APPENDIX 1

Temperature

1. Introduction

This appendix identifies how projected gradual trends in increasing temperature may affect operations, planning, and infrastructure across the electric, gas, and steam segments of Con Edison's business. As described in the report introduction, the analysis for this appendix involves a decision-first and risk-based approach, applying the best available climate science to produce flexible and adaptive solutions. The process was designed to be transparent and interactive so that it can be replicated and institutionalized. This appendix draws upon the most current climate science projections for the Con Edison service territory, over near- (2020), intermediate- (2050), and long-term (2080) time horizons.

The work covered by this appendix has three main objectives:

1. Develop an understanding of projected future temperature conditions for the Con Edison service territory.
2. Complete a risk assessment of potential impacts of temperature change on operations, planning, and infrastructure.
3. Establish a portfolio of effective and cost-efficient measures to improve resilience to increasing temperatures, with a focus on high-priority assets and relevant processes.

The Study team assessed the potential impact of a wide range of gradual temperature change related variables, including average air temperature, maximum air temperature, nighttime temperature, ground temperature, diurnal temperature range, and extreme cold. The impacts of temperature on load and the impacts of multi-day extreme temperature events (i.e., heat waves) are covered in the Humidity appendix (Appendix 2), because humidity plays an important role in these impacts.

This appendix is organized as follows:

- Section 2 provides an overview of the appendix highlights.
- Section 3 describes the screen of operations, planning, and asset types for temperature sensitivity.
- Section 4 reviews the risk-based prioritization of operations, planning, and asset types.
- Section 5 details primary vulnerabilities of high-risk assets.
- Section 6 identifies adaptation options to address the vulnerabilities.
- Section 7 analyzes the costs and benefits of adaptation options under a range of possible futures.
- Section 8 discusses the implementation of adaptation options over time.

2. Highlights

In this appendix, the Study team analyzed Con Edison's vulnerability to future changes in temperature and identified potential adaptation measures to address those changes in temperature. Electric substation transformers and overhead transmission feeder assets are the focus of this analysis. These assets are ranked as highest risk due to their high sensitivity to gradual temperature change and associated performance and financial consequences.

2.1. Screening and Asset Prioritization Process

The Study team used a high-level screening process to efficiently narrow all asset/climate combinations (e.g., underground transmission lines and maximum temperature above 95°F). The first step was to identify which assets are highly sensitive to temperature. Gas and steam were less sensitive than electric to hot temperatures, which is the focus of the analysis in this appendix. The second step was to examine the probability and consequence of the impact of temperature on these assets and rank them accordingly. The two-step prioritization process relied on information from Con Edison subject matter experts, relevant literature, and climate information provided by Columbia Center for Climate Systems Research (CCSR). The projected temperature changes provided by CCSR show gradual increases in average and maximum temperatures across the Con Edison territory. They also project a notable increase in the number of days per year in which average daily temperature exceeds 86°F (30°C) and maximum daily temperature exceeds 95°F (35°C). For example, daily average temperature in Central Park is projected to gradually increase to exceed the 86°F reference temperature[1] between 7 and 26 days per year by 2050, compared with just 2 days per year historically. Similarly, the number of days per year with maximum air temperatures above 95°F is projected to increase from 4 days historically to between 7 and 23 days per year at Central Park by 2050.

2.2. Priority Vulnerabilities

Higher average and maximum ambient temperatures could result in higher electrical demands on electrical infrastructure. This, in turn, creates the need to upgrade equipment to handle increased demands and, if not addressed, would increase the frequency with which equipment must be replaced due to wear.

Higher average or maximum ambient temperatures can also increase the aging rate of insulation in transformers and reduce the carrying capacity of electricity transmission and distribution lines, as well as transformers. This impact primarily affects asset performance and may result in increased costs. Additionally, three core operational and planning functions are affected by gradual changes in temperature: ratings, load forecasting, and load relief.

Increasing temperatures would require the derating[2] of transformers and therefore the most significant impact to Con Edison would be financial in terms of adding capacity. Increasing temperatures would also derate overhead transmission lines. However, for overhead transmission lines, increased temperatures can also lead to an increase in line sag if the derating is not

[1] Reference temperatures are used for planning and operations and provide an indicator of where individual climate variables become problematic for an asset or system.

[2] Rating of equipment capacity is performed using industry standard calculations adopted by Con Edison. For example, a transformer is rated based on functional temperature limits established for specific internal parts. A reference ambient temperature for the operating environment is also a part of the equation. The reference temperature determines the capacity rating of the unit at all the extreme boundaries. If a boundary is exceeded or a component is compromised in some way, the rating is lowered.

addressed. This would constitute a safety risk in terms of reduced clearances with property and vegetation in its path.

2.3. Systemwide Capacity Loss and Capital Costs

The Study team used as the base the most recent marginal costs of capacity presented in Rate Case 16-E-0060 to take a broader look at capacity loss from gradual increases in temperature and associated capital costs across the Con Edison system.[3] The Con Edison system as it stands today is designed to satisfy a summer peak demand of 13,300 megawatts (MW). Based on the range of projections for 2050, the capacity could be reduced by as little as 285 MW or as much as 693 MW by 2050. This could result in an additional capital cost of $237 million to $510 million.

2.4. Adaptation Options

Adaptation options for asset vulnerabilities include:

- Area substations: Install equipment capable of collecting, tracking, and organizing temperature data at substations to allow for location-specific ratings.
- Overhead transmission conductors: Track overhead lines with sag/clearance issues and replace lines, remove obstacles, or raise towers; increase capabilities to provide flexible, dynamic, and real-time line ratings.
- Underground assets: Make ground temperature data more accessible and track increases over time.

