetual inundation of coastal O&R assets. Future Hudson River 100-year tidal floods along with sea-level rise are projected to affect the Lovett substation.[xix] The projected increased frequency and intensity of severe coastal storms will also result in deeper and more extensive flooding, especially when coupled with sea-level rise. The combined effects of sea-level rise and storm surge can permanently shift riverbanks inland and result in added inundation of O&R assets.

The Study Team used the Hudson River Sea Level Rise Mapper to analyze future flood depths and extents along the Hudson River, as a result of sea level rise and storm surge.[24] The tool was developed to inform municipal planning decisions and convey flood depths along the Hudson River at a high resolution, for specific sea-level rise increments and storm scenarios. The Study Team leveraged Columbia and NYSERDA sea-level rise projections at the Battery (see Figure 10, above), and paired these with the 100- and 500-year storm surge scenarios to model coastal floodplains in the O&R service territory into the future.

Inland Flooding

Several river systems run through the O&R service territory, including the Neversink, the Wallkill, the Ramapo, and the Hudson. During and after periods of high precipitation, these rivers have

[xix] Future 100-year inland flood is approximated by the current 500-year inland flood.

the potential to overflow and inundate surrounding areas. Riverine floodplains are low-lying areas adjacent to rivers that are susceptible to flooding during a storm or high-precipitation event. FEMA 100- and 500-year floodplains refer to the areas of land that are flooded during the 100-year (*i.e.*, 1% annual chance) flood event and the 500-year (*i.e.*, 0.2% annual chance) flood event. These floodplain extents do not account for expected changes in future flooding.

The FEMA 100- and 500-year inland floodplains extend throughout the O&R service territory, with the largest and deepest areas of flooding occurring adjacent to river systems. O&R leveraged the FEMA flood data for Orange, Rockland, and Sullivan Counties to generate flood depth grids with a combination of the FEMA Base Flood Elevation ("BFE") data and high-resolution county Digital Elevation Models ("DEMs"). Figure 11 shows an example depth grid adjacent to O&R's Hartley Road Substation in Orange County.

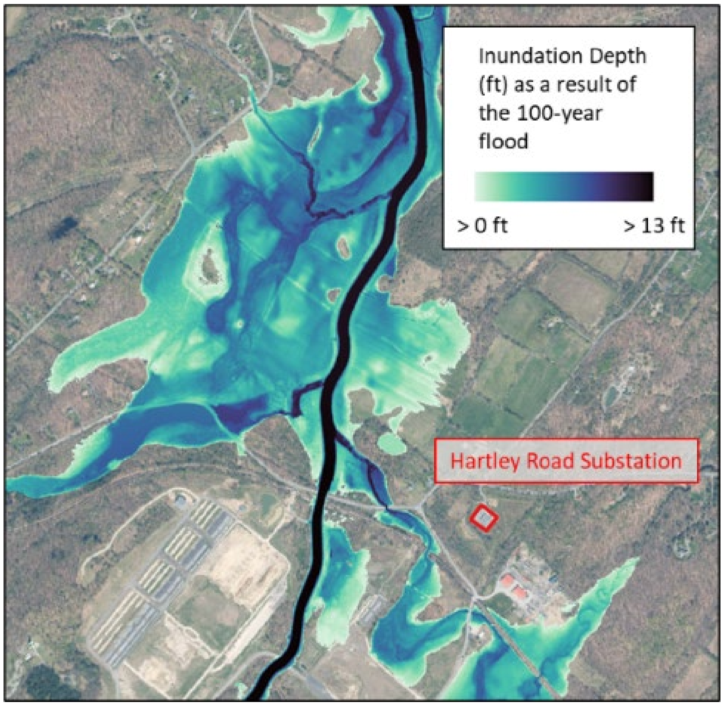


Figure 11. **100-year inland flood depths in an example floodplain adjacent to Hartley Road Substation, located in Orange County**

In the future, increased precipitation rates from tropical cyclones could lead to a greater risk of inland flooding. Given that the FEMA floodplains are not forward-looking, the present-day 500-year floodplain has been selected to represent the 100-year floodplain for a future with increasing precipitation intensity. The 500-year floodplain shows more extensive flooding throughout the O&R service territory than does the 100-year floodplain, and the highest levels of flooding remain adjacent to river systems.

Wind and Ice

Overall, O&R is likely to experience higher wind speeds and gusts during tropical cyclones, extratropical cyclones, and thunderstorms in the future[25] and the potential exists for increased radial icing intensity. Historically, strong winds associated with extreme weather events, such as hurricanes, thunderstorms, and extra-tropical cyclones, have posed a risk to the O&R service territory. These types of weather events are projected to become more intense (*i.e.*, produce stronger winds) in the future.[26] The Study Appendix illustrates recent historical hurricanes and their associated wind speeds.

Similar to hurricanes, nor'easters have historically been responsible for high winds, although not as extreme as hurricane winds impacting the service area, and they are projected to increase in the future. The Study Appendix illustrates recent historical nor'easters and their associated wind speeds.

In addition to the NYSERDA/Columbia climate data, O&R referenced a granular localized weather projection data set, developed by MIT, for informational purposes. This dataset ("the MIT data") contains projections for several hazards that were not available in the Columbia data, such as wind. The MIT data provide complementary insights to the NYSERDA/Columbia data with localized projections, on hourly time resolution, of wind and ice in the O&R service territory. Although limitations exist, the MIT data provide additional snapshots of climate change in the near future to help understand potential risks.

Limitations of the MIT data include future projections through only 2041 (instead of 2080 from the Columbia dataset), a single GCM and emissions scenario of the CMIP5 RCP 8.5, and limited baseline comparison with O&R weather stations. Furthermore, the MIT data does not account for low-frequency and high-impact storm event types, such as tropical cyclones, and may not be fully calibrated for all extreme variables (*e.g.*, deluge precipitation).

Applying the Science to Vulnerability Assessment: Wind

The Study Team evaluated projected changes in average wind speed, as well as expected changes in likelihood of extreme wind events, such as hurricanes.

The most common wind speeds between 2025 and 2041 at White Plains (the closest applicable station for this data set) are between 11 and 17 mph, with peaking speed at 53.4 mph (see Figure 12 below). The wind speed distribution shows a large range of higher wind speeds at White Plains in the MIT data. The strongest wind in the future projections occurs in the summer. Overall, the strongest winds are projected to occur during the winter months in the Northeastern United States. These winds are typically associated with strong polar cold fronts.

Table 4 below summarizes the 2025–2041 projected 1-in-5, 1-in-10, and 1-in-20-year wind speeds at the White Plains, Newburgh, Montgomery, Sussex, and Poughkeepsie weather stations based on the MIT data. The 1-in-5-year return period winds are projected to be between 38.4 and 45.1 mph for the analyzed stations, the 1-in-10-year return period winds between 41.5 and 48.4 mph, and the 1-in-20-year return period winds between 43.1 and 52.4 mph. Overall, White Plains is projected to have the strongest return period winds, with Newburgh and Poughkeepsie projected to have relatively weaker return period winds.

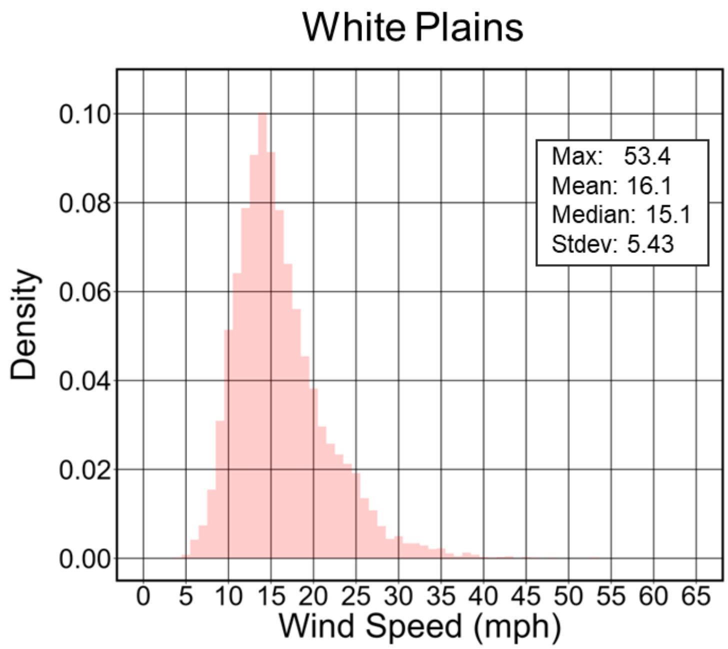


Figure 12. **A histogram of projected maximum daily wind speeds from 2025 to 2041 at White Plains, New York.** The maximum, mean, median, and standard deviation (stdev) can be seen in the top right corner of the figure.

Return Period Wind Speed	White Plains	Newburgh	Montgomery	Sussex	Poughkeepsie
1-in-5-Years	45.1	38.4	41.6	42.7	39.6
1-in-10-Years	48.4	41.9	44.4	45.7	41.5
1-in-20-Years	52.4	46.3	47.6	49.7	43.1

Table 4. **Summary of 2025–2041 Projected Return Period 1-Minue Sustained Wind Speeds (mph).**

Scientific literature, including the Fourth National Climate Change Assessment and reports by the New York City Panel on Climate Change, indicates that winds are projected to become more intense, with higher wind speeds in the future largely due to more intense storms.[27, 28, 29] Warming atmospheric and ocean surface temperatures will likely lead to more intense tropical cyclones in the North Atlantic, characterized by an increased frequency of major (Category 3+) hurricanes and a northward migration of hurricane intensity.[30, 31] Warming temperatures and increased moisture availability could also result in more favorable conditions for severe weather during the warm season and increased potential for thunderstorm activity and resulting extreme wind events.[32]

While scientific research is aligned on an increase in extreme wind projections, the magnitude of projected increases in future wind speeds have not reached a consensus due to uncertainty related to both modeling and physical processes. Potential changes in wind speeds provided in scientific literature include:

- Average hurricane maximum wind intensity (winds greater than 33 m/s or approximately 78 mph) could increase up to 2% in the near-term (2016-2035) and 4% by late-century (2081-2100);[33, 34]
- Maximum wind gusts in NYC could increase from 80 mph to 110 mph by mid-century;[xx, 35]
- The 1-in-700-year return period wind speed in NYC is projected to increase from 115 mph to 124 mph by mid-century;[36]
- Both average and maximum low-level wind speeds (10-meter height) associated with moderate extra-tropical cyclones are projected to increase by approximately 3-4% by the end of the century;[37]
- The number of days with conditions favorable for severe thunderstorms could double in NYC by late 21st century under a high emissions scenario;[38] and
- On average globally, environments favorable for thunderstorm development could increase in frequency by 5-20% per 1 ˚C warming.[39]

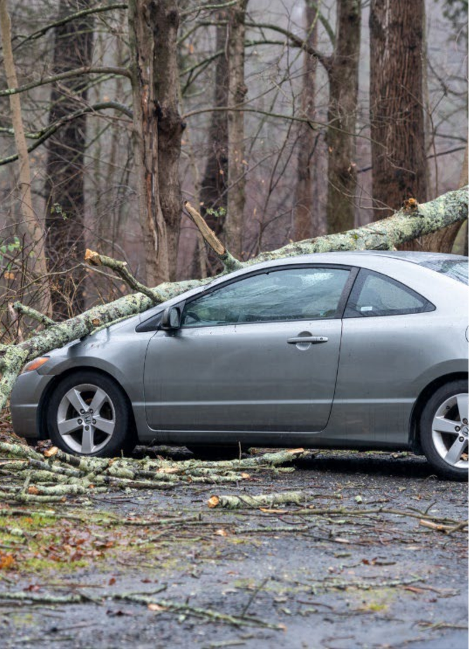
O&R's design standards for wind also include considerations of ice because both add stress on overhead equipment. Freezing rain is relatively common during winter months, but intense ice storms are rare. These events in the past have produced total ice accumulations of up to 2 inches, lasting from a few hours to upwards of five days. Impacts have ranged from a few hours to over 2 weeks after storms pass, especially when followed by a prolonged cold spell.[40] Table 17 below illustrates historical analogs for ice storms impacting the O&R service territory, as well as historical ice storms in surrounding areas.

Projections for the influence of climate change on ice storms are difficult to resolve and remain highly uncertain due to the specific atmospheric conditions required for ice storms to occur relative to other high-impact hazards.[41] The MIT data, however, does provide some useful insights. Annual radial icing (*i.e.*, the sum of all radial icing over the year) projections from the MIT data for White Plains show high interannual variability in both total radial icing accumulation and the number of hours of radial ice accumulation (see Table 4 below). Projections also show the potential for icing on occasion, as shown in the MIT projections for the years 2030 and 2040 in Table 4 below. Additionally, a review of the scientific literature demonstrates the potential for increased freezing rain frequency and ice accumulation in the region.[42]

[xx] While the study cited here was performed for New York City, it represents the closest geographic area with available projections. O&R's service territory is directly adjacent to New York City, and therefore should be impacted by similar trends.

Year	Total Annual Radial Icing over the Year (in.)	Number of Hours with Radial Ice Accumulation
2025	0.21	29
2026	0.05	7
2027	0.08	3
2028	0.07	11
2029	0.08	5
2030	0.76	28
2031	0.00	0
2032	0.06	3
2033	0.05	13
2034	0.04	3
2035	0.00	0
2036	0.17	6
2037	0.59	27
2038	0.11	10
2039	0.13	14
2040	0.96	58
2041	0.48	18

Table 5. **MIT data projections of annual radial icing totals (inches) and number of radial icing hours at White Plains.**



Extreme Events

Extreme weather events, including concurrent or consecutive extreme events, present unique challenges to operations, planning, and infrastructure across the electric system. Climate models have difficulty resolving extreme weather events due to the small space and time scales at which these events occur, as well as the rarity of the events themselves, necessitating an evaluation of extreme events using historical analogs and projections from the scientific literature. The current assessment focuses on hurricanes and tropical cyclones, snow and ice, cold snaps and polar vortex events, drought, wildfire, and lightning and tornadoes using findings from the most recent scientific literature. Table 6 below summarizes findings from the climate projections in Climate Data and Future Projections and the literature review on historical information and future projections of extreme events in the O&R service territory.

Extreme Event	Future Frequency	Future Intensity
Hurricanes and tropical cyclones	Unchanged	Increase
Snow and ice	Decrease	Increase
Cold snaps and polar vortex events	Decrease	Potentially Increase
Lightning and tornadoes	Potentially Increase	Potentially Increase
Drought	Increase	Increase
Wildfire	Increase	Increase
Multiple extreme weather events	Increase	Increase

Table 6. **Summarized future changes in frequency and intensity of extreme events in the Orange & Rockland service area.**

Hurricanes and Tropical Cyclones

Hurricanes, also referred to as tropical cyclones, are rapidly rotating low-pressure systems that produce extreme precipitation, high winds, and coastal storm surge. They are classified according to their intensity and wind speed, with Category 1 and Category 5 hurricanes which have minimum sustained winds of 74 mph and 157 mph, respectively.

Historical Information

The remnants of Hurricane Ida in 2021 brought flash flood and tornado warnings to the service area, causing transit shutdowns, widespread flooding, and extensive power outages.

Landfalling tropical cyclones in New York are rare (see the Study Appendix), as prevailing westerly winds over land generally steer hurricanes away from the coast as storms approach the Northeastern United States. When tropical cyclones do make landfall in New York, they typically approach the region from the southern Atlantic Ocean during the warmer months of July to October. Severe impacts can extend farther inland, as evidenced by Hurricane Irene and Tropical Storm Lee in 2011, which brought heavy rainfall and flooding into upstate New York. Additionally, after the remnants of Hurricane Ida hit the Northeast in 2021, an EF3 tornado hit Mullica Hill, New Jersey, and the first tornado emergency of its kind was issued in the Northeast.[43] Overall, New York has experienced 15 landfalling hurricanes (three of which were a major category 3 intensity or higher) from 1851 to 2020.[44] However, these storms have resulted in large impacts in recent years.

Future Projections

Projections show that warming atmospheric and ocean surface temperatures will likely invigorate hurricanes in the North Atlantic to become more intense (~5% increase) and have higher rainfall amounts (~10% to 15% increase) relative to historical hurricanes.[45, 46, 47] Increasing storm intensities imply stronger hurricane winds and, in turn, coastal storm surge. As a result, the frequency of strong storms will likely increase in the North Atlantic.[48, 49, 50] Projections and recent historical trends also show a northward migration of the location of maximum hurricane intensity, increasing the likelihood that a hurricane exceeding Category 3 status could make landfall in the O&R service territory in the future.[51, 52] At the same time, models of future hurricane activity in the North Atlantic suggest overall hurricane frequency will most likely remain the same or decrease slightly under average 21st century climate change projections,[53, 54] however this finding has been contested by studies that show a marked increase in the frequency of tropical cyclones globally through the end of the 21st century.[55] Ultimately, while the total number of hurricanes occurring in the North Atlantic may not change significantly over the next century, the percentage of very strong and destructive (*i.e.*, Category 4 and 5) hurricanes is projected to increase, confirmed by the latest IPCC Assessment Report.[56]

Snow and Ice

Nor'easters, also referred to as extratropical cyclones, are low-pressure systems driven by the convergence of cold polar air from Canada and warm air over the Atlantic Ocean. Nor'easters present a range of risks to the O&R service territory, including extremely heavy precipitation, hurricane-force winds, and coastal flooding. When an intensifying nor'easter interacts with cooler arctic air transported from Canada via the polar jet stream, snow, icing and strong winds can occur.

Ice storms often occur when the vertical temperature profile of the atmosphere reaches specific atmospheric conditions. Freezing rain typically occurs during temperature inversions, as warm air moves over colder, shallow air, thus creating conditions for precipitation to fall as a liquid and freeze on or near the surface. In New York, a typical ice storm may occur when a warm air mass travels from the south (originating near the Mississippi Valley) and intersects cold air as it travels towards the north.[57, 58]

Historical Information

The December 2020 nor'easter brought heavy snowfall, freezing rain, and up to a ½ inch of ice to the service area, causing power outages and damage from New Jersey to New York.

Historically, nor'easters are responsible for some of the heaviest snowfall on record in the service area, as well as extreme winds, coastal storm surge, and ice. From 1798 to 2021, the greater NYC region has experienced 29 snowstorms, each with snowfall totaling 15 inches or more.[59] The Northeast Snowfall Impact Scale ("NESIS"), developed by the National Climatic Data Center, characterizes and ranks high-impact Northeast snowstorms with large areas of snowfall accumulations of 10 inches or greater, using population data and meteorological measurements. The Study Appendix highlights recent historical analogs for high-impact nor'easters. Of note are the January 2016 and December 2020 storms that produced up to 24 inches of snow and blizzard conditions (*e.g.*, over 40 mph wind gusts) in the O&R service territory.

New York State experiences ice storms on an annual basis, recording an average of approximately 3-7 days with freezing rain per year, but the state has experienced up to 14 days with freezing rain in a year between 1948 and 2000.[60] Freezing rain has occurred in New York State as early as October and as late as April, with the greatest probability of occurrence in January. Historically, storms generating freezing rain originate in the South-Central United States, gathering moisture from the Gulf of Mexico or the Atlantic Ocean as the system tracks northeastward. While freezing rain is relatively common during winter months in the service area, intense ice storms are exceedingly rare (see the Study Appendix). These storms have produced total ice accumulations of up to 2-5 inches, lasting from a few hours to upwards of five days, leading to short-term (a few hours) and long-term impacts (>2 weeks) after storms pass, especially when followed by a prolonged cold spell.[61]

Future Projections

Studies agree that the O&R service territory is likely to see a shorter snow season, reduced snow cover and snow depth, and fewer snow events in the future. Models project that snowstorms are expected to decrease in frequency over the coming century in a warming climate.[62] This decrease is nonlinear across storm intensity: larger for less intense storms impacting small areas than for intense storms producing heavy snowfall and outsized impacts for large urban areas, including the O&R service territory.[63] This means that while the likelihood of a given nor'easter producing snow instead of rain is projected to decrease in the future, storms could produce more snow (or ice) than in the present day if atmospheric conditions are cold enough to support frozen precipitation.[64] Because a warmer atmosphere can hold more moisture, the largest snow events could produce increased snowfall totals.[65, 66]

As temperatures warm over New York State, the number of hours of freezing rain are also projected to decrease,[67] as the likelihood of more extreme freezing rain events shifts farther north into Canada.[68, 69] This is consistent with recent trends toward a gradual northward migration of the rain-snow transition zone across the United States.[70]

It is important to underscore that the findings highlighted here are drawn from a small set of research studies, and new research is needed to verify their results. Winter storms are highly sensitive to a range of underlying factors, including sea surface temperatures, jet stream activity, and land/atmosphere heat exchange, which remain difficult to incorporate into climate models. Thus, there is large uncertainty associated with future changes in winter storms.

Cold Snaps and Polar Vortex Events

Extreme cold events, often referred to as cold snaps, generally occur in New York State when extreme cold, polar air from Canada protrudes into the Northeast United States due to an unstable polar vortex or from northerly atmospheric circulation (winds) in the wake of a passing winter storm. An unstable polar vortex results from sudden stratospheric warming in the Arctic, which splits or weakens the vortex, allowing polar air to extend farther south into the northeastern United States.[71] Extreme cold snaps also can occur on the backend of significant winter storms. Passing winter storms circulate in a counterclockwise rotation while approaching from the west, leading to wind from the south on the leading edge of the storm and winds from the north on the backend. The northerly winds lead to cold air advection, or influx, of cooler air from Canada into New York and New Jersey. Extreme cold following an ice storm can exacerbate the impacts of the ice storm, preventing ice accumulation from melting and prolonging the impacts of the storm.

Historical Information

The coldest temperature recorded in Port Jervis was -26°F in 1912.

Extreme cold events are relatively common in New York State. Cold snaps can cause minimum temperatures in the single digits or below in southern New York. Some of the coldest temperatures recorded in the O&R service territory were -26°F at Port Jervis in 1912, -20°F at Mohonk Lake in 1934, and -10°F at Dobbs Ferry in 1994.[72] Often accompanying the cold snaps are stronger than average winds, and wind chill values can drop below 0°F for large portions of the O&R service territory during a significant event. Even if no precipitation occurs with extreme cold events, the below average temperatures and strong wind fields can cause many issues, including loss of power during times of high energy demand.

Future Projections

Climate change is projected to warm winter temperatures and reduce the overall frequency of cold snaps. However, climate change does not preclude the occurrence of cold snaps and some evidence shows that complex processes amplified by climate change could worsen some cold snaps, such as polar vortex events. Climate change is causing the Arctic to warm more quickly than lower latitudes (a phenomenon referred to as arctic amplification), which reduces the temperature gradient between high and mid latitudes. Some studies suggest that polar vortex events over the northeastern US may occur more frequently due to reduced sea ice and snow cover in the Arctic weakening the confinement of the polar vortex.[73, 74, 75] One such study proposed that extreme cold air outbreaks, possibly punctuated by widespread snow events, may become more common as high-latitude regions warm, due to resulting changes in the jet stream.[76, 77] A more recent study focused on polar vortex events dating back to the 1980s, links changes in the climate of the Arctic to the weakening of the polar vortex, which may encourage outbursts of Arctic air into the mid-latitudes.[78]

However, many climate scientists argue that even if cold snaps occur more frequently, there is high confidence that the Arctic is warming and, therefore, the cold air outbreaks will become warmer over time as well. Additionally, scientists argue that a longer record is needed to support research linking Arctic amplification to cold snaps. Ultimately, the relationship between the warming arctic and cold air outbreaks, particularly those affecting the Northeastern US, is still uncertain and more research is needed to improve model projections.[79]

Lightning and Thunderstorms

Thunderstorms develop when an unstable atmosphere leads to convection, or upward motion resulting from surface heating, in the lower atmosphere. Thunderstorms most commonly occur during the warmer afternoon and evening hours of the spring and summer months. There are several types of thunderstorms, including single-cell or supercell thunderstorms, squall lines, mesoscale convective systems ("MCS"), and derechos. An MCS, for example, is an organized complex of thunderstorms often acting as a single system that spans approximately 100 km and can spawn multiple types of severe weather including, but not limited to: squall lines, gust fronts, and tornadoes.[80] A derecho, which is a widespread, long-lived, and straight-line windstorm that is associated with a band of rapidly moving showers or thunderstorms, results from the violent outflow of an MCS, though they are not common. All thunderstorm types can lead to wind, flood, lightning, and hail damage over varying spatial scales.

Historical Information

In July 2023, severe thunderstorms brought damaging lightning and heavy rainfall, causing widespread power outages.

Thunderstorms can occur any time of the year in the O&R service territory but are most common during the warmer months of March through October. Thunderstorms are typically 15 miles in diameter and last an average of 30 minutes. Despite their small spatial and temporal size, they are still dangerous.[81] All thunderstorms produce lightning, which kills more people nationally each year than tornadoes. Other dangers associated with thunderstorms include strong winds, hail, flooding, and tornadoes. Flash flooding is the leading cause of death associated with thunderstorms, causing more than 140 fatalities each year.[82] New York State is considered to have a "moderate" occurrence of lightning, with 3.8 strikes occurring per square mile per year[83]. Most recently, severe thunderstorms in July 2023 caused numerous power outages in the O&R service territory due to damaging lightning, heavy rainfall, and downed trees.[84]

Future Projections

Projections of lightning and thunderstorms are highly uncertain, but some studies do suggest that these phenomena could increase as global mean temperatures continue to warm. Global mean temperatures are projected to increase due to increases in greenhouse gas concentrations by the end of this century, which are coupled with an anticipated increase in atmospheric water vapor and the potential intensification of precipitation.[85] These conditions could increase the frequency and intensity of thunderstorms and, therefore, lightning.

One study used GCMs and a high-resolution regional climate model to examine severe thunderstorm environmental conditions, which was used as a proxy to represent the number of days in which thunderstorms could form locally and potentially produce surface winds, hail, or tornadoes. That study found a net increase during the late 21st century in severe thunderstorm environmental conditions, attributed primarily to increases in atmospheric water vapor. The largest increases were shown during the summer months in the Gulf of Mexico and in Atlantic coastal regions, with a suggested future increase of 100% or more in days with environment conducive to severe thunderstorm development in New York.[86] Another study modeled the frequency of lightning strikes across the continental US and predicted that the number of lightning strikes could increase by approximately 12% for every degree Celsius of warming in global average air temperature.[87] This research suggests that the O&R service territory could see more lightning and thunderstorms as temperatures continue to warm.

Overall, thunderstorms and associated severe weather are projected to increase in frequency due to climate change. A signature indicator of severe weather is the amount of energy within the atmosphere produced by convection; in meteorology this is known as Convective Available Potential Energy ("CAPE"). As CAPE values increase, so too does the likelihood of severe weather, including the likelihood of thunderstorms, tornadoes, and lightning. Several studies have analyzed late 21st century climate and found increasing CAPE values mainly due to increasing moisture availability with higher surface temperatures.[88, 89, 90, 91] This future increase in CAPE, and thus favorable environments for severe weather formation, is most evident in the summertime when surface air temperature is warmest.[92]

Although CAPE is projected to increase, another severe weather variable, wind shear, is projected to decrease under future climate warming scenarios, mainly due to the reduction of the temperature gradients between the equator and poles.[93, 94, 95] Wind shear, changes in wind speed and/or direction with height that facilitate thunderstorm intensification, is notably important for the development and intensity of tornadoes and hail.[96] However, recent research suggests increases in atmospheric instability could influence projected trends and lead to more frequent severe thunderstorms.[97, 98]

The impacts of climate change on lightning strikes are poorly constrained, but a growing body of research suggests that the frequency and density of lightning could increase in the future across the continental United States. Historically, the lightning flash rate is roughly proportional to CAPE times the precipitation rate.[99] Based on this relationship, forward-looking simulations of CAPE and precipitation rates using an ensemble of 11 GCMs and RCP 8.5 drive an approximate 50% increase in lightning strikes across the US by 2080 relative to 2000, or about 12 ± 5% per degree Celsius of warming.[100] Another study found consistent results of an approximate 3%–14% increase in total lightning strikes across the continental per degree Celsius of warming under RCP 8.5.[101]

Drought

Drought is a prolonged period of dry weather caused by a lack of precipitation and warmer temperatures, resulting in a serious water shortage that could impact operations, populations, and ecological systems.[102] The U.S. Drought Monitor ("USDM") categorizes expert assessments of conditions related to dryness and drought, including observations of how much water is available in streams, lakes, and soils compared to average conditions for the same time of year.[103]

United States Historical Information

During the week of September 6, 2016, a drought of level 3 (extreme drought) affected 9.94% of New York State.

While the Northeast is generally a wet region that has had substantial increases in mean precipitation over past decades, it has also experienced damaging droughts and water warnings and emergencies.[104, 105] The 1960s drought impacted most of the northeastern United States between 1961 and 1969, particularly during the spring season. Studies have shown that it was the most severe drought in the region in the last few centuries.[106] From 1901-2015, there has been less frequent drought, although variability in water balance has increased and the duration and intensity of droughts that do occur has not changed significantly.[107] The USDM shows that the longest drought in New York State lasted 64 weeks, beginning on June 23, 2020, and ending on September 7, 2021. The most intense period of drought occurred the week of September 6, 2016, where a drought of level 3 (extreme drought) affected 9.94% of New York State.[108]

Future Projections

Despite the high confidence that heavy precipitation events in the Northeastern United States have increased in intensity and frequency since 1901,[109] the frequency and intensity of major droughts are projected to increase due to a combination of warmer temperatures leading to greater evapotranspiration and changing precipitation patterns leading to drier soil moisture.[110, 111] By the end of the 21st century, the effect of higher temperatures on evaporation is expected to outweigh the increase in precipitation, especially during the summer months, and this trend is expected to lead to an increased frequency of droughts, although the timing and magnitude of these drought projections are marked by relatively large uncertainty.[112]

Ultimately, studies suggest that the occurrence of drought in the O&R service territory could increase in the future due to climate change, but these projections are characterized by a high degree of uncertainty. Warming temperatures will increase the likelihood of severe drought should prolonged periods of reduced precipitation occur in the future.

Wildfire

Wildfires, also called forest fires, are unplanned or unwanted fires burning vegetation often in arid, or dry, landscapes. They may occur naturally from lightning, but human activities are the predominant cause of wildfires.[113] The risk of wildfire is exacerbated by periods of drought (highlighted in Drought above) which reduces fuel moisture and increases the aridity of landscapes. Fuel moisture refers to the amount of water within organic material, and it is controlled by seasonal, daily, and immediate weather changes, such as drought. Fuel moisture content limits fire propagation. When fuel moisture content is high, fires are difficult to ignite, and burn poorly, if at all. When fuel moisture is low, fires start easily, and wind and other driving forces may cause rapid and intense fire spread.[114]

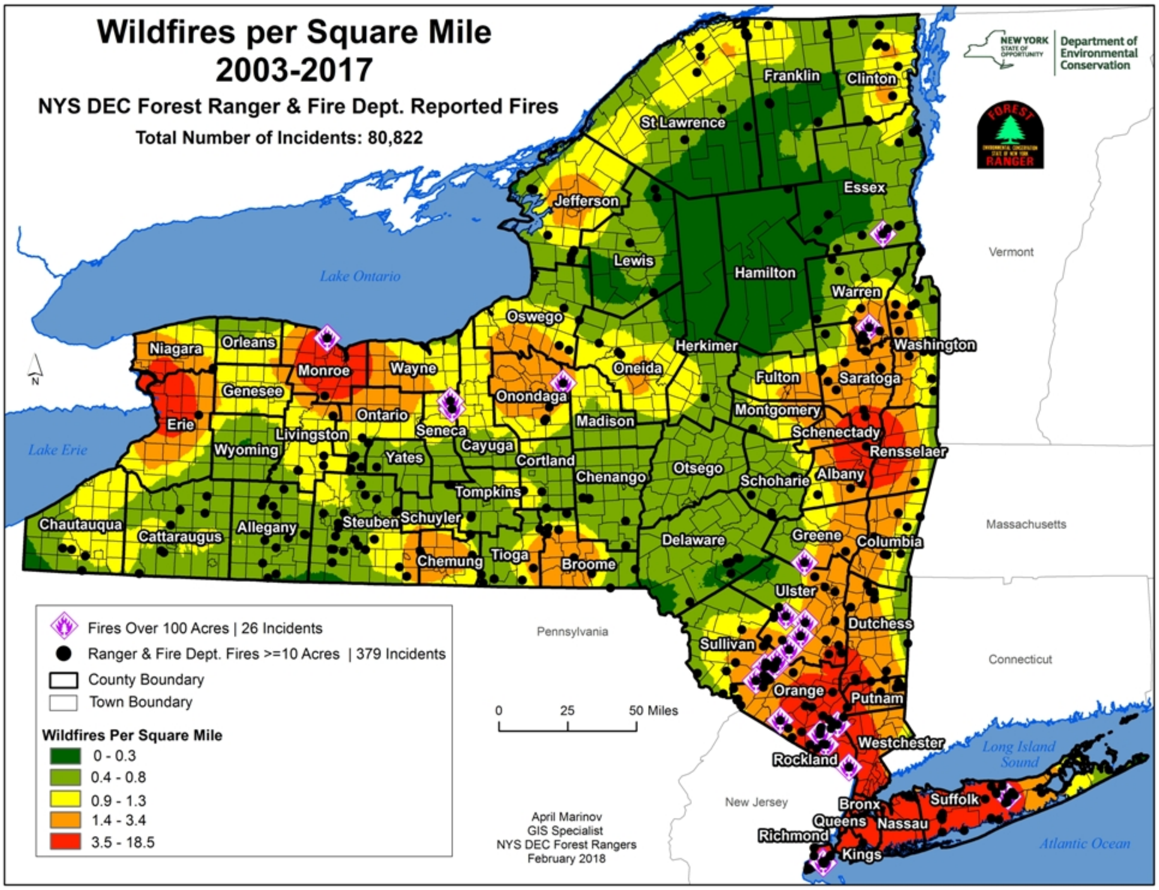
Historical Information

New York State is 30.9 million acres in size of which 18.9 million acres are non-federal forested lands, with an undetermined amount of open-space non-forested lands with wildfire potential.[115] Between 1891 and 2018, an average of approximately 776 wildfires damaged or destroyed approximately20,148 acres of New York State's forests per year.[xxi] The frequency of wildfires from 2003 to 2017, as reported by the New York State Forest Rangers and Fire Departments, is shown in Figure 13 below. As highlighted in the orange and red shading, there have been more wildfires in the southeastern regions of New York State, notably in Orange and Rockland counties.

More recently, the Harriman State Park wildfire was the largest wildfire in the Hudson Valley in May 2022. According to the New York State Department of Environmental Conservation, the wildfire burned ~62 acres of land.[116] Additionally, the CSX fire impacted Rockland County in April 2023, sparked by a freight train of the CSX railroad company and leading to significant damage to structures along O&R's transmission lines.[117] The fire burned approximately 50 to 70 acres across Rockland County and caused over 100 people to evacuate.

The CSX wildfire in April of 2023 burned ~50-70 acres of land in Rockland County and caused >100 evacuations.