Adaptation options for operations and planning vulnerabilities include:

- Asset ratings:
  - Routinely review asset ratings in light of observed temperatures.
  - Use consistent ambient reference temperatures across all assets for developing ratings.
  - For the load relief planning process, assess future asset ratings using temperature projections.
  - Update climate projections at least every 5–10 years.
- Load relief planning: Develop a load relief plan that integrates impact of future changes in temperature on the capacity of assets.
- Long-term planning: Track weather-related costs and impact thresholds over time.
- Grid modernization: Continue to invest in grid modernization to increase resilience to climate change through new technology and increased data acquisition.

[3] For this analysis, reductions in capacity and the associated costs were calculated for overhead transmission, switching stations (including transmission and substation functionality), area station and subtransmission, and network transformers.

2.5. Costs and Benefits of Adaptation Options Under a Range of Possible Futures

Con Edison currently considers costs and benefits to evaluate response options through the *Reforming the Energy Future* benefit-cost analysis framework (Con Edison, 2016). The framework includes the unit cost of a particular option per megawatt of delivery capacity, as well as an option's "social cost." The Study team considered a variety of resilience metrics that could be included in the load relief planning process that could account for the range of possible increasing temperatures. These metrics fall into two categories: co-benefits (reputational, safety, and customer financial benefits) and adaptation benefits (flexibility, reversibility, robustness, proven technology, and customer resilience).

Implementation of Temperature Adaptation Options Over Time

Con Edison already has an iterative process in place to guide the implementation of load relief options over time. This process could be strengthened by planning for capacity and load that incorporates projected climate conditions. Con Edison uses signposts to track the assumptions in its long-range plans, including forecasts of the local economy, employment, demographics, and shifts in energy use patterns**.** Con Edison could consider using additional signposts to help identify which climate projections to incorporate into load forecasting as information regarding climate change progresses.

3. Screen of Operations, Planning, and Asset Types for Climate Sensitivity

The Study team used a high-level screening process to answer these questions:

- Which temperature-related climate variables are relevant to Con Edison operations, planning, and assets?
- Which assets are highly sensitive to the identified temperature-related variables? The identification of these assets is based on prior impact, along with information from asset specifications or operation guidelines.

Con Edison SMEs (45) answered the questions through a workshop and follow-up individual data requests. The relevant temperature-related climate variables identified by the SMEs include:

- Average air temperature (i.e., ambient)
- Maximum air temperature
- Nighttime temperature
- Ground temperature
- Diurnal temperature range

Once the appropriate temperature-related climate variables were identified, the Study team used the information provided by the SMEs to rank the corresponding sensitivity of major asset types as high, medium, or low. To determine assets' sensitivity to projected changes in temperature, Con Edison SMEs were asked to consider each climate variable and asset type combination and identify to what extent the variable is a factor in asset design or operation, through questions such as:

- What previous significant weather events have impacted assets or operations?
- Is information about the climate variable used in design or operation?

- Is the variable a key input or critical factor to asset design or performance?

The combinations of assets and variables that SMEs initially identified as being highly sensitive were carried forward for further detailed analysis (see Section 4 – Risk-Based Prioritization of Asset Types).

This screening approach enabled the Study to narrow the 1,800 asset/climate combinations under review for temperature risks and focus on the highest priorities. Periodic evaluations of asset/climate combinations will support continued effective risk management as the climate changes.

4. Risk-Based Prioritization of Asset Types

Following the high-level screen for sensitivity, the Study team sought to develop a more detailed understanding of specific asset vulnerabilities, the likelihood of impacts over time, and the consequences of specific assets being impacted by changes in temperature. Focusing on the asset/climate combinations (Appendix 1.C, Table 9) the Study team used the Risk Workbook to guide SMEs through a structured process to identify:

- Specific reference temperatures at which the individual climate variables become problematic. These may include, for example, reference temperatures identified in design specifications or the temperatures currently used to rate equipment.
- What could happen if the reference temperatures were exceeded? For example, impacts could include reduced capacity, a reduction in an asset's useful life, or asset failure.
- Qualitative consequences of those impacts across four topic areas:
  - Safety
  - Reliability
  - Financial costs
  - Environmental damage

Con Edison SMEs reviewed operational protocols, planning requirements, asset design standards, and previous event experience for climate-relevant reference temperatures. Table **1** summarizes the key reference temperatures identified by the SMEs during their review and used by the Study team for analysis. Appendix 1.C – Asset Information provides more information about the asset prioritization process.

Table 1 ■ Reference temperatures

Daily maximum temperature (ºF/ºC)	Daily mean temperature (ºF/ºC)	Daily minimum temperature (ºF/ºC)
90º**F**/32ºC	79ºF/26ºC	0ºF/-18ºC
95/35	86/30	15/-9
100/38	90/32	50/10
104/40	95/35	56/13
—	—	65/18

4.1. Historical and Future Temperature

The Study team analyzed historical temperature in the Con Edison service territory and the projected changes throughout the 21st century. The reference period for the historical analysis observations of maximum and minimum temperatures is 1976 to 2005. Historical observations were collected from the U.S. Global Climatology Network, a quality-controlled database with daily observations and minimal gaps in the record. Observations were collected for the three stations within the Con Edison territory: Central Park, LaGuardia Airport, and White Plains (Figure 1).[4] Subsequent appendices will use the most applicable and relevant historical climate information, which may be different than the historical information used in Appendix 1. For instance, hazards that are driven by a combination of temperature and other variables (e.g., humidity) are addressed in subsequent appendices.

Figure 1 ■ Locations of stations used for historical climate information within the Con Edison service area. Counties within the service area are shaded by color according to the corresponding station.