[xxi] Averages taken from New York State Department of Environmental Conservation, Division of Forest Protection (https://www.dec.ny.gov/lands/42438.html)



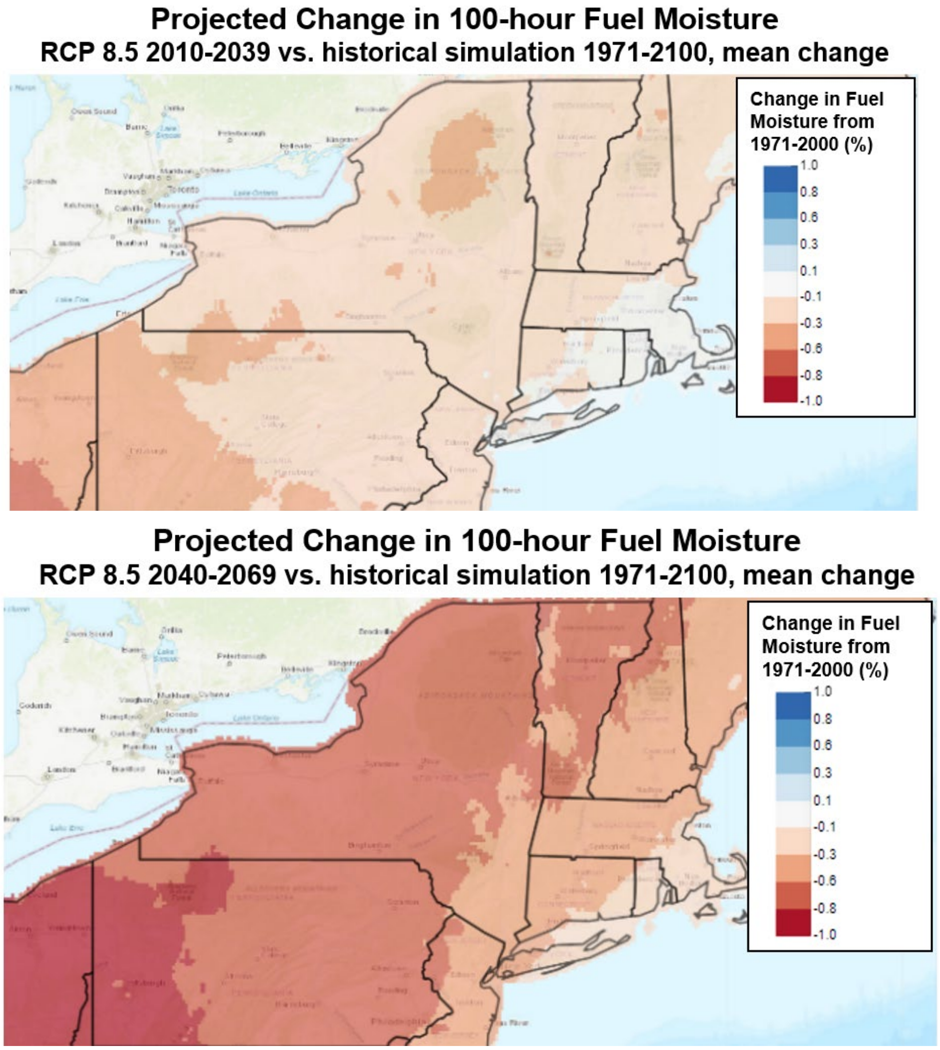
Source: https://www.dec.ny.gov/lands/68333.html

Figure 13. Map of wildfires as reported by NYS Forest Rangers and Fire Departments from 2003–2017 from the NYS Department of Environmental Conservation

Future Projections

The frequency and intensity of wildfires across the globe increased in recent years, which studies have linked to climate change such as increasing temperatures and drying patterns.[118, 119] Some studies suggest that lightning and thunderstorms could increase in the O&R service territory as global mean temperatures continue to warm, and therefore, the risk of wildfires sparked by lightning could also increase. Additionally, drought can increase the likelihood of fire weather (dry and hot weather conditions) and drier vegetation conditions. Studies have linked the co-occurrence of forest fires and drought and how plant responses to drought may affect forest flammability, specifically increased forest flammability with decreased fuel moisture and an increased ratio of dead to live fuels.[120] Warming temperatures lead to more frequent and longer-duration droughts that also increase the likelihood of fire weather and drier fuel conditions,[121] impacting the magnitude, timing, and frequency of wildfires.[122]

Models project fuel moisture decreases in the Northeastern United States due to future temperature increases, potentially preconditioning the service area to wildfires (see Figure 14 below).[xxii] Greater decreases are seen for the 2040–2069 period (bottom figure) than for the 2010–2039 period (top figure), reaching a –0.6% change in some areas of the states, as shown by the darker red shading.



Source: https://climatetoolbox.org/tool/Climate-Mapper

Figure 14. Projected change in 100-hour fuel moisture for summer months (*i.e.*, June, July, August) under RCP 8.5 between 2040-2069 and 1971-2000 and between 2010-2039 and 1971-2000 using a multi-model mean derived from 18 downscaled CMIP5 models.

Furthermore, one study used an ensemble of statistically downscaled GCMs combined with the Physical Chemistry Fire Frequency Model ("PC2FM") to project changing potential fire probabilities in the United States for the RCP 4.5 and RCP 8.5 scenarios. They found that regions not currently associated with frequent wildfires, such as New England, are projected to experience a doubling of occurrence probabilities by 2100 under RCP 8.5.[123]

[xxii] Projections are from 20 GCMs under RCP 4.5 and 8.5, which were downscaled to a ~4km resolution over the contiguous US using the Multivariate Adaptive Constructed Analogs version 2 ("MACAv2") statistical method with the gridMET training dataset from the University of California, Merced.

O&R and CECONY have formed a wildfire review team, consisting of various operational, engineering, environmental and planning organizations. The team's objective is to review the historical and future impacts of wildfire risk within the Companies' service territories. Based upon the findings of these efforts, the team will develop recommendations to address wildfire risk.

Ultimately, studies suggest that the occurrence of wildfires in the O&R service territory could increase in the future due to climate change in forested areas, but these projections are characterized by a high degree of uncertainty. Projected increases in temperatures, decreases in fuel moisture, and increases in the occurrence of lightning strikes could act to increase the likelihood of wildfires in the northeastern United States in the future. However, mitigation measures and investments in wildfire control measures, such as fuel reduction measures taken by the New Jersey Forest Fire Service, lessen the degree to which climate change increases risk.[124] Therefore, model projections that only consider the influence of climate change may overstate the amount that wildfire risk could increase in the future. Despite the potential for projected increases in wildfires, the overall risk in the O&R service territory remains relatively low, particularly relative to the risks associated with other extreme event hazards, such as tropical cyclones.

Multiple Extreme Events

Weather events can occur in complex combinations at any point during the year. When extreme weather events occur coincidently or sequentially to other events, efforts to respond become more difficult and the impacts can become intensified and cascading. For example, an ice storm followed by a cold snap could prevent maintenance crews from being able to address power outages due to prolonged freezing of roads and infrastructure. Multiple extreme events can exceed resilience thresholds on a range of spatial and temporal scales.

Historical Information

In March 2018, consecutive nor'easters impacted the service area, resulting in extensive O&R customer outages.

Studies indicate that the number of compound events has increased over the past century for several major coastal US cities.[125] In particular, New York has observed an increase in compound events that may be attributed to a shift toward storm surge weather patterns that favor high precipitation. Importantly, heavy precipitation coinciding with storm surge could lead to increased flooding and may hinder disaster response protocols. One compounding event that impacted the O&R service territory on a local scale was the consecutive nor'easters event in March 2018, which led to nearly 2 million power outages for customers throughout the

Northeast and affected many O&R customers.[126] These nor'easters occurred 5 days apart, hindering O&R's ability to complete the restoration of service to customers affected by the first storm before the second storm arrived. In this case, multiple events hampered O&R's emergency response by stretching workforce capacity, limiting work time, and restricting access to nearby mutual assistance resources.

Future Projections

While extreme events are strongly controlled by natural weather conditions at a range of spatial and time scales, it is helpful to understand that natural variability is superimposed on top of climate change trends. This means that, for example, long-term increases in mean temperature incrementally increase the likelihood that the O&R service territory will experience extreme heat waves over time. Similarly, long-term ocean temperature warming increases the likelihood of strong hurricanes and, potentially, nor'easters, even if individual storms are largely dependent on short-term natural variability such as weather patterns. As a result, many climate-related extremes are projected to increase in frequency and magnitude simultaneously throughout the coming century, ultimately increasing the likelihood that multiple events will occur concurrently, consecutively, or in a compounded nature.

Of principal concern is that heat waves will become much more common by the late century relative to historical conditions, increasing the likelihood that heat waves will occur coincidently or consecutively with other extreme events, such as hurricanes, humidity, or drought. The region could experience an increased risk of major hurricanes followed by extended extreme heat events,[127] which would compound impacts to O&R's system and customers power outages caused by the storm persisted through the heat wave. Multivariable heat and humidity events in the northeastern United States could also become approximately 30 times more common by the end of the 21st century under the RCP 8.5 scenario.[128] Furthermore, another study found that compound dry-hot extremes are increasing across this region.[129]

This combination of events may lead to high customer demand while critical system components are not functioning. One complication with dry-hot extremes is the potential for wildfires in more rural, wooded regions in and around O&R's service territory. Wildfires, while less of a risk than other climate hazards, can pose a unique challenge to maintaining reliability. However, there is not enough certainty in projected trends to make actionable company decisions regarding wildfire.

Large portions of O&R's customer base may lose cooling capabilities during coincident or consecutive extremes involving heat, exposing them to heat-related health and safety risks. In addition, other events like coastal flooding may damage the electric system and, if it cannot be fully repaired before a heat event, the stress of increased load may lead to additional failures.

Physical Asset Vulnerability Assessment

This section builds upon the climate science work described above by evaluating O&R's exposure and sensitivities to the studied climate hazards and identifying physical vulnerabilities. The Study Team developed vulnerability scores for each asset-hazard combination based on the asset's **exposure and sensitivity** to climate hazards, as visualized in Figure 15 below. Vulnerability scores ranging from low to high represent which asset-hazard combinations are **priorities** to address in the CCRP.

Methods

The vulnerability assessment methodology produces an understanding of the nature, extent, and priority of the vulnerabilities that O&R may face as a result of climate change. This is a refined methodology based on O&R and ICF's prior experience, and it draws from many established and widely adopted frameworks, including guidance from the U.S. Department of Energy.[130]

Vulnerability is defined as the potential for assets or operations to be negatively affected by climate change. As shown in Figure 15 below, vulnerability incorporates exposure and sensitivity. **Exposure** is defined as the degree to which assets may be exposed to climate hazards, and **sensitivity** is defined as the degree to which assets would experience degradation or failure from climate hazards.[xxiii]

[xxiii] In many frameworks, consequence is another consideration in vulnerability assessments. However, because all components of the electric system are essential for providing service to customers, so at the scale of this assessment, consequence does not provide a meaningful differentiation in overall vulnerability scores. O&R likely will revisit consequence in the development of the CCRP and program implementation.

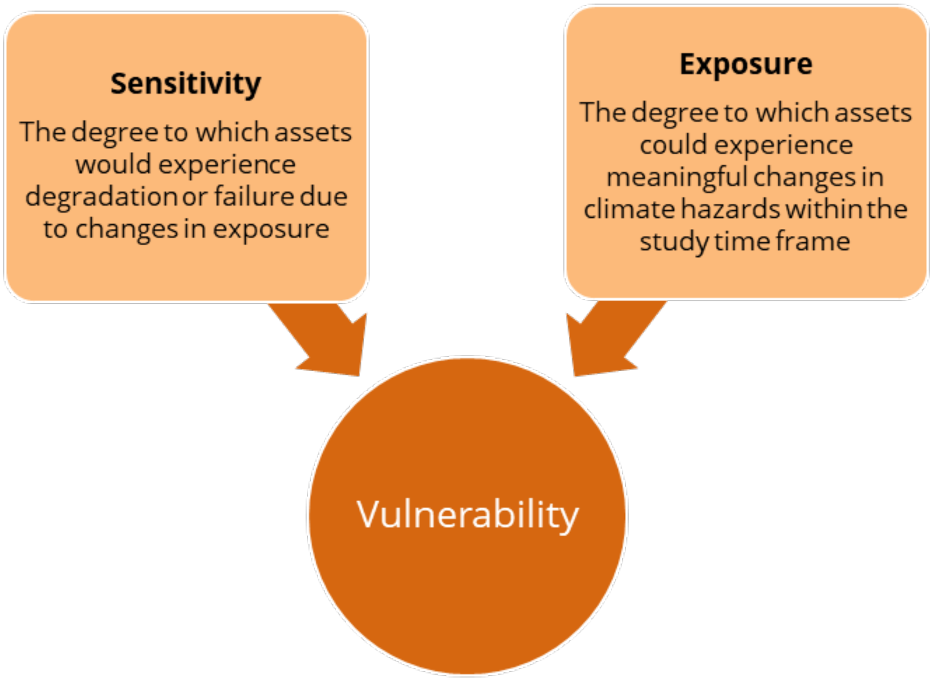


Figure 15. Components of Vulnerability

The Company qualitatively and quantitatively assessed **exposure** using the findings from the climate science analysis. For flooding risks (*i.e.*, sea level rise, precipitation), specific asset locations were geospatially compared to the extent of flood risks to develop counts of exposed assets. For the other hazards, the Company assumed exposure to be the same throughout the O&R service territory and the core question focused on when the climate would change significantly enough to lead to impacts to the assets.

Subject matter experts from O&R and ICF assessed asset **sensitivity** (*i.e.*, the degree to which assets, operations, or systems could be affected by exposure) by:

- Understanding past impacts to the electric system from weather/climate events; and
- Reviewing technical specifications of the electric system components to determine how climate change may affect their operation.

Exposure and sensitivity information for each major asset group (*e.g.*, overhead transmission, substations, underground distribution) and climate hazard (*i.e.*, high heat and humidity, flooding, wind and ice) combination, was used to generate an understanding of overall vulnerability. The vulnerability rating is summarized as low, medium, or high (see Table 7 below for definitions). These ratings reflect the overall priority level of potential vulnerabilities between now and 2050.

The vulnerability rubric (see Table 7 below) describes the vulnerability ratings and the criteria that influence them. Assets considered to have low vulnerability will experience minimal negative outcomes or affects when exposed to a given climate hazard. Assets considered to have moderate vulnerability typically have increased exposure or sensitivity to a given climate hazard or experience increased degradation over time under circumstances of chronic exposure. Assets considered to have high vulnerability are typically associated with a risk of major individual failure or severe degradation of service when exposed to a given climate hazard. Highly vulnerable assets are typically very sensitive or particularly exposed to a given climate hazard.

Vulnerability	
Low	Asset/system has low vulnerability to the given climate hazard.
Moderate	Asset/system is moderately vulnerable to the given climate hazard. Vulnerability is influenced by one or more factors including: • Asset is expected to experience increased degradation over time; and • Asset is moderately sensitive to the given climate hazard and/or the increase in magnitude of exposure for the given hazard is moderate, resulting in limited risk of major failure.
High	Asset/system is highly vulnerable to the given climate hazard. Vulnerability is due to: • Asset is highly sensitive and/or the increase in magnitude for the given climate hazard is high, resulting in a high risk of major individual failure or severe degradation of service.

Table 7. Vulnerability Rubric

The asset groups included in the assessment are transmission and area substations, overhead transmission and distribution equipment ("overhead T&D"), underground transmission and distribution equipment ("underground T&D"), and Company facilities. Each asset group comprises highly critical parts and sub-components which contribute to the functionality and resilience of O&R's electric system. A non-exhaustive list of example subcomponents is shown in Table 8 below.

Substations	Overhead T&D	Underground T&D	Company Facilities
• Transformers Circuit breakers Switches	• Conductor • Shield wire • Insulator • Wood poles • Steel towers	• Conductor • Conduit • Manholes	• Office buildings • Battery storage • Operations centers

Table 8. Example Asset Subcomponents

Summary of Findings

Table 9 below summarizes the findings of the vulnerability assessment. The table shows each combination of asset group and climate hazard and represents vulnerability on a midcentury (2050) timeframe. The highest rated vulnerabilities of the asset/hazard combinations are substations/extreme flooding and overhead distribution/wind and ice. The sections below are organized by climate hazard and provide additional insights on these ratings.

	Temperature and Temperature Variable (TV)	Extreme Flooding	Extreme Wind & Ice
Substations	Moderate	High	Low
Overhead Transmission	Moderate	Moderate	Moderate
Overhead Distribution	Moderate	Low	High
Underground Transmission	Moderate	Moderate	Low
Underground Distribution	Moderate	Moderate	Low
Company Facilities	Moderate	Moderate	Low

Green: Asset/system has low vulnerability to the given climate hazard.

Yellow: Asset/system is moderately vulnerable to the given climate hazard. Vulnerability is typically driven by assets' propensity to experience degradation from exposure to hazard overtime.

Red: Asset/system is highly vulnerable to the given climate hazard. Vulnerability is typically driven by asset's high sensitivity or a significant expected increase in magnitude of given climate hazard, resulting in a high risk of major failure or severe degradation of service.

Table 9. **Summary of Vulnerabilities**

Temperature and Temperature Variable

The Study examined three temperature-related hazards: increasing average temperatures, more frequent and intense heat waves, and increasing heat and humidity (temperature variable, or "TV"). The primary sensitivities of electric assets to the projected changes in temperature and TV are:

Accelerated asset deterioration and decreased system reliability: Assets are designed to operate within a particular environment. When temperatures exceed the design parameters, several components (*e.g.*, insulation) age at an accelerated rate. This accelerated aging can result in premature asset failure, which if unexpected, could result in customer outages and repair costs.

Decreased asset capacity: Because an asset's internal temperature is the result of the temperature in which it operates, as well as the amount of power it delivers, operating at ambient temperatures above design references decreases the operational rating of assets. However, derating the system due to increasing temperatures would effectively decrease the capacity of the system. When the capacity of the system is decreased, O&R must make investments to replace that capacity or risk customer outages (*i.e.*, preventative load shedding) if demand exceeds capacity.

Increased system load: During periods of coincident high temperature and humidity (as represented by high TV values), temperatures feel warmer, resulting in increases in electric demand that cannot be approximated by temperature alone. The O&R electric system has historically experienced a spike in load, primarily due to air conditioner use, during such conditions. These high load situations could, in certain circumstances, exceed system capacity. This impact can be amplified during extended periods of high heat, such as a heat wave. In this situation, O&R would preemptively implement a load shedding process, resulting in customer outages, to avoid system impacts and more costly and longer repairs. O&R tends to experience a spike in reliability issues during the first heat wave of the summer.

The Risk of Extreme Events

In the face of climate change, heat waves are becoming more frequent and intense, especially in summer months. When power failure or blackout events overlap in time with heat waves, population exposures to extreme heat can reach dangerously high levels. Research published in the journal Environmental Science & Technology in 2021 found that simulated compound heat wave and grid failure events of recent intensity and duration may expose urban populations to an elevated risk of heat exhaustion and/or heat stroke (Stone et al. 2021).

Considering both exposure and sensitivity, the overall vulnerability of O&R's electric assets to changes in temperature and TV within the next 20 years is summarized below.

Substations are moderately vulnerable. Substations in the O&R service territory are expected to experience impacts from heat waves,[xxiv] especially when they coincide with periods of high humidity. Additionally, the duration of heat waves with maximum daily temperatures over 95°F are expected to increase to 14 days by 2080, which will reduce the opportunity for equipment to cool down. During periods of high TV, the O&R electric system experiences a spike in demand, primarily due to air conditioner use. Therefore, O&R uses TV as a proxy to represent potential electric demand on its system.

Within a substation, transformers are the most sensitive subcomponent to temperature because their design reference temperatures (*e.g.*, 86° F). tend to be lower than that of other assets Operating substation transformers above this threshold during a prolonged heat event can lead to accelerated degradation of the transformer. Climate projections show increases in the number of days per year when average temperatures exceed 86°F (by the 2050s, up to 20 days

[xxiv] Defined here as 3 or more consecutive days with maximum temperatures over 90°F.

per year from a baseline of 1 day in Dobbs Ferry, and up to 8 days per year from a baseline of 0 days in Mohonk).

In addition, higher temperatures decrease the operational rating of substation assets, effectively lowering the capacity of the electric system. A decrease in rating, combined with higher demand due to increased air conditioner usage, could, in a worst-case scenario, lead to a shortfall in system capacity. O&R's current design standards require substations to support the potential electric demand for a TV of 85° F. The Company is already planning to increase this threshold to 86° F in 2030, and to 87° F in 2040 to account for higher TV projections. Climate projections indicate that days with maximum summer TV of 85°F or above could become more common, occurring approximately 18 times per year by 2050 and 51 times per year by 2080, relative to a baseline of 1 day per year.

Substations transformers are currently based on a 97°F peak design temperature. A maximum temperature of 99°F would reduce substation transformer ratings by 1.45%, and a maximum temperature of 104°F would reduce the ratings by 2.87%. Long-term increases in TV may require changes to transformer sizing guidelines so that the electric system has adequate capacity to provide reliable service.

Overhead transmission and distribution are moderately vulnerable. Overhead T&D systems could see impacts from intense heat wave events and increasing TV.

In general, prolonged heat waves may cause a need for derating to reduce heat generated by electric load. If lines are not derated to reduce electric load, they can be subject to increased deterioration, reduced system capacity, and increased risk of failure.[xxv, xxvi] Assets with existing defects are particularly at risk of failure due to temperature increase. Although climate projections indicate low exposure through 2050 under the SSP5-8.5 climate scenario, the number of heat waves[xxvii] could increase to 3 events per year by 2080, relative to a baseline of 0 events.

When high heat coincides with high demand due to TV, derating could mean the line can no longer fully meet customer demand. In addition, in conditions of high heat and high load, transformer fuses may be triggered, resulting in transformer failure. The number of days per summer with TV greater than 85°F is projected to increase from 1 to 18 by the 2050s and could be as high as 51 by the 2080s. High temperature events can also cause conductors to sag, decreasing clearances and increasing the risk of vegetation contact.

Underground transmission and distribution are moderately vulnerable. Temperatures underground are typically more stable than air temperatures due to the thermal conductivity

[xxv] Evidence exists that suggests conductors may lose 1.5% of capacity for each 1 degree C increase in temperature over 40° C. Sathaye, J. A., et al., 2013. Estimating impacts of warming temperatures on California's electricity system. Global Environmental Change, 23(2), 499-511
[xxvi] Another study conducted by Oak Ridge National Laboratory found that an ambient temperature of 37.78°C resulted in 7-8% capacity loss below normal design ratings. Allen-Dumas, M., et al., 2019. Extreme Weather and Climate Vulnerabilities of the Electric Grid. Oak Ridge National Laboratory https://www.energy.gov/sites/prod/files/2019/09/f67/Oak%20Ridge%20National%20Laboratory%20EIS%20Response.pdf
[xxvii] Defined here as 3 or more consecutive days when average temperatures exceed 90°F.

and transmissivity of soil.[131] However, extreme temperatures or very prolonged high heat can cause soil temperatures to increase and retain heat. During periods of high temperature and TV, the O&R electric system also experiences high demand, causing underground conductors to run at higher temperatures. If soil temperatures are already high, this heat will dissipate to the atmosphere more slowly, increasing the risk that conductors will need to be derated to prevent overheating.

Underground distribution reliability, specifically, is sensitive to changes in TV. When load is high, the temperature of underground conductors increases, and that extra heat is trapped underground. This can be compounded by higher ambient air temperatures, reducing the rate of heat dissipation from the ground to the air. Above their reference ground temperature, lines may require derating (and thus investment in additional capacity to absorb the deration) or in a worst-case scenario, they may fail.

Company facilities are moderately vulnerable. Office buildings may increase the use of air conditioning during high heat or TV events, leading to additional stress on heating, ventilation, and air conditioning ("HVAC") systems. In extreme cases, HVAC systems may not be sufficiently sized to cool facilities, leading to insufficient cooling for critical equipment and human health. TV is projected to increase from 1 day per year above 85° to 18 days per year by 2050 and could pose a risk for some facilities.

O&R is currently undertaking an assessment of all Company offices' HVAC systems and will identify Company facilities which may require improvement.

Flooding

The O&R service territory contains numerous rivers, lakes, and other waterways that have the potential to overflow after large rain events, causing flooding. In addition, the Hudson River is tidally influenced as far north as Troy, NY, exposing the O&R service territory to sea level rise and tidal flooding risks. Flood conditions and durations can vary significantly depending on the cause, as described in Table 10 below.

Precipitation	Storm Surge	Sea Level Rise	Combination
Heavy precipitation can result in ponding, flash floods, and overflow of water bodies. Floodwater typically recedes after precipitation ends, depending on drainage conditions.	High winds from coastal storms such as Superstorm Sandy can drive large amounts of water onto land, causing extreme inundation over a large area. Floodwater can recede quickly or linger for days.	Rising seas can result in frequent flooding in low-lying coastal areas. Flood depth increases gradually over time, with inundation typically occurring at high tide and receding at low tide. For assets at low elevation, sea level rise can even cause permanent inundation.	Multiple flooding sources can occur at once and exacerbate impacts. For example, as sea levels rise, coastal floodplains will expand further inland. This can also result in longer periods of inundation.

Table 10. Selected Causes of Flooding

The primary sensitivities of electric assets to flooding are:

Equipment damage: Flood water can disable electric equipment, affect system reliability and life expectancy of the assets, all resulting in the potential for premature failure and outages. Salt water can also cause arcing and failure of components, resulting in outages. In addition, continued exposure to water can rot wooden assets like poles.

Soil weakening: Exposure to water can weaken the foundation of equipment in instances of prolonged inundation, increasing the overall risk of equipment damage.

Limited accessibility: Flooding presents access issues. If assets are flooded or surrounded by water at high tide or during storms, it becomes more difficult to access the locations for maintenance and on-site operations. If equipment is damaged and results in outages, repairs may have to wait for flood waters to recede.

Equipment corrosion: Sea level rise and coastal flooding pose a particular threat to coastal assets due to the corrosive properties of salt water, which can damage electronic components. These impacts may not be immediately evident but can cause issues over time that may result in asset failures and outages. Saltwater exposure can also be caused by runoff from salted roadways.

When considering both exposure and sensitivity, the overall vulnerability of O&R's electric assets to changes in flooding within the next 20 years is summarized below.

Substations are highly vulnerable. Substation equipment is typically not designed to come into contact with water and can experience sudden failure if exposed. Flooding impacts can be severe enough to disable equipment and lead to circuit failures, which can affect system reliability and life expectancy of the assets. In addition, the following assets are unable to tolerate inundation without disruption or failure: substation transformers and regulators, protection and control devices, circuit breakers, and instrument transformers.

For the Study, O&R assessed flood vulnerability based on projected changes to precipitation, as well as geospatial overlays with inland and coastal floodplains.

Of O&R's 89 total substations, three are located within or adjacent to floodplains:

- **Hillburn station** is located near the Ramapo River and is at risk of inundation from a 500-year flood. Projected flood depths at the station are approximately 1 foot.
- **Summitville station** is located adjacent to the Delaware and Hudson Canal and is within the 100-year floodplain, as shown in Figure 16. Projected flood depths at the station range from approximately 0.03 ft to 2.2 ft.
- **Lovett station** is located adjacent to the Hudson River and is within the present day 100-year coastal floodplain. Coastal floods, such as storm surge, can amplify the damage to substations due to their severity and intensity. Saline exposure from storm surges can cause corrosion to the equipment and decrease the asset's health and lifespan. In addition, flood waters often carry potential damaging debris which can cause physical damage to the substation. As sea levels increase in the Hudson River, flooding at the Lovett station is expected to worsen. Projected flood depths at the station are 3.5 ft in 2030 and 5.2 ft in 2080 during the 100-year flood and 5.0 ft in 2030 and 6.7 ft in 2080 during the 500-year flood.

Figure 16. Summitville substation (red point) with the FEMA 100- and 500-year floodplains overlaid.

Climate projections show that the precipitation intensity for a 25-year, 24-hour rain event could increase to 7.2 inches in Mohonk, from 6.35 inches, and 7.7 inches in Dobbs Ferry, relative to a baseline of 6.7 inches, by 2050.[xxviii, xxix] This aligns with an overall trend in the service territory towards intensifying rain events (see the Precipitation section above). More intense precipitation can lead to stream and river overflows, as well as ponding and flash floods. These impacts are not necessarily confined to areas near water bodies. Assets not located near water can still be damaged during extreme precipitation events.

[xxviii] Rainfall return period projections use the ensemble mean rather than the 75th percentile because they use a different methodology than other climate projections used in this guidance and cataloged in the lifecycle tables. This information is publicly available through Cornell University (http://ny-idf- projections.nrcc.cornell.edu/index.html).

[xxix] Historical heavy rainfall is provided by the NOAA Atlas-14 for the entire U.S. A point-and-click map interface with historical heavy rainfall amounts based on IDF estimates and 90% confidence intervals can be found on their website (https://hdsc.nws.noaa.gov/pfds/pfds_map_cont.html?bkmrk=ny)

Underground transmission and distribution systems are moderately vulnerable. O&R designs underground assets to be submersible (*i.e.*, not immediately impacted by exposure to water). However, underground assets such as conduit, conductors, and transformers can still degrade over time by corrosion from being inundated by flood waters, particularly if that water contains salts from the Hudson River or runoff from roadway salting in the winter. Transformer components that experience corrosion may require cleaning and/or replacement of the asset.

Padmount Transformers

O&R's underground and overhead systems are supported by assets located at ground level, such as padmount transformers. These ground-level assets may be more vulnerable to flooding than the rest of the overhead and underground systems.

In addition, if climate change leads to longer periods of inundation during and after a flood event, the likelihood of water intrusion into the conductor increases. This can cause accelerated corrosion, or even sudden asset failure.

Underground T&D assets may also experience permanent (or frequently recurring) inundation due to sea level rise. In addition to the risks described above, this can result in restricted access to equipment, making maintenance and repairs more difficult.

In extreme cases, such as storm surge, flooding can lead to heavy inundation of land surrounding T&D infrastructure, weakening the load bearing capacity of soil. Weakened soil can increase the risk of damage to underground transmission and may cause damage to pad mount transformers at ground level.

Overhead transmission systems have moderate vulnerability. In general, overhead transmission equipment is elevated off the ground and therefore not directly exposed to flooding. However repeated exposure to inundation may lead to erosion of an asset's foundation and negativity affect the structural stability of towers and poles. O&R has experienced this issue in the past after flood events in its service territory.

Overhead distribution systems have low vulnerability. Like transmission, overhead distribution equipment is elevated off the ground and therefore not directly exposed to flooding. While repeated exposure to inundation has the potential to affect the structural stability of tower and pole footings, there are poles in the O&R service territory that are flooded year-round and are not negatively impacted.

Company facilities are moderately vulnerable. O&R facilities include one facility in West Nyack that could be exposed to riverine flood events. The facility is adjacent to the Hackensack River and has experienced flood events in the past. Past events have primarily impacted the parking area and site grounds, restricting access to the facility. However, the 100-year floodplain intersects with the building, and the majority of the site is within the 500-year floodplain, as shown in Figure 17. In the event of a more extreme flood, the entire site could be inundated.

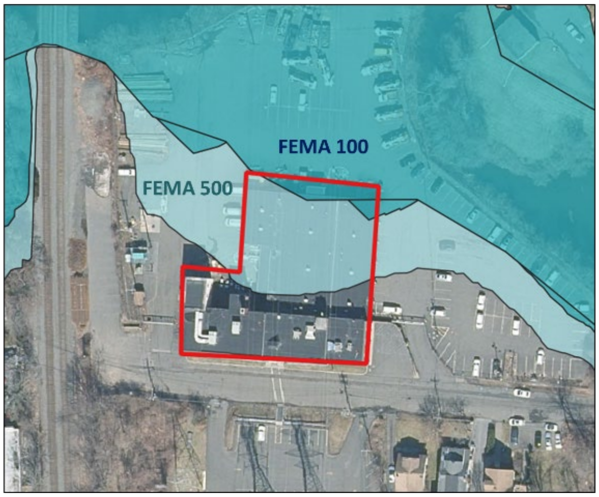


Figure 17. West Nyack Facility (red outline) overlaid on the FEMA 100- and 500-year floodplains.

Wind and Ice

The primary sensitivities of electric assets to the projected changes in wind and ice are:

Direct failure: O&R's electric system is built to withstand defined design tolerances for combined ice and wind loading, consistent with the National Electric Safety Code ("NESC") Rule 250B. Winds or ice loading that exceed these standards can result in asset failure, leading to outages and repair costs.

Vegetation impacts: Strong winds and ice accumulation can cause trees and tree limbs to fall, which can lead to contact with electric equipment, lines, and structures, potentially resulting in widespread outages.

When considering both exposure and sensitivity, the overall vulnerability of O&R's electric assets to changes in wind and ice within the next 20 years is summarized below.

Overhead distribution systems are highly vulnerable. Current standards are designed for combined wind and ice events up to 100 mph,[xxx] as per the ASCE 7 and NESC Heavy 250B standards. Findings from the Extreme Weather Events Literature Review suggest that events with high wind speeds, such as tropical cyclones, could become more intense in the O&R service territory in the future.[132] Furthermore, projections show that heavy wind events could become stronger within the 2050 timeframe.[133] Under the RCP 8.5 scenario, maximum wind gusts (which are often associated with tropical cyclones) in the greater NYC area could reach 110 mph in the future (2017-2050), in comparison to the recent maximum wind gust of 80 mph (during Superstorm Sandy) for the historical period from 1973-2017.[134] While this study was completed for the NYC area, the Hudson Valley could experience similar increases in peak wind gusts, although peak wind gusts may be lower during tropical cyclones (*i.e.*, Superstorm Sandy) farther inland.

[xxx] There are exceptions, such as a wind loading district close to the Hudson River, which is designed to greater than 100 mph.

Overhead distribution assets are sensitive to both the direct impacts of wind and the indirect impacts of nearby vegetation contact with the electric system. While O&R has a robust vegetation management program (as described in Vegetation Management), tree contact with lines remains a large concern. Distribution lines tend to have relatively smaller clearance gaps, increasing the risk of tree contact with distribution conductors and poles. Ice accumulation on distribution poles and lines can also result in unbalanced structural loading and line failure, especially when accompanied by wind. Damage is more likely to occur if poles are older or have existing damage.

Overhead transmission systems are moderately vulnerable. Ice accumulation on transmission towers and lines can result in unbalanced structural loading and subsequent transmission line failure. The risk intensifies when ice accumulation is accompanied by heavy winds. While overhead transmission assets are designed to withstand winds of up to 100 mph (as per O&R Transmission Design Load Criteria[xxxi]), projections indicate that more intense and stronger wind gusts in O&R's service territory are possible. Overhead transmission assets are rated moderately vulnerable to wind and ice compared to overhead distribution assets, because transmission assets have larger clearances between towers and surrounding vegetation.

Substations have low vulnerability. Substation designs incorporate high wind loading thresholds and are not typically vulnerable to increasing average wind speeds or extreme wind events. Some assets, such as circuit breakers, circuit switchers, and disconnect switches, have a lower structural wind load of 90MPH, but are located in cabinets that limit their exposure. In rare cases, wind driven debris can cause damage to unprotected assets.

Underground transmission and distribution systems are not vulnerable. Underground assets do not experience wind and ice hazards due to them being located underground.

Company facilities have low vulnerability. Facilities are not typically vulnerable to average wind speeds. Although unlikely, some damage may occur from extreme wind events. Ice exposure does not pose a risk for facilities.

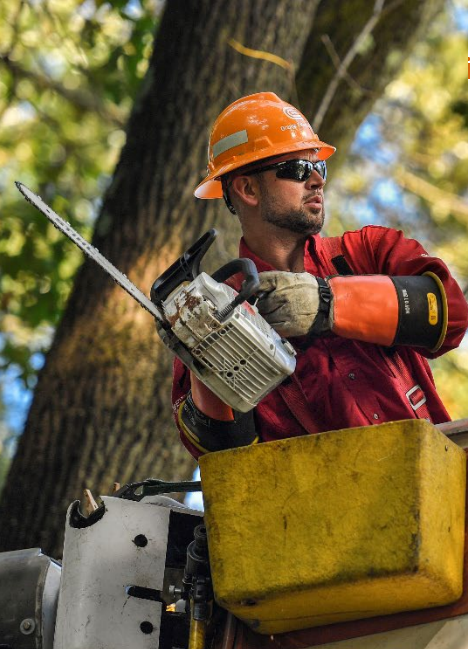
Compound and Sequential Events

Multiple weather events can occur in complex combinations. When extreme weather and climate events occur coincidently or sequentially to other events, their impacts can become intensified and cascading. Failing to account for a reality in which there are multiple climate risk drivers, multiple climate risks, and multiple impacts can lead to blind spots in adaptation planning and risk management. For example, in July 2023, the O&R service territory experienced a heavy rain event followed by high winds. The heavy rain caused soils to soften, making trees' root systems less stable. When high winds followed, trees were knocked down and came into contact with transmission lines.

[xxxi] Aligns with external standards ASCE 7 and NESC Heavy 250C.

Evidence published in the journal *Nature Climate Change* indicates that the number of compound events has increased over the past century at several major coastal US cities.[135] Relevant to O&R's context and service territory, the study found that NYC has observed an increase in compound events which may be attributed to a shift towards storm surge weather patterns that also favor high precipitation. Importantly, heavy precipitation coinciding with a storm surge could lead to increased flooding and may hinder disaster response protocols.