Temperature projections are based on daily outputs of maximum and minimum air temperature from 2006 to 2095 from the suite of available global climate models (GCMs).[5] GCMs divide the globe into grid boxes and simulate the climate within those boxes; each grid box typically spans 1 to 2.5 degrees of latitude and longitude (1 degree of latitude or longitude corresponds roughly to a distance of 100 kilometers or 62 miles; see Figure 16 in Appendix 1.A for an illustration). Data are presented annually and seasonally, with summer defined as June through August and winter defined as December through February.

The Study team selected Representative Concentration Pathways (RCP) 4.5 and 8.5 as scenarios to be assessed for under each GCM. The RCPs, originally developed for use by the Intergovernmental Panel on Climate Change, are a range of scenarios that depict how global greenhouse gas concentrations could evolve over the course of this century. The scenarios are generally consistent

[4] Available at: https://www1.ncdc.noaa.gov/pub/data/cdo/documentation/GHCND_documentation.pdf

[5] Global climate model data are available at: https://esgf-node.llnl.gov/search/cmip5/

with plausible based assumptions about the use of fossil fuels, changes in technology, population growth, and other driving factors. RCP 4.5 represents a moderately warmer future, where radiative forcing is projected to increase by 4.5 watts per square meter (W/m^2) by 2100. RCP 8.5 represents a much hotter future, where radiative forcing is projected to increase by 8.5 W/m^2 by 2100. The latter scenario represents business-as-usual, in which society continues to heavily depend on carbon-intensive fuels and little effort is made to reduce greenhouse gas emissions. To support a risk-based assessment of Con Edison's vulnerability to climate change, the Study drew upon all 32 available GCMs for the required climate variables, spanning a large set of possible outcomes.

Historical Temperature Summary

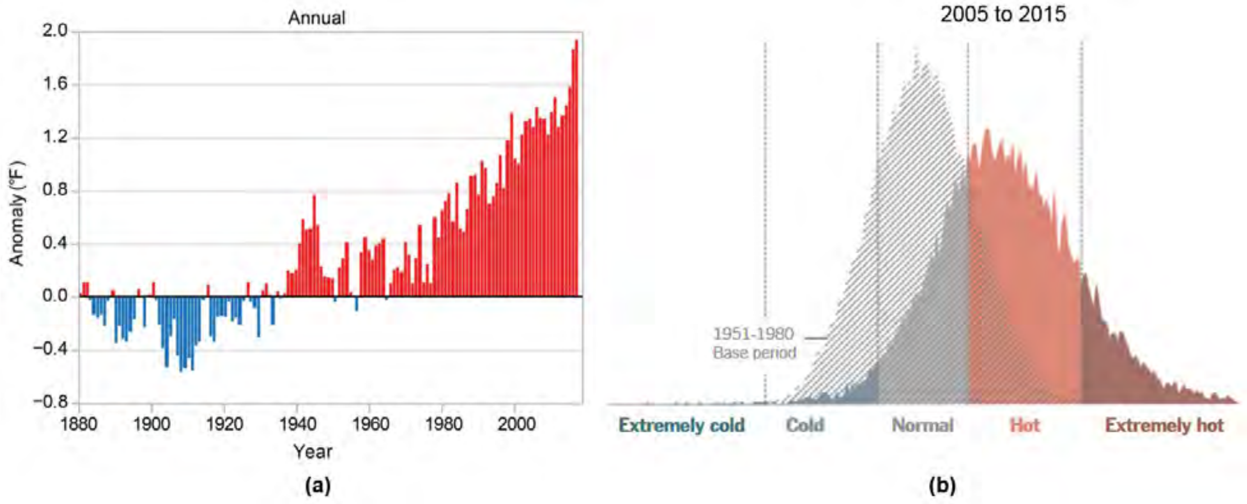
Average annual temperature in the Con Edison service territory has gradually increased by a rate of 0.3°F per decade over the 1900–2013 period, with substantial variation due to high sulphate aerosol emissions and natural variability across the region (Horton et al., 2015). Annual average air temperatures and the number of days with average, maximum, or minimum temperatures below or above key reference temperatures are listed in Table 2. Average and maximum temperatures for LaGuardia Airport and Central Park are close in comparison, but cooler for White Plains.

Table 2 ■ Historical values (1976–2005)

Historical	Central Park	LaGuardia	White Plains
Daily mean temperature	55.0°F	55.2°F	51.3°F
Daily minimum temperature	47.7°F	48.4°F	43.0°F
Daily maximum temperature (summer)	82.4°F	82.4°F	79.9°F
Number of days per year with minimum temperature at or below 50°F	201 Days	196 Days	230 Days
Number of days per year with mean temperature at or above 86°F	2 Days	3 Days	0.3 Days
Number of days per year with maximum temperature at or above 95°F	4 Days	4 Days	1 Day

Daily mean temperatures in Central Park have increased by a rate of 0.3°F per decade, from 1900 to 2013 (Horton et al, 2015). This rise in temperature in the Con Edison service territory is consistent with recent regional and global trends (Figure 2a). Globally, temperatures have increased by 1.5°F since 1880 (Hartmann et al., 2013). Comparing the first half of the 20th century (1901 to 1960) to the present day (1986 to 2016), the Northeast region of the United States experienced an increase of 1.4°F in annual average temperature and an increase of 1.2°F in annual average maximum temperature (Wuebbles et al., 2017). More broadly, most summers in the Northern Hemisphere are now considered hot or extremely hot, in comparison to the mid-20th century (Figure 2b). From 1951 to 1980, roughly one-third of summer days were considered hot. Nearly two-thirds of summer days were considered hot between 2005 and 2015, and 15% were considered extremely hot (Popovich and Pearce, 2017).