These compound events are a type of "threat multiplier". For example, two of the medium vulnerabilities identified above could occur at the same time (or back-to-back) and together present a high risk to the Company. Estimating the likelihood of compound or concurrent events is statistically difficult, and results typically present a high degree of uncertainty, but that does not mean that they should be ignored. Instead, when developing resilience investment options, O&R engineers will be asking these "what if" questions. For example, what if a barrier to prevent riverine flooding ends up trapping local precipitation behind it and creating a different set of flooding issues? Asking these questions will help ensure a holistic and comprehensive approach to resilience.




Operational Vulnerability Assessment

Background

Resilience to climate change cannot be achieved solely through hardening of physical infrastructure. In addition to assessing the physical vulnerabilities of O&R's infrastructure to climate hazards, the Company evaluated potential climate risks to O&R's **operations and planning processes**. The operations and planning functions reviewed include emergency response, vegetation management, design standards, reliability planning, load forecasting, load relief planning, and workforce safety.

To complete the assessment, the Study Team developed an analysis of how the selected operational and planning functions may be impacted by climate hazards. The analysis was then tailored to O&R's electric system, through interviews conducted by the Study Team with subject matter experts and reviewing relevant O&R specifications and operational documents, including emergency response procedures and environmental health and safety standards, among others. This review was used to further inform and refine the analysis so that it reflected the specifics of the Company's operations.

Table 11 below shows the operations and planning categories evaluated along with the studied climate hazards. Shaded cells indicate which climate hazards pose a risk to each operational and planning area.

Operations and Planning Process	Temperature	TV	Wind	Flooding	Extreme Events
Emergency Response	■		■	■	■
Vegetation Management	■		■		■
Design Standards	■	■	■	■	■
Reliability Planning	■	■			
Load Forecasting and Relief Planning	■	■			
Workforce Safety	■	■	■	■	■
Asset Management	■			■	■
Spare Equipment Management			■	■	■

Table 11. **Operations and Planning Climate Risk Summary**

Emergency Response

Background and Description of Operational Area

O&R has a robust emergency preparedness and response department that helps the Company prepare for and recover from emergencies. The Company maintains emergency response plans for storms, wind, snow, ice, heat, and other weather events, in addition to non-physical hazards like cybersecurity. The most common events requiring emergency response plan activation are heavy, wet snow, sustained winds above 40 mph, and thunderstorms. In recent years, the incidence of tornadoes in the O&R service territory has also increased.

During heavy precipitation, wind, or other extreme events, an emergency response can be delayed if roads are damaged or blocked by trees from the storm. If the asset or facility that is damaged is not accessible, O&R's response to repair the

Accessibility Issues During a System Outage:

In July 2023, O&R experienced a delay in responding to a system outage due to limited site access. During a storm event, a tree fell onto a transmission tower and caused a system outage that required immediate response. However, there was no convenient access roads to allow crew to reach the site. Response crews had to make use of mats to construct a temporary "road" to access the transmission right of way. This process took two days, greatly extending the outage duration. Approximately 60% of O&R's right-of-way have similarly restricted access.

asset is delayed and the system outage remains until the asset is accessible.

O&R has historically not experienced frequent heat-related emergencies, although that could change as temperatures rise due to climate change. The current thresholds for heat activation are based on the total forecasted system load, as shown below in Table 12 below. In the last several years, there have been several incidents of heat watch, but none that rose to the level of a heat alert.

System Load	Status	Activities
1300 MW or less	Normal Operations	Normal operations continue.
1301–1499 MW	Heat Watch	Emergency Response group contacts operations, system planners, the Control Center, and Vice President of Operations. That team then monitors and prepares for further heat impacts.
1500 MW or more	Heat Alert	All of above activities, including: • Load reduction measures on all O&R facilities, • Distribution Auto Loop schemes disabled on circuits exceeding design criteria, • Staffing increases in the Control Center and Call Center, • Activate Direct Load Control Program ("DLCP") and Commercial System Relief Program ("CSRP") system wide.

Table 12. Heat Response Thresholds and Corresponding Operational Activities

The Company also regularly conducts drills and exercises to simulate and prepare for real-life emergencies. These include exercises simulating a large-scale outage, a storm coinciding with work stoppage, a cyber outage, and more. The Company also works with municipalities in its service territory to run localized exercises.

Potential Climate Related Risks and Variables – *Wind, Temperature, Flooding*

By 2030 under the chosen SSP5-8.5 pathway, the region is projected to experience gradual increases in average temperature, as well as more frequent and intense extreme heat events, heat watch events, and even heat alerts. For example, the days per year with maximum daily temperature at or above 95˚F at Mohonk could increase by a factor of seven, from historically averaged approximately 1.3 days to 7.1 days.

Projected increases in the intensity and frequency of extreme precipitation events could lead to more frequent activation of emergency response protocols. The Company is likely to experience more intense rainfall events, which could increase the risk of flooding in the O&R service territory. Response times may be delayed if access to the asset is hindered by flooded roads or downed trees. Historically, Dobbs Ferry and Mohonk have experienced approximately 3.4 and

3.1 days per year with more than 2 inches of precipitation. By mid-century (2050), the number of days is expected to approach 5.

Dynamically downscaled global climate models project warming atmospheric and ocean surface temperatures that could lead to more intense hurricanes in the North Atlantic, increasing maximum sustained wind speeds by approximately 5%.[136] Accompanying projections of more intense hurricanes are studies that project stronger wind gusts in O&R's service territory. A 2020 study published by Comarazamy et al. used a statistical downscaling technique under the RCP 8.5 scenario to show that maximum wind gusts (which are often associated with tropical cyclones) in NYC are expected to reach 110 mph in the future (2017–2050), up from the recent maximum wind gust of 80 mph for the historical period from 1973-2017.[137] The study also found that while the 700-year return period for wind gusts was historically 115 mph, the future 700-year return period is expected to be 124 mph.

Vegetation Management

Background and Description of Operational Area

O&R has a long history of vegetation management practices and updates them regularly. After Superstorm Sandy in 2012, O&R updated clearance requirements and implemented an aggressive vegetation management program that better responds to increasing extreme weather events. As part of the Company's practices, O&R regularly inspects and manages the vegetation along T&D lines and substations to provide safe and reliable service. Vegetation surrounding the approximately 4,000 miles of overhead distribution lines are pruned on a 4-year cycle. Trees are generally pruned so that there is 15 feet of clearance above the single-phase lines, 15 feet of clearance underneath and on the sides, and 20 feet of clearance above the three-phase lines. The Company has also instituted a Hazard Tree removal program across the O&R service territory.

O&R has made several updates to their Transmission Vegetation Management Plan ("TVMP"), including after Superstorm Sandy and to incorporate additional PSC requirements in 2012. The TVMP was updated again in January 2023. O&R conducts a 3-year maintenance cycle on over 500 miles of transmission lines. During year 1, noncompatible vegetation[xxxii] is removed along the ROW so that vegetation does not come into contact with equipment and interrupt service. During year 2, noncompatible species are individually targeted through a low volume foliar herbicide application. Typically, nothing major is required during year 3 of the 3-year cycle, although in the case of a major climate or weather event, the schedule is modified so that lines remain safe for operation. In addition, O&R inspects the transmission system several times a

[xxxii] Noncompatible species are trees that have the potential to grow high enough to interfere with lines. O&R maintains a list of noncompatible species.

year by helicopter and once by a ground patrol, and for the critical NERC transmission lines,[xxxiii] O&R also completes a dedicated vegetation inspection of those lines.

Potential Climate Related Risks and Variables – *Temperature, Precipitation, and Wind*

The primary cause of climate change is an increasing concentration of carbon dioxide in the atmosphere. This, combined with an increase in average temperatures, may cause some species of plants to experience accelerated growth.[138] Accelerated growth presents two risks: (1) over time, accelerated growth due to an increasing number of growing degree days could disrupt O&R's vegetation management cycles and (2) other hazards, such as high winds and ice storms, could increase the risk of vegetation coming in contact with lines — a risk which becomes more likely if average temperature increases reduce the strength of trees, causing them to be more vulnerable to storms.[139] Specifically, off-ROW tree contact with overhead transmission lines is major concern for O&R. During a recent storm, O&R had to build a temporary road to access a damaged overhead transmission tower to clear vegetation and clear an outage. As many as 9 out of 10 contacts are off-ROW trees.

Changes to regional temperatures and climate patterns can also allow new tree species, including invasive species, to enter and thrive in the O&R region. This may lead to O&R needing to revise its trimming cycle to keep up with the pace of invasive species growth.[140]

Less distinct seasons with warmer and shorter winters are altering environments in ways that adversely impact forestry.[141] Because extreme winter cold days are important in limiting the occurrence of some forest pests, mild winters can often result in conditions ideal for disease, pests, and insects to thrive and disrupt tree growth and health in the Northeastern United States.[142, 143, 144] Increased spread of disease and insects can put additional stress on trees and increase their chances on of falling on lines or the right of way. Some notable pests and pathogens associated with warmer temperatures include hemlock woolly adelgid (an invasive insect), ticks, bark beetles, algal blooms, growing deer populations, and kudzu (an invasive plant).[145] This list is not exhaustive, but it provides examples of species which have been expanding their range and contributing to a loss of biodiversity and resilience in some ecosystems located within or surrounding the O&R service territory.

Vegetation management is also a key component in mitigating wildfire risk. While the O&R service territory has not historically experienced wildfire activity, overall drier conditions in the future could increase the chance of a fire event. If this occurs, maintaining clearances around lines will become even more critical in order to protect assets from fire damage.

[xxxiii] The North American Electric Reliability Corporation (NERC) develops reliability standards for transmission lines in the US. Their vegetation management standard applies to transmission lines operating at 200 kV or higher, as well as select other lines.

Design Standards

Background and Description of Operational Area

As a regulated utility, O&R is subject to regulation and oversight at the federal, state, and municipal levels. At the state level, O&R is subject to supervision by the PSC. O&R also complies with the Federal Energy Regulatory Commission's ("FERC") Standards of Conduct, North American Reliability Corporation ("NERC"), and the National Electrical Safety Code ("NESC"). O&R maintains design and purchasing standards that guide the development of new infrastructure. For example, design standards for assets such as conductors contain temperature and wind-loading thresholds that dictate how poles and lines must be reinforced.

Potential Climate-Related Risks – *Flooding, Temperature, Wind, Major Winter Storms*

Increased exposure to hazards including heat events, flooding, and windstorms may exceed current standards for a variety of assets throughout O&R's electric system, causing potential shortening of asset lifespans, or in select cases, asset failure.

As part of its climate change adaptation efforts, O&R will adopt a Climate Change Planning and Design Guideline. Going forward, this Guideline will be used by the Company's engineers to incorporate climate change considerations into design work. This Guideline is a joint document between O&R and Con Edison and will be governed by a joint Climate Resilience and Resilience Executive Committee ("CRREC").

Reliability Planning

Background and Description of Operational Area

O&R is continuously investing in the reliability and resilience of its electric system under all operating conditions, ranging from blue sky days to the most extreme storm events. While resilience typically refers to recovering from gray/black sky days,[xxxiv] reliability refers to

[xxxiv] Black Sky Event: A catastrophic event or events compromising electric reliability and the country's collective effort to respond and restore service. This could be a devastating natural disaster or a combination of incidences. The resulting impact could mean a utility is unable to restore service safely.
Grey Sky Operations: An operating day or days in which a utility faces severe weather or other incident which causes reliability concerns. For example, a natural disaster that causes temporary power disruptions, but does not impact utility private ICT networks, allowing restoration and recovery to proceed as safely and quickly as possible.
(Definitions from the Utilities Technology Council, https://utc.org/wp-content/uploads/2018/10/Definitions_Final-Version_October-2018.pdf).

maintenance of service on blue sky days.[xxxv] Importantly, many of the systems used for reliability planning also help with resilience and by investing in one, the other is improved.

Although climate change will result in temperature increases overall, that does not negate the potential for future cold-weather extremes in the O&R service territory. O&R processes and procedures which are affected by cold weather should continue to account for cold-weather extremes in order to meet necessary safety factors. In October 2022, O&R meteorologists performed an analysis to compare O&R cold weather alerts with Con Edison cold weather alerts. O&R also operates the system to comply with the NERC Extreme Cold Weather Standard and the FERC rulemaking on extreme weather.[146]

In an effort to prepare O&R for climate change and climate-driven increases in demand, O&R's reliability planning team regularly sets reliability performance targets, seeks to understand trends in historical reliability performance, identifies weak spots and remediates them, and identifies investments necessary to fill projected gaps in reliability performance. Reliability planning also includes accounting for system conditions such as customer demand at specific locations and circuit configuration.

Potential Climate-Related Risks – *TV, Temperature, Wind & Ice*

O&R's climate change pathway indicates the electric system will encounter higher temperatures and longer periods of prolonged heat and humidity than experienced under historical conditions. Heat and humidity increase customers' need for air conditioning and place more demand on O&R's electric-delivery system. Distribution equipment failure rates tend to rise with demand (particularly at the beginning of the summer). Therefore, failure to consider climate change conditions in reliability planning could result in an inaccurate picture of future reliability and resilience investment needs.

In addition, studies suggest that extreme weather events (*e.g.*, wind, storms) will continue to increase in frequency and intensity as a result of a warming climate. Future storms are an additional consideration in both resilience and reliability planning, particularly for O&R's overhead distribution system.

Ultimately, gradual increases in average temperatures and duration of heat waves, alongside increases in the frequency and severity of storms, have the potential to impact reliability and may require adjusting planning processes.

[xxxv] Blue Sky Operations: A normal, routine operating day for an energy utility. This generally means moderate temperatures resulting in manageable load expectations, no weather, or physical incidents or emergencies. (Definition from the Utilities Technology Council). https://utc.org/wp-content/uploads/2018/10/Definitions_Final-Version_October-2018.pdf,https://utc.org/wpcontent/uploads/2018/10/Definitions_Final-Version_October-2018.pdf).

Load Forecasting and Relief Planning

Background and Description of Operational Area

Load forecasting develops customer load projections in the O&R service territory to identify areas where additional electrical infrastructure may be necessary (areas in the system where customer *demand* may *exceed* available *capacity*). O&R's' peak demand forecasts and volumetric forecasts are distinctly sensitive to temperature and TV.

As temperature and humidity rise, peak summer demand (driven primarily by air conditioning use) will increase. If this change is not accounted for, the load forecast could be underestimating future demand. In addition, increasing rates of electrification (including electric vehicle adoption rates and building electrification) also impact future load forecasts.

O&R carries out repairs during periods of lower load on the system. Due to electrification, this period is shifting towards the winter, and will therefore require O&R to reassess the timing of conducting critical maintenance and repairs. This will likely be an ongoing reassessment as the system load profile changes and will be further complicated by extreme weather.

Potential Climate-Related Risks – *Temperature, TV*

Climate projections indicate an increase in both temperature and humidity (TV), which are expected to lead to higher peak summer demand. To prevent unforeseen equipment overload and impacts to service reliability from high demand, it is important for customer demand models to account for such projected changes.

Increased loads (due to increased TV) and decreased system capacity (due to increases in temperature) may require additional load relief investments. O&R's load relief planning is based on the weather-adjusted peak TV forecast, which typically occurs when the load peaks due to air conditioning at design weather conditions.

Although O&R is planning several projects to increase the capacity of the electric system in preparation for increased demand from building electrification and electric vehicles, the available capacity to meet customer demand remains a concern. O&R's forecasting group has estimated that a 1°F increase in TV corresponds to an increase of 48MW in system load. This has the potential to affect O&R's ability to deliver reliable electric service.

Workforce Safety

Background and Description of Operational Area

O&R workforce safety encompasses policies and procedures designed to keep employees safe while performing their jobs. O&R is committed to continued improvement and excellence in its

Environmental, Health and Safety ("EH&S") performance, while complying with all applicable laws and regulations. All O&R employees are held accountable for knowing the corporate EH&S requirements that apply to their assigned responsibilities and for using the information in planning and completing their work. O&R engages in proactive, continuing, aggressive, and effective accident prevention and safety programs designed to protect the safety, health and well-being of all employees.

Potential Climate-Related Risks – *Temperature, TV, Flooding, Wind & Ice*

Although a number of climate hazards have the potential to disrupt worker safety procedures, including flooding and storms, the most direct impact to worker safety in the O&R service territory will likely come from increasing average temperature and humidity. Under O&R's selected climate change pathway, there will be an increase in the number of days per year with an unsafe heat index. To prevent adverse impacts to workers, O&R may need to implement a formal process that identifies a heat index threshold and requires workers to rest once the heat index is reached. Other heat stress related solutions could include utilizing tents to work in shade and portable air conditioning units. In extreme cases, delays to projects could occur and consequently lead to further reliability disruptions.

Another risk to workforce safety that was not directly studied in this analysis is air quality. Recent events in the Northeastern United States have shown that climate change has implications for regional air quality due to wildfires in other parts of the world. O&R must therefore be prepared to respond to air quality events that may become more frequent and severe.

Asset Management

Background and Description of Operational Area

O&R's engineering departments are responsible for evaluating, maintaining, and replacing equipment across the electrical system. This includes over 500 miles of electric transmission lines, almost 4,000 miles of overhead electric distribution lines, and over 1,800 miles of underground electric distribution lines, among other equipment. O&R also performs preventive maintenance on assets, invests in reliability measures, and evaluates the conditions and performance of assets.

Potential Climate-Related Risks – *Heat, Precipitation*

In general, climate change is likely to have a negative impact on O&R's assets, leading to shorter asset lifespans on average.

Electric equipment ratings are sensitive to increases in temperature, specifically transformers, cable, busbar, and connections. As ambient temperatures increase, an asset's ability to dissipate heat decreases. To maintain the asset's useful life, O&R may need to lower (*i.e.*, "de-rate") the normal and emergency ratings; otherwise, the load may exceed asset ratings on a more routine basis.

Assets in or near a floodplain may require protection in the future. O&R's' selected pathway (SSP8.5 75^{th} percentile) shows an increase in heavy rain events, increasing the risk of infiltration into underground assets. Failure to account for this risk could result in increased asset damage. In addition, flooding can increase the chances of pole rot on distribution poles and increase the rate at which poles require replacement.

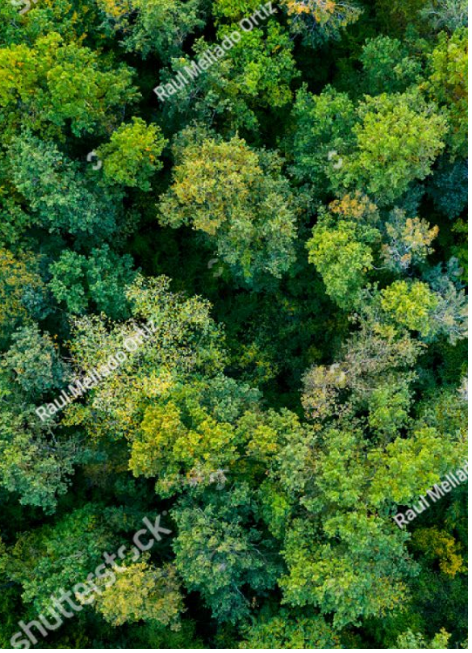
Spare Equipment Management

Background and Description of Operational Area

O&R maintains a stock of spare equipment that can be used to repair or replace assets after major events that damage the O&R electric system. This has become increasingly important in recent years, as the COVID-19 pandemic has negatively affected the supply chain for numerous types of electrical equipment. For example, the time it takes to receive a new transformer after ordering is approximately 36 months, compared to 12 before the COVID-19 pandemic. Because of that, O&R has identified an inventory of critical equipment with long lead times to stock for storm response.

Potential Climate-Related Risks – *Flooding, Wind & Ice*

Climate change is expected to cause an increase in the frequency and intensity of extreme storms, which can cause high wind speeds and flooding. While O&R maintains enough spare stock to respond to an event of a similar magnitude to Superstorm Sandy, that may not be sufficient for a larger storm or a series of multiple storms occurring close together.



Potential Adaptation Measures

In light of the climate vulnerabilities described above, O&R will file a CCRP in November 2023. That plan will include a suite of selected adaptation measures to reduce risk to the O&R electric system. The Company will select measures using the resilience framework developed in the CCRP. The purpose of this framework is to encourage holistic thinking about the types of measures that may help build a more resilient electric system and will encompass the following guiding principles:

- **Prevent** climate change impacts by hardening infrastructure;
- **Mitigate** the impacts from outage-inducing events by minimizing disruptions; and
- **Respond** rapidly to disruptions by reducing recovery times.

Many adaptation strategies fall under the "prevent" category. This component of the framework prepares for both gradual and extreme climate risks through resilience actions throughout the life cycle of the assets. Investments to increase the resilience of the O&R electric system to withstand climate events also provide co-benefits such as enhanced blue-sky functionality and reliability of O&R's electric system. O&R has developed potential adaptation measures as shown in Table 13 below.

Hazard	System	Asset	Potential Adaptation Measure
Flooding	Distribution	Conductors (underground)	Retrofit ventilated equipment with submersible equipment
Flooding	Transmission	Structures Poles/Towers	Increase robustness of foundations
Flooding	Substation	Transformer moats	Raise height of transformer moats
Flooding	Substation	Transformer moats	Install additional oil-water separator capacity

Hazard	System	Asset	Potential Adaptation Measure
Flooding	Substation	All	Increase pumping capacity behind flood walls
Flooding	Substation	All	Perimeter protection (temporary barrier or permanent flood wall)
Flooding	Substation	All	Elevate equipment above DFE
Flooding	Substation	All	Install flood pumps
Flooding	Substation	Substation Transformers/Regulators	Protect specific transformers/regulators via flood enclosures
Heat	Substation	All	Install temperature data collection equipment to allow for real-time rating and operations decisions
Heat	Distribution	Conductors (overhead)	Implement autoloop sectionalization and increase feeder diversity
Heat	Transmission	Conductors (overhead)	Energy efficiency/demand response
Heat	Transmission	Conductors (overhead)	Reconductor to increase capacity
Heat	Transmission	Conductors (overhead)	Voltage upgrade to increase capacity
Heat	Transmission	Conductors (overhead)	Install additional feeder(s) to reduce loading
Heat	Transmission	Conductors (overhead)	Non-wires solutions to reduce loading
Heat	Transmission	Conductors (overhead)	Dynamic line rating to unlock capacity
Heat	Substation	Substation Transformers/Regulators	Energy efficiency/demand response
Heat	Substation	Substation Transformers/Regulators	Replace transformer/regulator with higher-rated unit
Heat	Substation	Substation Transformers/Regulators	Install additional transformers or substations to reduce loading
Heat	Substation	Substation Transformers/Regulators	Non-wires solutions to reduce demand
Heat	Substation	Substation Transformers/Regulators	Additional cooling
Wind	Transmission	Structures Poles/Towers	Replace towers
Wind	Transmission	Structures Poles/Towers	Reinforce towers
Wind	Transmission	Conductors (overhead)	Undergrounding
Wind	Distribution	Conductors (overhead)	Undergrounding
Wind	Distribution	Conductors (overhead)	Retrofits for open wire design with aerial cable and stronger poles
Various	Distribution	Overall system	Self-healing technologies

Hazard	System	Asset	Potential Adaptation Measure
Various	Distribution	Overall system	Advanced voltage optimization
Various	Distribution	Overall system	Intelligent grid technologies
Various	Remote sensing	Overall system	Address space and time gaps in the observational record (*e.g.*, associated with the micronet)
Various	Remote sensing	Overall system	Near-real time monitoring (*e.g.*, to aid storm recovery such as flood and system damage monitoring and assessment)
Various	Remote sensing	Overall system	Near-real time information to feed into storm response programs
Various	Remote sensing	Overall system	Long-range historical Urban Heat Island analyses
Various	Remote sensing	Overall system	System-wide vegetation management
Various	Micronet and in-situ observation	Overall system	Fill observational gaps spatially between existing micronet stations or assets
Various	Micronet and in-situ observation	Overall system	Expand observations in Westchester County and O&R service territory to constrain Urban Heat Island effect and other phenomena
Various	Micronet and in-situ observation	Overall system	Standardize observations across stations

Table 13. **Potential Adaptation Measures Inventory.**

Conclusions and Next Steps

The Study considers climate hazards that are most likely to impact the O&R service territory over the coming 20 years and evaluates how those hazards may affect O&R's electric assets and operations.

The Study Team used climate projections to evaluate O&R's asset exposure to temperature, temperature and humidity, flooding, and wind and ice. Combining that with an understanding of asset sensitivity, the Study Team developed ratings of asset vulnerability to each hazard, summarized in Table 14 below. The Study Team also worked with O&R subject matter experts to evaluate the implications of climate change for O&R's operations.

	Temperature and Temperature Variable (TV)	Flooding	Wind & Ice
Substations	Moderate	High	Low
Overhead Transmission	Moderate	Moderate	Moderate
Overhead Distribution	Moderate	Low	High
Underground Transmission	Moderate	Moderate	Low
Underground Distribution	Moderate	Moderate	Low
Company Facilities	Moderate	Moderate	Low

Green: Asset/system has low vulnerability to the given climate hazard.

Yellow: Asset/system is moderately vulnerable to the given climate hazard. Vulnerability is typically driven by assets' propensity to experience degradation from exposure to hazard overtime.

Red: Asset/system is highly vulnerable to the given climate hazard. Vulnerability is typically driven by asset's high sensitivity or a significant expected increase in magnitude of given climate hazard, resulting in a high risk of major failure or severe degradation of service.

Table 14. Summary of O&R System Vulnerabilities.

The Company will develop adaptation measures for each high vulnerability combination using the list in Potential Adaptation Measures as a starting point. The Company will identify adaptation measures on 5-, 10-, and 20-year timescales. Asset-hazard combinations with moderate vulnerability may also be selected for adaptation options development, if deemed prudent by system engineers and climate change experts.

O&R has begun development of the CCRP and will file it with the PSC in November 2023.

Climate science and projections of future hazards are continuously evolving as new data become available. Therefore, O&R will need to update the Study periodically to incorporate the most recent developments in climate data science. This will also fulfill the requirement of PSL §66 that utilities update their CCVS every five years.

There are also areas of climate science which have less certainty, such as wind modeling. O&R may therefore require additional investment in sensors and weather stations to better understand climate conditions and inform projections.

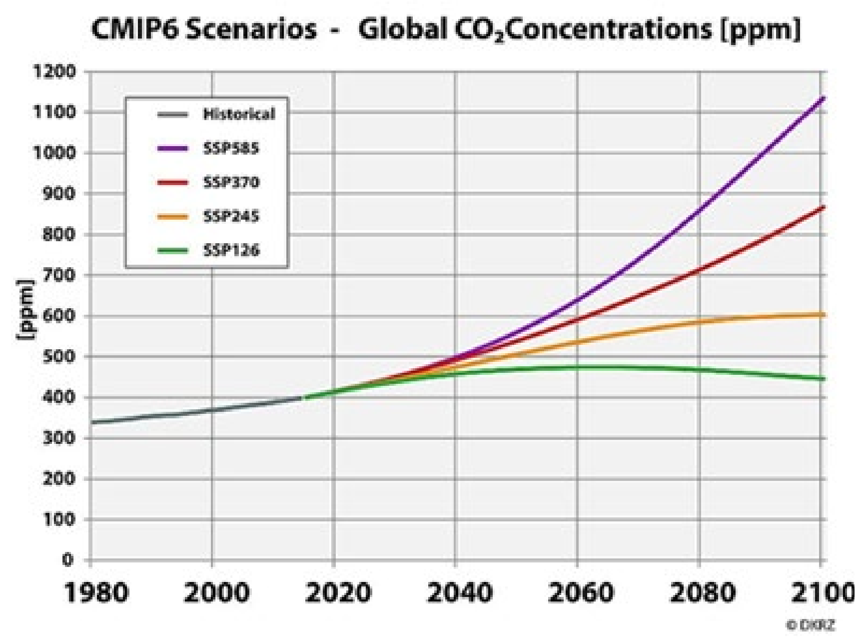
Appendix

Climate Science Methodology

To obtain meteorologically realistic projections that better resolve climate extremes, O&R downscaled daily temperature and precipitation projections from each GCM using the quantile mapping methodology. Such methodology adjusts model values by mapping percentiles of the model's distribution onto percentiles of historical observations.[147, 148, 149]

O&R's pathways use the 75th projection percentile of the Shared Socio-economic Pathway (SSP) 5-8.5 emissions scenario for temperature, precipitation, and related variables. Figure 18 below shows global CO2 concentrations over time for all SSPs. The 75th projection percentile was drawn from an ensemble of 16 GCMs for variables related to daily temperature and precipitation, and 14 GCMs for variables related to hourly temperature and humidity.

Using the datasets from Columbia University, ICF developed projections for tailored variables based on the constraints of O&R's electric system related to climate and extreme weather. Prioritized variables covered hazards such as extreme heat, heavy precipitation, combined heat and humidity, and flooding. Variables relevant to asset ratings included days per year with average ambient temperatures above 86°F and days per year with maximum daily temperatures above 95°F, among others. Variables relevant to inland flooding included maximum 5-day precipitation totals and days per year exceeding 2 inches of precipitation, among others.



Source: https://www.dkrz.de/bilder/bilder-cmip6/co2-emissions

Figure 18. Historical and projected global CO2 concentrations for the SSP emissions scenarios. Projections corresponding to SSP5-8.5 are used in the Study.

Prioritized Climate Variables

The following variables were selected for analysis at the outset of the Study.

Hazard	Prioritized Variables	Dataset
Extreme Heat	• Days per year with maximum daily temperature above 95°F • Days per year with maximum daily temperature above 104°F • Days per year with average ambient temperature above 86°F • Days per year with average ambient temperature above 95°F • Number of heat waves per year with 3 or more consecutive days over 90°F • Highest maximum annual temperature	Columbia CMIP6 dataset
Average Temperature	Mean daily ambient summer temperature (6/1 – 8/31)	Columbia CMIP6 dataset
Heat Index	Days with heat index exceeding 95°F	Columbia CMIP6 dataset
Temperature Variable (TV)	Days per summer with TV >85°F, >90°F Annual maximum summer TV	Columbia CMIP6 dataset
Energy Demand	Cooling Degree Days Heating Degree Days	Columbia CMIP6 dataset
Extreme Cold	Number of days with minimum daily temperatures below 32°F Annual coldest daily temperature	Columbia CMIP6 dataset
Heavy Precipitation	1- and 5-day maximum precipitation Days per year with >0.75 and >2 inches of precipitation	Columbia CMIP6 dataset
Return Period Precipitation	25-year, 24-hour precipitation event	NYSERDA/Cornell CMIP5 Intensity-duration-frequency (IDF) curve dataset
Coastal Flooding	Projected sea-level rise Inundation extent and depth	Columbia CMIP6 dataset for sea-level rise and Columbia Hudson River flood datasets
Inland flooding	100- and 500-year floodplain extent	FEMA floodplains
Wind	Constraint on mean wind speed Constraint on max wind gusts	Literature review and optional supplementary analysis of Spring Valley weather station observational dataset
MIT Projections	• Hourly time series of accumulated rain • 24-hour running total accumulated rain • Hourly time series of surface runoff • Hourly time series of accumulated snow and ice • Hourly time series of snow water equivalent depth • Hourly time series of physical snow depth	MIT dynamically-downscaled hourly climate projections

Hazard	Prioritized Variables	Dataset
	• Hourly time series of radial ice accumulation • Hourly time series of 2-meter dry-bulb temperature • Time series of hourly maximum wind speed at 10 meters • Hourly time series of wind direction at 10 meters	
Other extreme events	• Hurricanes and tropical storms • Snow and ice • Cold Snaps and polar vortex events • Drought • Wildfire • Lightning and tornadoes • Multiple extreme weather events	Literature review

Table 15. Climate hazards and prioritized variables selected for analysis in this study

Historical Analogs of Extreme Events

The following tables illustrate historical analogs of hurricanes and tropical cyclones, ice storms, and nor'easters in the O&R service area and surrounding areas.

Name	Date	Winds	Rainfall	Impacts
Hurricane Ida	September 1, 2021	EF3 tornado in New Jersey with highest winds of 150 mph 150	~4.06 to 6.06 inches	A tornado watch was issued for the area; the storm forced most of the subway system to close with flooded stations; NYC was put under a flash flood emergency for the first time.
Hurricane Henri	August 2, 2021	Maximum sustained winds of 50 mph	~0 to 0.05 inches	Set a daily rainfall record, later broken by Hurricane Ida.
Tropical Cyclone Isaias	August 4, 2020	70 mph peak gusts, sustained winds of 39 mph	~0.45 to 0.72 inches	Flash Flood Emergency plan was activated, tornado watch issued, over 579,000 lost power in New York.
Superstorm Sandy	October 29, 2012	30 to 55 mph, gusts to 75 mph	~0 to 0.62 inches	Major power outages in the O&R service territory; Record maximum water level at the Battery.
Hurricane Irene	August 28, 2011	30 to 45 mph, gusts to 65 mph	~4.38 to 5.18 inches	Inland flooding (upwards of 12 inches of rain northwest of the O&R service territory). Marked the second hurricane to hit New Jersey in 108 years. 151
Hurricane Floyd	September 19, 1999	25 to 40 mph, gusts to 45 mph	~5 inches	Major inland flooding (10-12 inches of rain) in areas southwest of the O&R service territory.

Name	Date	Winds	Rainfall	Impacts
Hurricane Gloria	September 27, 1985	Gusts to 50 mph	~3.81 to 6.43 inches	Worst impacts were over Long Island, with strong winds of approximately 90 mph and heavy rainfall (~6 to 8 inches)
Hurricane Agnes	June 22, 1972	Gusts to 55 mph	~1 to 2 inches	Slow-moving storm that caused rainfall flooding just to the west of the O&R service territory. Locations in Pennsylvania saw approximately 10 inches of rain
Hurricane Donna	September 12, 1960	Gusts to 75 mph	~3.19 to 3.62 inches	Strongest wind gusts of ~100 mph over New Jersey.

Note: Wind data are the range of observations from Central Park, LaGuardia, and White Plains, unless otherwise specified. Precipitation data are the range of observations from Port Jervis and Westchester. Data are from NOAA.

Table 16. Recent historical hurricane analogs relevant to the O&R service area.

Date	Radial ice accumulation	Impacts
January 31–February 3, 2011	Up to 1.0 inches in northern New Jersey and NYC	Many areas of the Northeastern U.S. saw over 1.0 inches of ice accumulation, with power outages, flight cancellations, airport closures, roof collapses and more affecting this area. There were at least 36 fatalities and $1.8 billion in damages.
December 11–12, 2008	Up to 0.9 inches in Schenectady and Albany counties, NY	Widespread tree and power line damage, which contributed loss of customer power in New York and New England with some outages lasting for several days after the storm ended, hourly ice accumulation rates of ½ to 1/3 inches per hour recorded, considered a benchmark for impacts to trees and power infrastructure from 0.5 to 1.25 inches of icing.
January 14–15, 2007	Up to 1.0 inches in Saratoga County	Widespread power outages, primarily impacted Capital Region and North Hudson Valley, winds in the wake of the storm caused additional power outages, arctic air drawn into region dropping temperatures into the single digits to below zero.
March 3–4, 1991	1–2 inches in most affected areas	Over 17 hours of freezing rain and snow, power outages due to downed power lines and trees, 18 counties with disaster declarations in New York, impacts in Rochester and Watertown.
December 4–5, 1964	Up to 1.5 inches in east central New York	Widespread power loss for up to two weeks, over 1 week for ice to thaw leading to additional outages from snapped wires 1 week after event, icing extended from Buffalo to Boston.