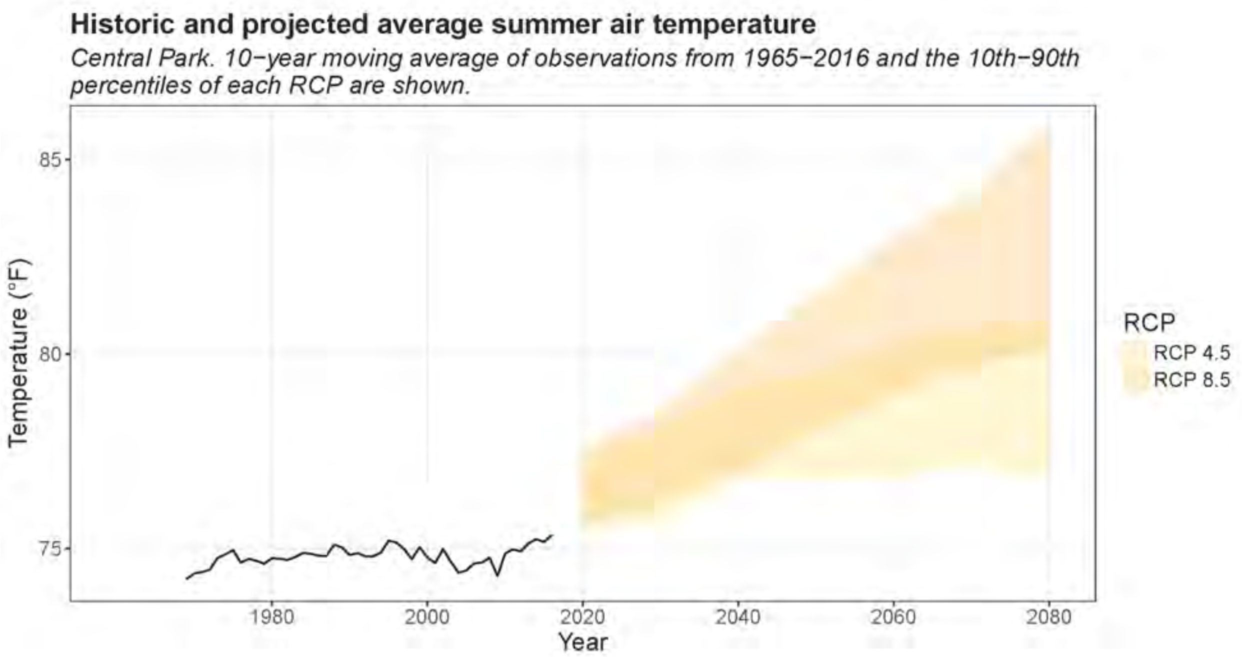
Figure 2 ■ Panel (a), at left, shows global annual average temperatures over land and ocean for 1880–2016 relative to a reference period of 1901–1960. Red bars show temperatures above the 1901–1960 average; blue bars indicate temperatures below the average. Source: Wuebbles et al., 2017. Panel (b), at right, shows that the number of hot and extremely hot summer days has shifted substantially from 2005–2015, compared to 1951–1980, in the Northern Hemisphere. Source: Popovich and Pearce, 2017.



Temperature Projections

The comprehensive set of 32 GCMs and 2 RCPs (4.5 and 8.5) was used to project the range of possible future temperatures. Although the increase in temperature is gradual over time, there is a relatively wide range of possible temperature outcomes for a given time period due to the spread across climate models. This spread reflects everything from natural variability, to differences in how each model responds to increases in greenhouse gas concentrations, to greenhouse gas concentrations themselves. In an attempt to manage the risk posed by increasing temperatures, we account for both the upper-end estimates of this range (i.e., the 90th percentile of projections across climate models), as well as lower-end (i.e., the 10th percentile of projections across models), across the RCPs. Because the 50th percentile reflects the midpoint of the range of possible outcomes, it cannot begin to capture the range of possible temperature outcomes. From a risk-based perspective, it is valuable to know about a range of possible temperature outcomes, including lower probability but high consequence scenarios. As RCP 8.5 results in higher warming and thus higher temperatures than RCP 4.5, particularly over the second half of the century, we highlight the full range of possible future temperatures by using the 10th percentile of RCP 4.5 as the lower-end estimate and the 90th percentile of RCP 8.5 as the upper-end estimate (Figure 3).

Figure 3 ■ Historic and projected average air temperature during the summer under greenhouse gas scenarios RCP 4.5 and 8.5.



Temperature values were projected for the beginning of each decade from 2020 to 2080. As discussed in Appendix 1.A – Climate Model Information, projections are a statistical representation using a 30-year time slice, centered on the beginning of each decade. This is important to keep in mind for near-term periods, such as 2020.

While projections for all stations were calculated, Central Park is used as the central reference point in the body of this appendix.

Average and maximum temperatures are both projected to increase throughout the century (Figure 4 and Figure 5). For example, average daily temperature is expected to gradually increase to exceed an 86°F reference temperature between 7 days (10th percentile under RCP 4.5) and 26 days (90th percentile under RCP 8.5) per year at Central Park by 2050 (Figure 6), compared with just 2 days per year historically.

Figure 4 ■ Daily mean temperature during the summer under greenhouse gas scenarios RCP 4.5 and RCP 8.5.

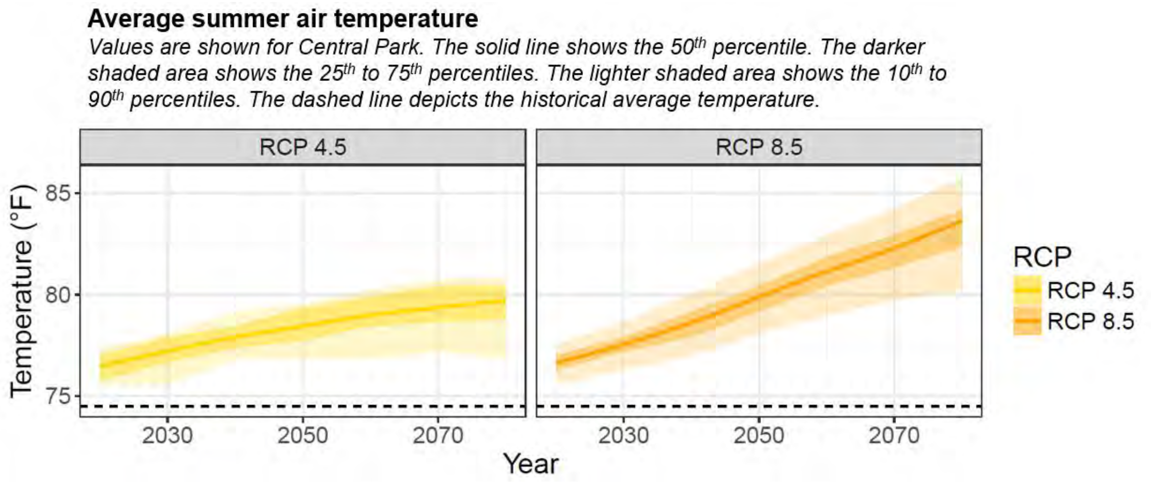


Figure 5 ■ Daily maximum temperature during the summer under greenhouse gas scenarios RCP 4.5 and RCP 8.5.

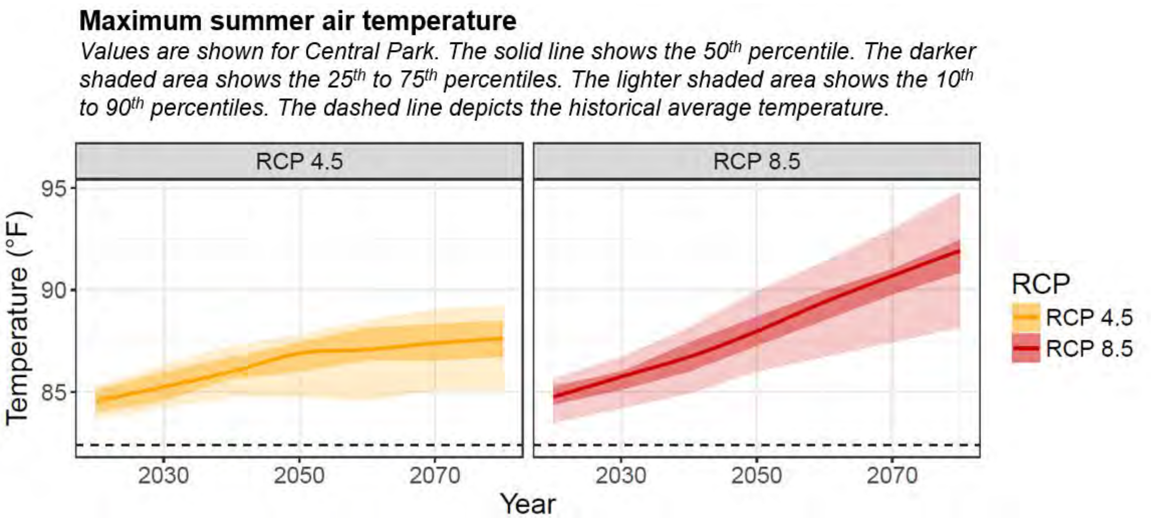
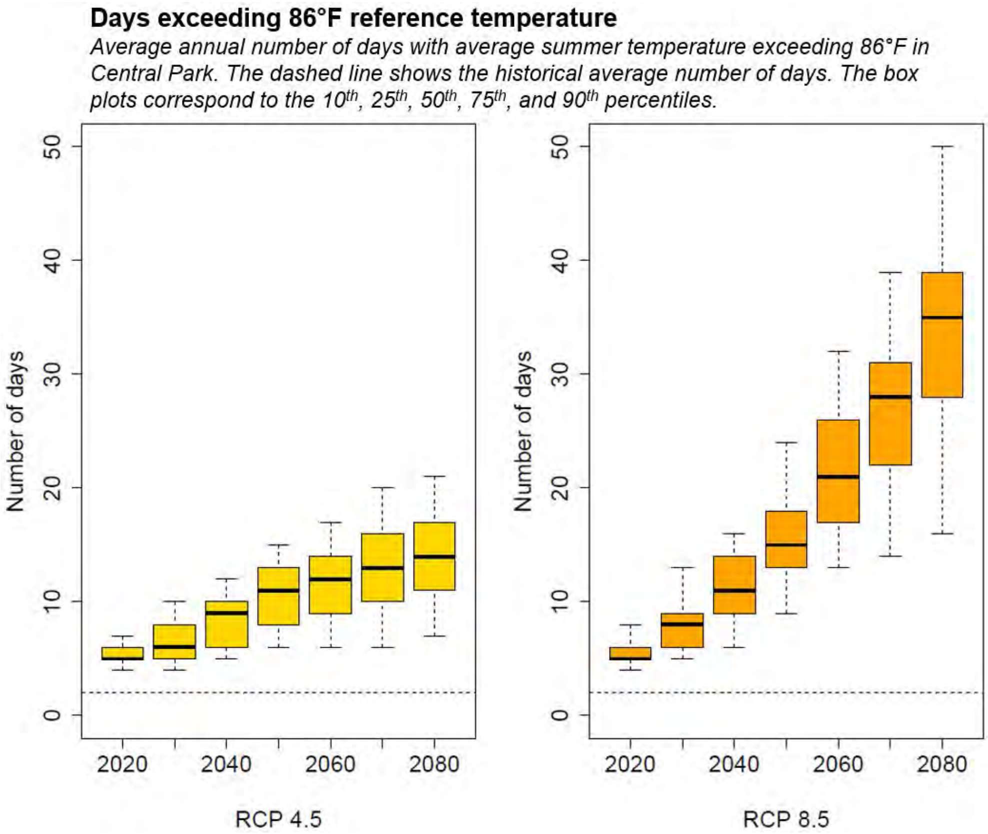