Table 17. Historical analogs for ice storms impacting the O&R service territory and surrounding areas. [152] **Analogs are illustrative and not a comprehensive set of historical extreme events.**

Date	Winds	Impacts
January 31–February 2, 2021	40 to 55 mph wind gusts	Over $100 million in damages across the Northeastern United States.
December 14–19, 2020	62 mph wind gusts in Mantoloking, New Jersey	Snowfall eclipsed the entire snowfall total from the previous winter season (surpassing 4.8 inches) and killed at least 7 people.
March 2, 2018	40 to 50 mph winds, gusts up to 65 mph	Multiple tide cycles with coastal flooding. Strong winds caused tree and wire damage.
January 23–24, 2016	30 to 40 mph winds, gusts up to 75 mph on Block Island, New Jersey	Largest snowstorm on record in NYC (Central Park) Blizzard conditions observed across the service territory with storm surge in New Jersey equal to or worse than Superstorm Sandy.
December 26–27, 2010	25 to 40 mph gusts up to 65 mph	The heaviest snowfall from northeastern New Jersey into the lower Hudson Valley. Blizzard conditions observed across the O&R service territory.
February 16–17, 2003	25 to 50 mph winds	Cold temperatures (in the teens) combined with very heavy snowfall and strong wind gusts.
January 7–8, 1996	30 to 50 mph winds, gusts up to 55 mph	Multi-day event with widespread heavy snowfall. Days after the storm, temperatures rose quickly, bringing rain and flooding.
March 13, 1993	Gusts of 60 to 70 mph	Snow changed to rain, then back to snow. Extreme wind gusts caused power outages. Coastal flooding was also reported.
December 10–12, 1992	Gusts of 65 to 75 mph, 80 mph gusts at Cape May, New Jersey	Flooding and high tides in New Jersey and New York. Power outages impacted transportation systems. Snow fell the next day (~6 inches)

Note: Wind data are the range of observations from Central Park, La Guardia, and White Plains, unless otherwise specified. Data are from NOAA.

Table 18. Recent Historical Nor'easter and extra-tropical cyclone analogs and their associated winds in and nearby the O&R service territory.

References

[1] Komurcu, M., K. A. Emanuel, M. Huber, R.P. Acosta, High-Resolution Climate Projections for the Northeastern United States, *Earth and Space Science*, 2018, doi:10.1029/2018EA000426.

[2] The data were developed by the MIT Joint Program on the Science and Policy of Global Change as described in Komurcu and Paltsev (2021), MIT Joint Program Report 352, available at: https://globalchange.mit.edu/publication/17608

[3] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate. doi:10.1017/9781009157896.

[4] IEEE Standard for Calculating the Current-Temperature Relationship of Bare Overhead Conductors 2013 IEEE Std 738-2012 (Revision of IEEE Std 738-2006—Incorporates IEEE Std738-2012 Cor 1 2013) (doi:10.1109/ieeestd.2013.6692858)

[5] Impacts of rising air temperatures on electric transmission ampacity and peak electricity load in

the United States, Matthew Bartos et al 2016 Environ. Res. Lett. 11 114008

[6] "Stakeholders may at any time submit new climate science information for consideration by the Company." Case 19-E-0065, Appendix 16 Actions to Address Climate Change**.**

[7] Frankson, R., et al., 2022. New York State Climate Summary. NOAA Technical Report NESDIS 150-NY. https://statesummaries.ncics.org/chapter/ny/

[8] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate. doi:10.1017/9781009157896.

[9] New York State Senate, Consolidated Laws of New York, Chapter 48, Article 4, Section 66(29). https://www.nysenate.gov/legislation/laws/PBS/66

[10] Case 22-E-0222, *Proceeding on Motion of the Commission Concerning Electric Utility Climate Vulnerability Studies and Plans,* Order Initiating Proceeding (issued June 16, 2022).

[11] Section 25-A. https://www.nysenate.gov/legislation/laws/PBS/25-A

[12] New York State Climate Justice Working Group https://climate.ny.gov/resources/climate-justice-working-group/

[13] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate. doi:10.1017/9781009157896.

[14] Ibid.

[15] Ibid.

[16] Kossin, J.P., et al., 2017. Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wehner, M. F., Arnold, J. R., Knutson, T., Kunkel, K. E., & LeGrande, A. N (eds.)]. U.S. Global Change Research Program, Washington, DC, USA. https://science2017.globalchange.gov/

[17] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate. doi:10.1017/9781009157896.

[18] Riahi, K., et al., 2017. The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. Global Environmental Change, 42, 153–168. https://doi.org/10.1016/j.gloenvcha.2016.05.009

[19] Colle, B.A., et al., 2013. Historical evaluation and future prediction of Eastern North American and Western Atlantic extratropical cyclones in the CMIP5 models during the cool season. Journal of Climate, 26, 6882-6903. https://doi.org/10.1175/JCLI-D-12-00498.1

[20] Zarzycki, C. M. 2018. Projecting changes in societally impactful northeastern U.S. snowstorms. Geophysical Research Letters, 45, 12067-12075. https://doi.org/10.1029/2018GL079820

[21] McCray, C. D., Paquin, D., Thériault, J. M., & Bresson, É. 2022. A Multi-Algorithm Analysis of Projected Changes to Freezing Rain Over North America in an Ensemble of Regional Climate Model Simulations. Journal of Geophysical Research: Atmospheres, 127(14), e2022JD036935. https://doi.org/10.1029/2022JD036935

[22] Easterling D et al 2017 Precipitation change in the United States Climate Science Special Report: Fourth National Climate Assessment Vol I, ed D J Wuebbles Coauthors (Washington DC, USA: U.S. Global Change Research Program) pp 207–30 https://doi.org/10.7930/J0H993CC

[23] NOAA, Tides and Currents data, Relative Sea Level Trend https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8518750

[24] Center for International Earth Science Information Network, Columbia Univrsity. Hudson River Flood Impact Decisions Support System Version 2. http://www.ciesin.columbia.edu/hudson-river-flood-map/

[25] Comarazamy, D., González-Cruz, J., & Andreopoulos, Y. (2020). Projections of Wind Gusts for New York City Under a Changing Climate. Journal of Engineering for Sustainable Buildings and Cities.

[26] Knutson, T., Sirutis, J., Vecchi, G., Garner, S., Ming, Z., Kim, H.-S., . . . Villarni, G. (2013). Dynamical Downscaling Projections of Twenty-First-Century Atlantic Hurricane Activity: CMIP3 and CMIP5 Model-Based Scenarios. Journal of Climate.

[27] Easterling, D., Fahey, D., Hayhoe, K., Doherty, S., James, K., William, S., . . . Mearns, L. (2018). Chapter 2 Our Changing Climate. Retrieved from Fourth National Climate Change Assessment: https://nca2018.globalchange.gov/chapter/2/

[28] Horton, R., Little, C., Bader, D., & Oppenheimer, M. (2015). New York City Panel on Climate Change 2015 Report. Chapter 2: Sea level rise and coastal storms. Annals of the New York Academy of Sciences.

[29] Orton, P., Lin, N., Gornitz, V., Colle, B., Booth, J., Feng, K., . . . Patrick, L. (2019). New York City Panel on Climate Change 2019 Study Chapter 4: Coastal Flooding. Annals of the New York Academy of Science.

[30] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp. doi:10.1017/9781009157896. https://www.ipcc.ch/report/ar6/wg1/

[31] Horton, R. M., & Jiping, L., 2014. Beyond Hurricane Sandy: What might the future hold for tropical cyclones in the North Atlantic? Journal of Extreme Events. https://www.semanticscholar.org/paper/Beyond-Hurricane-Sandy%3A-What-Might-the-Future-Hold-Horton-Liu/945bf17ac65ea4497738ea6876ea69ae218bce8f

[32] Trapp, R. J., et al. 2007. Changes in severe thunderstorm environment frequency during the 21st century caused by anthropogenically enhanced global radiative forcing. Proceedings of the National Academy of Sciences, 104(50), 19719-19723. https://doi.org/10.1073/pnas.0705494104

Lepore, C., et al. 2021. Future global convective environments in CMIP6 models. Earth's Future, 9(12), e2021EF002277. https://doi.org/10.1029/2021EF002277

[33] Emanuel, K. (2013). Downscaling CMIP5 climate models shows increased tropical cyclone activity. Proceedings of the National Academy of Sciences of the United States of America.

[34] Knutson, T., Sirutis, J., Vecchi, G., Garner, S., Ming, Z., Kim, H.-S., . . . Villarni, G. (2013). Dynamical Downscaling Projections of Twenty-First-Century Atlantic Hurricane Activity: CMIP3 and CMIP5 Model-Based Scenarios. Journal of Climate.

[35] Comarazamy, D., González-Cruz, J. E., and Andreopoulos, Y. (September 3, 2020). "Projections of Wind Gusts for New York City Under a Changing Climate." ASME. J. Eng. Sustain. Bldgs. Cities. August 2020; 1(3): 031004. https://doi.org/10.1115/1.4048059

[36] Comarazamy, D., González-Cruz, J. E., and Andreopoulos, Y. (September 3, 2020). "Projections of Wind Gusts for New York City Under a Changing Climate." ASME. J. Eng. Sustain. Bldgs. Cities. August 2020; 1(3): 031004. https://doi.org/10.1115/1.4048059

[37] Michaelis, A., Lackmann, G., Willison, J., & Robinson, W. (2017). Changes in Winter North Atlantic extratropical cyclones in high-resolution regional pseudo–global warming simulations. Journal of Climate.

[38] Trapp, R. J., et al. 2007. Changes in severe thunderstorm environment frequency during the 21st century caused by anthropogenically enhanced global radiative forcing. Proceedings of the National Academy of Sciences, 104(50), 19719-19723. https://doi.org/10.1073/pnas.0705494104

[39] Lepore, C., et al. 2021. Future global convective environments in CMIP6 models. Earth's Future, 9(12), e2021EF002277. https://doi.org/10.1029/2021EF002277

[40] DeGaetano, A. T. 2000: Climatic perspective and impacts of the 1998 northern New York and New England ice storm. Bulletin of the American Meteorological Society, 81(2), 237-254. https://doi.org/10.1175/1520-0477(2000)081<0237:CPAIOT>2.3.CO;2

[41] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate. doi:10.1017/9781009157896.

[42] Jeong, D. I., Cannon, A. J., & Zhang, X. 2019: Projected changes to extreme freezing precipitation and design ice loads over North America based on a large ensemble of Canadian regional climate model simulations. Natural Hazards and Earth System Sciences, 19, 857–872. https://doi.org/10.5194/nhess-19-857-2019

[43] Hurricane Ida tornado outbreak, 2023. https://en.wikipedia.org/wiki/Hurricane_Ida_tornado_outbreak

[44] NOAA, 2023. Hurricanes Frequently Asked Questions. https://www.aoml.noaa.gov/hrd-faq/#landfalls-by-state

[45] Knutson, T., Camargo, S. J., Chan, J. C., Emanuel, K., Ho, C. H., Kossin, J., et al. 2020. Tropical cyclones and climate change assessment: Part II: Projected response to anthropogenic warming. Bulletin of the American Meteorological Society, 101(3), E303-E322. https://doi.org/10.1175/BAMS-D-18-0194.1

[46] Knutson, T. R., Sirutis, J. J., Vecchi, G., Garner, S., Zhao, M., Kim, H. S., et al. 2013. Dynamical downscaling projections of twenty-first-century Atlantic hurricane activity: CMIP3 and CMIP5 model-based scenarios. Journal of Climate, 26(17), 6591-6617. https://doi.org/10.1175/JCLI-D-12-00539.1

[47] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate. doi:10.1017/9781009157896.

[48] Knutson, T., Camargo, S. J., Chan, J. C., Emanuel, K., Ho, C. H., Kossin, J., et al. 2020. Tropical cyclones and climate change assessment: Part II: Projected response to anthropogenic warming. Bulletin of the American Meteorological Society, 101(3), E303-E322. https://doi.org/10.1175/BAMS-D-18-0194.1

[49] Knutson, T. R., Sirutis, J., Zhao, M., Tuleya, R. E., Bender, M., Vecchi, G. et al. 2015. Global projections of intense tropical cyclone activity for the late twenty-first century from dynamical downscaling of CMIP5/RCP4.5 scenarios. Journal of Climate. 28(18), 7203-7224. https://doi.org/10.1175/JCLI-D-15-0129.1

[50] Knutson, T. R., Sirutis, J. J., Vecchi, G., Garner, S., Zhao, M., Kim, H. S., et al. 2013. Dynamical downscaling projections of twenty-first-century Atlantic hurricane activity: CMIP3 and CMIP5 model-based scenarios. Journal of Climate, 26(17), 6591-6617. https://doi.org/10.1175/JCLI-D-12-00539.1

[51] Kossin, J. P., Knapp, K. R., Olanderc, T. L., and Velden, C. S., 2020, "Global Increase in Major Tropical Cyclone Exceedance Probability Over the Past Four Decades," PNAS, 117(22), pp. 11975-11980. https://doi.org/10.1073/pnas.1920849117

[52] Baldini, L., Baldini, J., McElwaine, J. et al. Persistent northward North Atlantic tropical cyclone track migration over the past five centuries. Sci Rep 6, 37522 (2016). https://doi.org/10.1038/srep37522

[53] Knutson, T., Camargo, S. J., Chan, J. C., Emanuel, K., Ho, C. H., Kossin, J., et al. 2020. Tropical cyclones and climate change assessment: Part II: Projected response to anthropogenic warming. Bulletin of the American Meteorological Society, 101(3), E303-E322. https://doi.org/10.1175/BAMS-D-18-0194.1

[54] Knutson, T. R., Sirutis, J. J., Vecchi, G., Garner, S., Zhao, M., Kim, H. S., et al. 2013. Dynamical downscaling projections of twenty-first-century Atlantic hurricane activity: CMIP3 and CMIP5 model-based scenarios. Journal of Climate, 26(17), 6591-6617. https://doi.org/10.1175/JCLI-D-12-00539.1

[55] Emanuel, K. A. 2013. Downscaling CMIP5 climate models shows increased tropical cyclone activity over the 21st century. Proceedings of the National Academy of Sciences. 11 (30). 12219-12224. https://doi.org/10.1073/pnas.130129311

[56] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate. doi:10.1017/9781009157896.

[57] Robbins, C. C., & Cortinas, J. V. 2002. Local and synoptic environments associated with freezing rain in the contiguous United States. Weather and Forecasting, 17(1), 47-65. https://doi.org/10.1175/1520-0434(2002)017<0047:LASEAW>2.0.CO;2

[58] DeGaetano, A. T. 2000: Climatic perspective and impacts of the 1998 northern New York and New England ice storm. Bulletin of the American Meteorological Society, 81(2), 237-254. https://doi.org/10.1175/1520-0477(2000)081<0237:CPAIOT>2.3.CO;2

[59] Historical snowstorms impacting NYC (http://www.weather2000.com/NY_Snowstorms.html). Data is from NYC's official weather station data for years 1869-present and from the following sources for earlier years:

Kocin, Paul & Uccellini, Louis. Northeast Snowstorms. Boston: American Meteorological Society, 2004.

Ludlum, D. M. Early American Winters (Parts I & II). Boston: American Meteorological Society, 1966 & 1968.

[60] Changnon, S. A., & Karl, T. R. 2003: Temporal and Spatial Variations of Freezing Rain in the Contiguous United States: 1948–2000. Journal of Applied Meteorology and Climatology, 42(9), 1302–1315. https://doi.org/10.1175/1520-0450(2003)042<1302:TASVOF>2.0.CO;2

[61] DeGaetano, A. T. 2000: Climatic perspective and impacts of the 1998 northern New York and New England ice storm. Bulletin of the American Meteorological Society, 81(2), 237-254. https://doi.org/10.1175/1520-0477(2000)081<0237:CPAIOT>2.3.CO;2

[62] Zarzycki, C. M. 2018. Projecting changes in societally impactful northeastern U.S. snowstorms. Geophysical Research Letters, 45, 12067-12075. https://doi.org/10.1029/2018GL079820

[63] Zarzycki, C. M. 2018. Projecting changes in societally impactful northeastern U.S. snowstorms. Geophysical Research Letters, 45, 12067-12075. https://doi.org/10.1029/2018GL079820

[64] Zarzycki, C. M. 2018. Projecting changes in societally impactful northeastern U.S. snowstorms. Geophysical Research Letters, 45, 12067-12075. https://doi.org/10.1029/2018GL079820

[65] Cohen, J., and Coauthors, 2021: Linking Arctic variability and change with extreme winter weather in the United States. Science, 373, 1116–1121, https://doi.org/10.1126/science.abi9167.

[66] Demaria, E. M. C., Roundy, J. K., Wi, S., & Palmer, R. N. (2016). The Effects of Climate Change on Seasonal Snowpack and the Hydrology of the Northeastern and Upper Midwest United States. Journal of Climate, 29(18), 6527–6541. https://doi.org/10.1175/JCLI-D-15-0632.1

[67] McCray, C. D., Paquin, D., Thériault, J. M., & Bresson, É. 2022. A Multi-Algorithm Analysis of Projected Changes to Freezing Rain Over North America in an Ensemble of Regional Climate Model Simulations. Journal of Geophysical Research: Atmospheres, 127(14), e2022JD036935. https://doi.org/10.1029/2022JD036935

[68] Lambert, S. J., & Hansen, B. K. 2011. Simulated changes in the freezing rain climatology of North America under global warming using a coupled climate model. Atmosphere-Ocean, 49(3), 289-295. https://doi.org/10.1080/07055900.2011.607492

[69] Cheng C., Li G., & Auld, H. 2011: Possible impacts of climate change on freezing rain using downscaled future climate scenarios: updated for eastern Canada, Atmosphere-Ocean, 49(1), 8-21. https://doi.org/10.1080/07055900.2011.555728

[70] Easterling D et al 2017 Precipitation change in the United States Climate Science Special Report: Fourth National Climate Assessment Vol I, ed D J Wuebbles Coauthors (Washington DC, USA: U.S. Global Change Research Program) pp 207–30 https://doi.org/10.7930/J0H993CC

[71] NOAA, 2021. Understanding the Arctic polar vortex. https://www.climate.gov/news-features/understanding-climate/understanding-arctic-polar-vortex

[72] Northeast RCC CLIMOD 2 http://climod2.nrcc.cornell.edu/

[73] Zhang, P., Y. Wu, I.R. Simpson, K.L. Smith, X. Zhang, B. De, & P. Callaghan. 2018: A stratospheric pathway linking a colder Siberia to Barents-Kara Sea sea ice loss. Science Advances, 4(7), eaat6025. https://doi.org/10.1126/sciadv.aat6025

[74] Overland, J. E., & Wang, M. 2018. Resolving future Arctic/Midlatitude weather connections. Earth's Future, 6, 1146–1152. https://doi.org/10.1029/2018EF000901

[75] Cohen, J., and Coauthors, 2021: Linking Arctic variability and change with extreme winter weather in the United States. Science, 373, 1116–1121, https://doi.org/10.1126/science.abi9167.