Figure 6 ■ The average number of days per year in which average air temperatures exceed the 86°F reference temperature under two greenhouse gas scenarios, RCP 4.5 and RCP 8.5.



Maximum air temperatures are expected to exceed 95°F substantially more often in the coming decades than they have historically. For example, the number of days per year with maximum air temperatures above 95°F is projected to increase from 4 days historically to between 7 days (10th percentile under RCP 4.5) and 23 days (90th percentile under RCP 8.5) per year at Central Park by 2050 (Figure 7). Minimum temperatures are expected to fall below 50°F much less frequently than they have in the past, projected to range from 160 to 173 days per year at Central Park by 2050 (Table 3), compared with 201 days historically.

Figure 7 ■ The average number of days per year in which maximum air temperatures exceed the 95°F reference temperature under two greenhouse gas scenarios, RCPs 4.5 and 8.5.

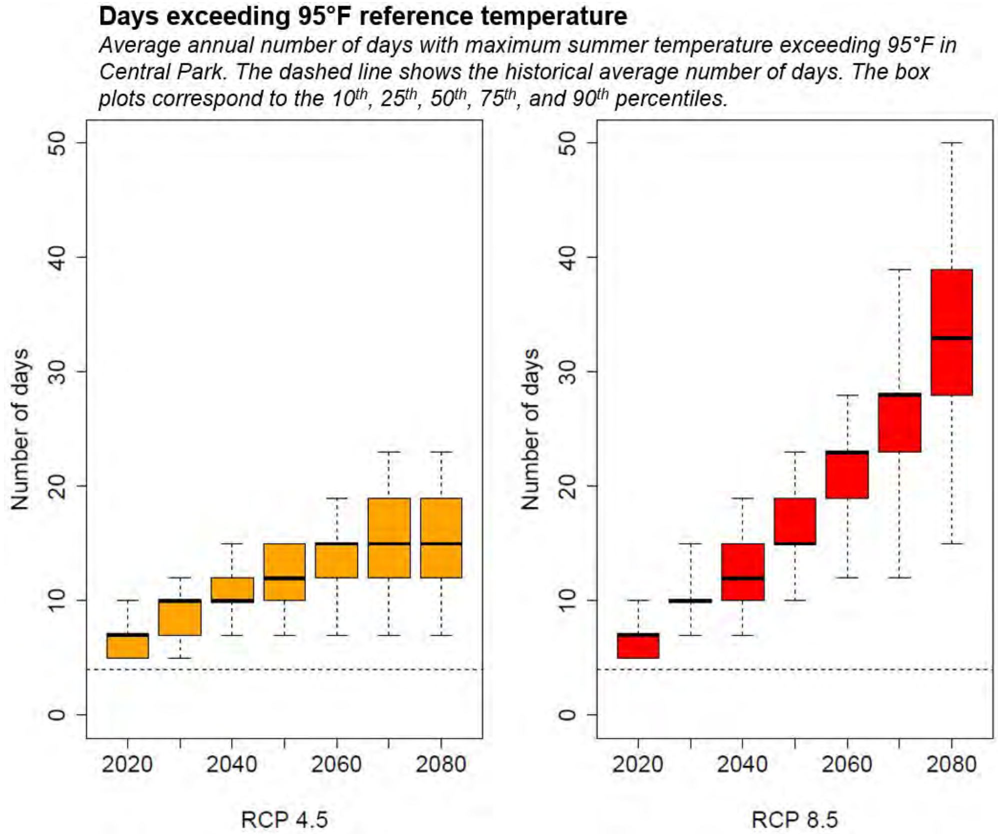


Table 3 illustrates projections across locations and key reference temperatures for 2050. While climate change is expected to gradually increase average and maximum temperatures across the Con Edison territory, it significantly increases the number of days per year in which average temperature exceeds 86°F and in which maximum temperature exceeds 95°F. For example, while the lower and upper bounds for Central Park by 2050 span a range of about 4°F, the number of days per year in which average temperature exceeds 86°F is 7 days under the lower bound and 26 days under the upper bound. Projections for each variable for all decades and reference temperatures can be found in Appendix 1.D – Climate Information.

Table 3 ■ Projected values for the lower and upper bounds (2050)

2050 Projection	Central Park		LaGuardia		White Plains	
	Lower Bound *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*
Daily mean temperature	57.4°F	61.7°F	57.5°F	61.9°F	53.8°F	57.9°F
Daily minimum temperature	50.2°F	54.5°F	50.9°F	55.2°F	45.7°F	49.8°F
Daily maximum temperature (summer)	84.7°F	90.0°F	84.6°F	90.0°F	82.0°F	87.4°F
Number of days per year with minimum temperature at or below 50°F	173 Days	160 Days	169 Days	156 Days	205 Days	190 Days
Number of days per year with mean temperature at or above 86°F	7 Days	26 Days	18 Days	29 Days	1 Day	10 Days
Number of days per year with maximum temperature at or above 95°F	7 Days	23 Days	7 Days	23 Days	3 Days	13 Days

4.2. Asset Prioritization

To prioritize assets for further analysis, the Study team assessed risk by screening for potential worst-case impacts of increasing temperature. The Study team used climate information provided by Columbia University to determine the probability of exceeding the reference temperatures previously identified by SMEs (see Section 4 – Risk-Based Prioritization of Asset Types). The probability of exceedance values were categorized as high, medium, or low as follows: low, less than 33.3%; medium, 33.3% to 66.7%; high, greater than or equal to 66.7%.