[76] Liu, J., Curry, J. A., Wang, H., Song, M., & Horton, R. M. (2012). Impact of declining Arctic sea ice on winter snowfall. Proceedings of the National Academy of Sciences, 109(11), 4074–4079. https://doi.org/10.1073/pnas.1114910109

[77] Francis, J. A., & Vavrus, S. J. (2012). Evidence linking Arctic amplification to extreme weather in mid-latitudes. Geophysical Research Letters, 39(6). https://doi.org/10.1029/2012GL051000

[78] Cohen, J., and Coauthors, 2021: Linking Arctic variability and change with extreme winter weather in the United States. Science, 373, 1116–1121, https://doi.org/10.1126/science.abi9167.

[79] Kossin, J.P., T. Hall, T. Knutson, K.E. Kunkel, R.J. Trapp, D.E. Waliser, and M.F. Wehner, 2017: Droughts, Floods, and Wildfire. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wehner, M. F., Arnold, J.

R., Knutson, T., Kunkel, K. E., & LeGrande, A. N (eds.)]. U.S. Global Change Research Program, Washington, DC, USA. https://science2017.globalchange.gov/chapter/8/

[80] NOAA. Severe Weather 101 – Thunderstorms. National Severe Storms Laboratory. https://www.nssl.noaa.gov/education/svrwx101/thunderstorms/types/

[81] State of New Jersey Office of Emergency Management, 2023. Thunderstorms & Lightning. https://nj.gov/njoem/plan-prepare/thunderstorms-lightning.shtml

[82] Ibid.

[83] New York City Emergency Management. Thunderstorms & Lightning. https://nyc.gov/site/em/ready/thunderstorms.page

[84] Con Edison Media Relations, 2023. Orange and Rockland Utilities Restored power to about 7,000 Hit by Severe T-Storms Last Night. Con Edison.https://www.coned.com/en/about-us/media-center/news/2023/07-14/oru-restored-power-to-about-7000-hit-by-severe-t-storms-last-night

[85] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp.

[86] Trapp, R. J., N. S. Diffenbaugh, H. E. Brooks, M. E. Baldwin, E. D. Robinson, and J. S. Pal, 2007: Changes in severe thunderstorm environment frequency during the 21st century caused by anthropogenically enhanced global radiative forcing. Proc. Natl. Acad. Sci. USA, 104, 19 719–19 723, https://doi.org/10.1073/pnas.0705494104.

[87] Romps, D., Seeley, J., Vollaro, D., Molnari, J. 2014. Projected increase in lightning strikes in the United States due to global warming. Science. Vol. 346. Issue. 6211. P. 851-854. https://doi.org/10.1126/science.1259100

[88] Del Genio, A.D., Yao, M.-S., & Jonas, J. 2007. Will moist convection be stronger in a warmer climate? Geophysical Research Letters, 34(16), L16703. http://dx.doi.org/10.1029/2007GL030525

[89] Trapp, R. J., N. S. Diffenbaugh, H. E. Brooks, M. E. Baldwin, E. D. Robinson, and J. S. Pal, 2007: Changes in severe thunderstorm environment frequency during the 21st century caused by anthropogenically enhanced global radiative forcing. Proc. Natl. Acad. Sci. USA, 104, 19 719–19 723, https://doi.org/10.1073/pnas.0705494104.

[90] Van Klooster, S.L., & Roebber, P.J. 2009. Surface-based convective potential in the contiguous United States in a business-as-usual future climate. Journal of Climate, 22(12), 3317-3330, http://dx.doi.org/10.1175/2009JCLI2697.1

[91] Brooks, H. E. 2012. Severe thunderstorms and climate change. Atmospheric Research, 123, 129-138. ISSN 0169-8095, https://doi.org/10.1016/j.atmosres.2012.04.002

[92] Trapp, R.J., Diffenbaugh, N.S., & Gluhovsky, A. 2009. Transient response of severe

thunderstorm forcing to elevated greenhouse gas concentrations. Geophysical Research Letters, 36(1), L01703, http://dx.doi.org/10.1029/2008GL036203.

[93] Trapp, R. J., N. S. Diffenbaugh, H. E. Brooks, M. E. Baldwin, E. D. Robinson, and J. S. Pal, 2007: Changes in severe thunderstorm environment frequency during the 21st century caused by anthropogenically enhanced global radiative forcing. Proc. Natl. Acad. Sci. USA, 104, 19 719–19 723, https://doi.org/10.1073/pnas.0705494104.

[94] Van Klooster, S.L., & Roebber, P.J. 2009. Surface-based convective potential in the contiguous United States in a business-as-usual future climate. Journal of Climate, 22(12), 3317-3330, http://dx.doi.org/10.1175/2009JCLI2697.1

[95] Brooks, H. E. 2012. Severe thunderstorms and climate change. Atmospheric Research, 123, 129-138. ISSN 0169-8095, https://doi.org/10.1016/j.atmosres.2012.04.002

[96] Brooks, H. E. 2012. Severe thunderstorms and climate change. Atmospheric Research, 123, 129-138. ISSN 0169-8095, https://doi.org/10.1016/j.atmosres.2012.04.002

[97] Brooks, H. E. 2013. Severe thunderstorms and climate change. Atmospheric Research. Vol. 123. P. 129-138. ISSN 0169-8095. https://doi.org/10.1016/j.atmosres.2012.04.002

[98] Diffenbaugh, N., Scherer, M., Trapp, R. 2013. Robust increases in severe thunderstorm environments in response to greenhouse forcing. National Academy of Sciences. Vol. 110. No. 41. P. 16361-16366. https://doi.org/10.1073/pnas.1307758110

[99] Romps, D., Seeley, J., Vollaro, D., Molnari, J. 2014. Projected increase in lightning strikes in the United States due to global warming. Science. Vol. 346. Issue. 6211. P. 851-854. https://doi.org/10.1126/science.1259100

[100] Romps, D., Seeley, J., Vollaro, D., Molnari, J. 2014. Projected increase in lightning strikes in the United States due to global warming. Science. Vol. 346. Issue. 6211. P. 851-854. https://doi.org/10.1126/science.1259100

[101] Finney, D., Doherty, R., Wild, O., Stevenson, D., MacKenzie I., Blyth, A. 2018. A projected decrease in lightning under climate change. Nature Climate Change, 8 (3). pp. 210-213. ISSN 1758-678. https://doi.org/10.1038/s41558-018-0072-6

[102] US EPA, OAR. 2016. "Climate Change Indicators: Drought" Reports and Assessments. https://www.epa.gov/climate-indicators/climate-change-indicators-drought

[103] NOAA, 2023. U.S. Drought Monitor (USDM). Drought.gov. https://www.drought.gov/data-maps-tools/us-drought-monitor

[104] Krakauer, Nir Y., Tarendra Lakhankar, and Damien Hudson. 2019. "Trends in Drought over the Northeast United States" Water 11, no. 9: 1834. https://doi.org/10.3390/w11091834

[105] Huang, H., Winter, J. M., Osterberg, E. C., Horton, R. M., & Beckage, B. (2017). Total and extreme precipitation changes over the northeastern United States. Journal of Hydrometeorology, 18(6), 1783-1798. https://doi.org/10.1175/JHM-D-16-0195.1

[106] Seager, R., Pederson, N., Kushnir, Y., Nakamura, J., & Jurburg, S. (2012). The 1960s drought and the subsequent shift to a wetter climate in the Catskill Mountains region of the New York City watershed. Journal of Climate, 25(19), 6721–6742. https://doi.org/10.7916/D8ST80K3

[107] Krakauer, Nir Y., Tarendra Lakhankar, and Damien Hudson. 2019. "Trends in Drought over the Northeast United States" Water 11, no. 9: 1834. https://doi.org/10.3390/w11091834

[108] NOAA, 2023. Droughts in New York. Drought.gov. https://www.drought.gov/states/new-york#historical-conditions

[109] Easterling D et al 2017 Precipitation change in the United States Climate Science Special Report: Fourth National Climate Assessment Vol I, ed D J Wuebbles Coauthors (Washington DC, USA: U.S. Global Change Research Program) pp 207–30 https://doi.org/10.7930/J0H993CC

[110] Kossin, J.P., T. Hall, T. Knutson, K.E. Kunkel, R.J. Trapp, D.E. Waliser, and M.F. Wehner, 2017: Droughts, Floods, and Wildfire. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wehner, M. F., Arnold, J. R., Knutson, T., Kunkel, K. E., & LeGrande, A. N (eds.)]. U.S. Global Change Research Program, Washington, DC, USA. https://science2017.globalchange.gov/chapter/8/

[111] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate. doi:10.1017/9781009157896.

[112] Horton, R., Gornitz, V., Bowman, M. and Blake, R. (2010), Chapter 3: Climate observations and projections. Annals of the New York Academy of Sciences, 1196: 41-62. https://doi.org/10.1111/j.1749-6632.2009.05314.x

[113] New York State Department of Environmental Conservation. Wildfires. https://www.dec.ny.gov/lands/4975.html

[114] National Wildfire Coordinating Group. Weather and Fuel Moisture. https://www.nwcg.gov/publications/pms425-1/weather-and-fuel-moisture

[115] New York State Department of Environmental Conservation. Wildfires. https://www.dec.ny.gov/lands/4975.html

[116] New York State Department of Environmental Conservation, 2022. DEC Forest Rangers – Week in Review. https://www.dec.ny.gov/press/125388.html

[117] Fan, Christin & Reid, Alecia, 2023. Rockland County officials, residents demand investigation into CSX after freight train ignited brush fires. CBS New York. https://www.cbsnews.com/newyork/news/rockland-county-brush-fires-csx-freight-train-investigation/

[118] Gannon, C, & Steinberg, N. 2021. A global assessment of wildfire potential under climate change utilizing Keetch-Byram drought index and land cover classifications. Environmental Research Communications, 3, 035002. https://dx.doi.org/10.1088/2515-7620/abd836

[119] Gao, P., Terando, A.J., Kupfer, J.A., Varner, M., Stambaugh, M.C., Lei, T.L., Hiers, K. 2021. Robust projections of future fire probability for the conterminous United States. Science of the Total Environment, 789, 0048-9697. https://doi.org/10.1016/j.scitotenv.2021.147872

[120] Nolan, R.H.; Blackman, C.J.; de Dios, V.R.; Choat, B.; Medlyn, B.E.; Li, X.; Bradstock, R.A.; Boer, M.M. Linking Forest Flammability and Plant Vulnerability to Drought. Forests 2020, 11, 779. https://doi.org/10.3390/f11070779

[121] Jones, W. M., Smith, A., Betts, R., Candaell, G. J., Pretice, I., & Le Quere, C. 2020. Climate change increases the risk of wildfires. ScienceBrief Review, 116, 117. https://www.preventionweb.net/files/73797_wildfiresbriefingnote.pdf

[122] Jia, G., Shevliakova, E., Artaxo, P., De Noblet-Ducoudré, N., Houghton, R., House, J., Kitajima, K., Lennard, C., Popp, A., Sirin, A., Sukumar, R., & Verchot, L. 2019. Land–climate interactions. In Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. IPCC. https://www.ipcc.ch/site/assets/uploads/sites/4/2021/07/05_Chapter-2-V6.pdf

[123] Gao, P., Terando, A.J., Kupfer, J.A., Varner, M., Stambaugh, M.C., Lei, T.L., Hiers, K. 2021. Robust projections of future fire probability for the conterminous United States. Science of the Total Environment, 789, 0048-9697. https://doi.org/10.1016/j.scitotenv.2021.147872

[124] New Jersey Department of Environmental Protection. Wildfire Hazard Mitigation. https://www.nj.gov/dep/parksandforests/fire/about/wildfirerisk.html

[125] Wahl, T., Jain, S., Bender, J. et al. Increasing risk of compound flooding from storm surge and rainfall for major US cities. Nature Climate Change 5, 1093–1097 (2015). https://doi.org/10.1038/nclimate2736

[126] Orange and Rockland, 2018. In the Matter of Utility Preparation and Response to Power Outages during March 2018 Winter Storms. https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7BD4946A3C-18A2-4FCC-914A-1C7B8508AE1C%7D

[127] Matthews, T., Wilby, R.L. & Murphy, C. An emerging tropical cyclone–deadly heat compound hazard. Nat. Clim. Chang. 9, 602–606 (2019). https://doi.org/10.1038/s41558-019-0525-6

[128] Coffel, E. D., Horton, R. M., & Sherbinin, A. de. (2017). Temperature and humidity based projections of a rapid rise in global heat stress exposure during the 21st century. Environmental Research Letters, 13(1), 014001. https://doi.org/10.1088/1748-9326/aaa00e

[129] M.R. Alizadeh, J. Adamowski, M.R. Nikoo, A. AghaKouchak, P. Dennison, M. Sadegh. A century of observations reveals increasing likelihood of continental-scale compound dry-hot extremes. Science Advances, 6 (39) (2020). https://doi.org/10.1126/sciadv.aaz4571

[130] 2 U.S. Department of Energy Office of Energy Policy and Systems Analysis. "Climate Change and the Electricity Sector: Guide for Assessing Vulnerabilities and Developing Resilience Solutions to Sea Level Rise." 2016.

[131] Heat Flow and Thermal Effects in Soils – Soil Hydrology and Biophysics (oregonstate.education)

[132] Knutson, T., Camargo, S. J., Chan, J. C., Emanuel, K., Ho, C. H., Kossin, J., et al. 2020. Tropical cyclones and climate change assessment: Part II: Projected response to anthropogenic warming. Bulletin of the American Meteorological Society, 101(3), E303-E322. HYPERLINK "https://doi.org/10.1175/BAMS-D-18-0194.1"https://doi.org/10.1175/BAMS-D-18-0194.1

[133] Comarazamy, D., González-Cruz, J. E., and Andreopoulos, Y. (September 3, 2020). "Projections of Wind Gusts for New York City Under a Changing Climate." ASME. J. Eng. Sustain. Bldgs. Cities. August 2020; 1(3): 031004. https://doi.org/10.1115/1.4048059

[134] Comarazamy, et al., 2020

[135] Wahl, T., Jain, S., Bender, J. et al. Increasing risk of compound flooding from storm surge and rainfall for major US cities. Nature Climate Change 5, 1093–1097 (2015). https://doi.org/10.1038/nclimate2736

[136] Knutson, T., Sirutis, J., Vecchi, G., Garner, S., Ming, Z., Kim, H.-S., . . . Villarni, G. (2013). Dynamical Downscaling Projections of Twenty-First-Century Atlantic Hurricane Activity: CMIP3 and CMIP5 Model-Based Scenarios. Journal of Climate.

[137] Comarazamy, D., González-Cruz, J. E., and Andreopoulos, Y. (September 3, 2020). "Projections of Wind Gusts for New York City Under a Changing Climate." ASME. J. Eng. Sustain. Bldgs. Cities. August 2020; 1(3): 031004. https://doi.org/10.1115/1.4048059

[138] Cho, Renne, 2022. How Climate Change Will Affect Plants. Columbia Climate School. https://news.climate.columbia.edu/2022/01/27/how-climate-change-will-affect-plants/

[139] Supriya, 2018. Climate change is making trees bigger, but weaker. Science.org. https://www.science.org/content/article/climate-change-making-trees-bigger-weaker

[140] Brown, Elizabeth, 2021. Climate Change and Invasive Species. https://www.nisaw.org/climatechange/

[141] Dupigny-Giroux, L.A., E.L. Mecray, M.D. Lemcke-Stampone, G.A. Hodgkins, E.E. Lentz, K.E. Mills, E.D. Lane, R. Miller, D.Y. Hollinger, W.D. Solecki, G.A. Wellenius, P.E. Sheffield, A.B. MacDonald, and C. Caldwell, 2018: Northeast. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II. U.S. Global Change Research Program, Washington, DC, USA, pp. 669–742. doi: 10.7930/NCA4.2018.CH18. https://nca2018.globalchange.gov/chapter/18/

[142] Simon, 2021. Climate change is killing trees, and they're toppling onto power lines. NPR. https://www.npr.org/2021/09/21/1038078093/climate-change-is-killing-trees-and-causing-power-outages

[143] Changing Climate, Changing Forests: The Impacts of Climate Change on Forests of the Northeastern United States and Eastern Canada (2012, US Forest Service), Lindsey Rustad, John Campbell, Jeffrey S. Dukes, Thomas Huntington, Kathy Fallon Lambert, Jacqueline Mohan, and Nicholas Rodenhouse

[144] Goodsman, D.W., Grosklos, G., Aukema, B.H., Whitehouse, C., Bleiker, K.P., McDowell, N.G., Middleton, R.S. and Xu, C. (2018): The effect of warmer winters on the demography of an outbreak insect is hidden by intraspecific competition; Global Change Biology, doi:10.1111/gcb.14284

[145] EPA. Climate Change Impacts in the Northeast. https://climatechange.chicago.gov/climate-impacts/climate-impacts-northeast

[146] Federal Energy Regulatory Commission, 2022. FERC Acts to Boost Grid Reliability Against Extreme Weather Conditions. https://cms.ferc.gov/news-events/news/ferc-acts-boost-grid-reliability-against-extreme-weather-conditions

[147] Cannon, A. J., Sobie, S. R., & Murdock, T. Q., 2015. Bias Correction of GCM Precipitation by Quantile Mapping: How Well Do Methods Preserve Changes in Quantiles and Extremes? Journal of Climate, 28(17), 6938–6959. https://doi.org/10.1175/JCLI-D-14-00754.1

[148] Thrasher, B., et al., 2012. Technical Note: Bias correcting climate model simulated daily temperature extremes with quantile mapping. Hydrology and Earth System Sciences, 16(9), 3309–3314. https://doi.org/10.5194/hess-16-3309-2012

[149] Zhao, T., et al., 2017. How Suitable is Quantile Mapping For Postprocessing GCM Precipitation Forecasts? Journal of Climate, 30(9), 3185–3196. https://doi.org/10.1175/JCLI-D-16-0652.1

[150] Hurricane Ida tornado outbreak, 2023. https://en.wikipedia.org/wiki/Hurricane_Ida_tornado_outbreak

[151] NOAA, 2011. August 2011 Tropical Cyclones Report. https://www.ncei.noaa.gov/access/monitoring/monthly-report/tropical-cyclones/201108

[152] NOAA, 2020. Major Winter Storms Albany, NY. https://www.weather.gov/aly/MajorWinterStorms