The Study team then used the Risk Workbook to calculate the highest risk assets. The overall climate risk score was calculated using "probability of impact" scores and "consequence of impact" scores. *Probability* of impact is scored based on ratings for probability of exceeding the reference temperature and the impact if the reference temperature is exceeded. *Consequence* of impact is scored based on weighted ratings for safety, reliability, financial costs, and environmental damage consequences.

The final outcomes of the Risk Workbook analysis indicate that there are ***two assets at high or high risk to gradual changes in temperature***, as shown in Table 4. All of the high-risk assets are from the electric sector. In general, gas and steam assets and systems are less likely to be negatively impacted by projected gradual increases in temperature, because more of their infrastructure is below ground and they are winter-peaking commodities rather than summer-peaking. The remainder of the detailed analysis focuses on the two high-risk electricity assets: overhead transmission lines and transformers.

Table 4 ■ High-risk assets

			Probability of Impact			Consequence of Impact					
Functional Area	**Asset**	**Variable**	**Probability of Exceeding Reference Temperature**	**Impact if Reference Temp-erature Exceeded**	**Overall**	**Safety**	**Reliability**	**Financial Costs**	**Environmental Damage**	**Overall**
Transmission Feeders, Overhead	Transmission Lines, Conductor	Daily mean temperature Daily maximum temperature	High	Medium	**High**	High	Medium	Medium	Low	**Medium**
Substation, Transmission, and Area	Transformer Insulation	Daily mean temperature Daily maximum temperature	High	Medium	**High**	Low	Medium	High	Low	**Medium**

There were differences in the overall risk ratings of several similar types of assets. Some examples of the differences include:

- **Overhead and underground transmission lines:** Overhead lines are expected to experience more performance rating impacts from the projected increases in ambient temperature than underground lines. The primary reason for this difference is that they operate in the open ambient environment, unlike underground lines (which experience variations in temperature more gradually due to the insulating qualities of being in earth). In addition, overhead lines can sag on hot days, increasing the potential for contact with vegetation, which could result in damage, failure, or unsafe conditions.
- **Transformers:** Substation transformers are differentiated as a higher risk asset under increases in temperature from distribution transformers because they have a more significant financial impact.

In general, across all electric assets, projected gradual increases in temperature affect assets and planning similar to how an increase in load growth affects assets and planning. The impacts to Con Edison are similar, as are the options for addressing the impacts. These impacts and adaptation options are discussed in more detail in the following sections.

A summary of the potential impacts of changes in temperature on medium- and high-risk assets is included below.

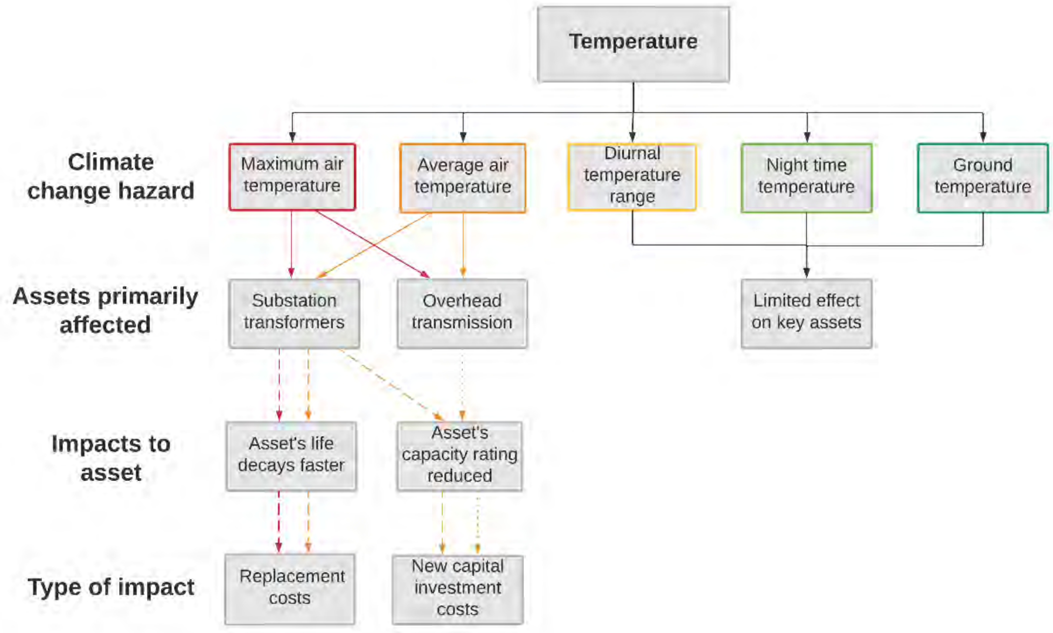
5. Priority Vulnerabilities

This section provides an in-depth review of the sensitivity of high-risk assets to temperature change and potential impacts on the system. A high-level overview of the vulnerabilities of assets to weather variables can be found in Appendix 1.C – Asset Information.

The assets at highest risk to increases in temperature are substation transformers and overhead transmission lines. Figure 8 illustrates the mechanisms by which gradual temperature change affects priority assets.

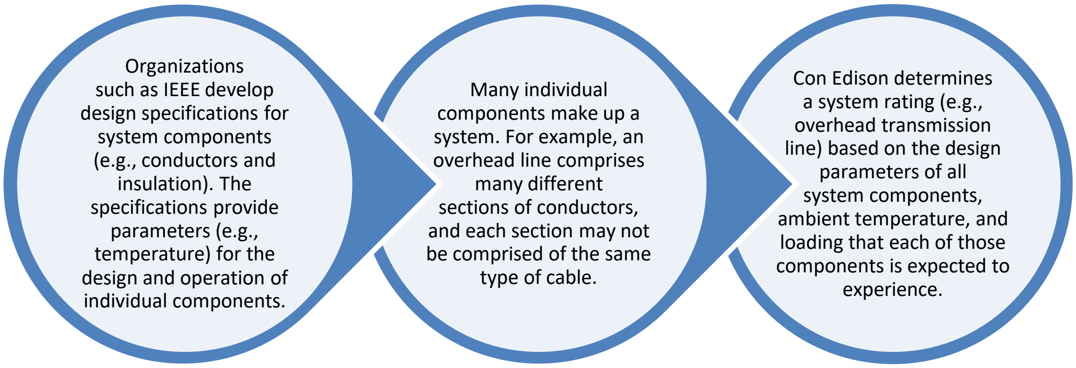
Higher average or maximum ambient temperatures can increase the aging rate of insulation in transformers and reduce the carrying capacity of electricity transmission and distribution lines, as well as of transformers. This impact on carrying capacity may result in increased costs.

Figure 8 ■ Illustration of the mechanisms through which gradual changes in temperature affect Con Edison's priority high-risk assets. Impacts related to maximum air temperature are in red and impacts related to average air temperature are in orange.



Vulnerabilities to temperature can be inherent in the design of individual components of Con Edison's system (physical vulnerabilities) or they can be introduced in the ratings that dictate the appropriate operations of a particular system that is made up of several components (operational vulnerabilities). Figure 9 provides a more detailed perspective on the relationship between design parameters and ratings, which provides context for the following sections.

Figure 9 ■ Relationship of design parameters to ratings



5.1. Physical Vulnerabilities

Area Substations

For each of the high-risk asset types, the Study team identified the reference ambient temperature values used in its design or operation (see Table 10 in Appendix 1.C – Asset Information). Within a substation, transformers are the asset most likely to be affected by projected higher temperatures because their ambient temperature design reference temperature is lower (i.e., 86°F) than that of the majority of other assets (e.g., buses, disconnect switches, circuit breakers, or cables, which have a design reference temperature of 104°F or higher).

The paper insulation in substation transformers is the component that is most sensitive to temperature. Maintaining a transformer's paper insulation temperature within design limits optimizes the insulation's lifespan and thus lengthens the transformer's lifetime (typically considered 30 years or more for utility assets), while excursions above the designed-for temperature will degrade the asset's useful life. However, not every excursion above the designed-for temperature will result in a decreased service life. Two conditions must be met in order for the useful life of the transformer insulation to experience an increased rate of decay:

1. The ambient reference temperature rating must be exceeded.
2. The transformer must be operating at peak load as a result of the network experiencing a single or double contingency.

If the frequency of contingency events is held constant, rising ambient temperatures alone would lead to an increased frequency of excursions above the reference temperature rating, which could cumulatively lead to a reduced service life.

Overhead Transmission Conductors

The primary impact of increases in ambient temperatures on overhead transmission lines (assuming peak load) is increased line sag, which can present safety concerns in areas with clearance limitations. Con Edison uses LiDAR data to determine the line height above the ground and to track changes in line clearance due to changes in the built and natural environment. Insufficient clearance presents a safety risk if standard measures such as vegetation management do not alleviate the risk. If standard measures cannot be applied, the lines would have to be derated and investments would be needed to replace the diminished capabilities of the line.

5.2. Operations and Planning Vulnerabilities

Three core operational and planning functions are affected by gradual changes in temperature: asset ratings, load relief planning, and load forecasting.

Asset Ratings

Exceeding the established reference temperatures of an asset operating at peak load will result in degradation. While some of these reference temperatures come directly from industry specifications, others have been informed by Con Edison's operational and engineering experience. For example, the 40°C ratings for disconnect switches are based on an Institute of Electrical and Electronics Engineers (IEEE) standard, the ratings for overhead transmission lines are based on a dataset from LaGuardia Airport, and substation transformer ratings are updated annually based on the historical hottest day on which a system peak load occurred. Con Edison uses 92.1°F as the reference temperature for rating substation transformers. This reference temperature was established based on the highest daily mean temperature in Central Park on July 7, 1999. This temperature has not been exceeded to date. Con Edison's rating specifications for transmission line reference temperatures are currently based on the 1995 New York Power Pool *Tie-Line Ratings Task Force Final Report*. This report relies on weather station data from LaGuardia Airport from 1983 to 1992, which is a short historical time period and does not include recent data. Overall, key operating ambient reference temperatures span a wide range, from 77° to 95°F, with 86°F and 95°F as more common reference temperatures (see Appendix 1.D – Climate Information). Note that daily mean temperature can serve as a proxy for ambient temperature.

To better understand the potential divergence of future temperatures from the current ratings, the Study team identified how often these reference temperatures were exceeded historically. Historically (1976–2005) the probability of daily mean temperature exceeding these reference temperatures ranged from 0% to nearly 8%, depending on the temperature and location (Table 5).

Table 5 ■ Historical probability of daily mean temperature on a given day exceeding key ambient reference temperatures

Ambient *reference temp*[6] °F/°C	Historical daily probability of exceedance		
	Central Park	LaGuardia	White Plains
79°*F*/26°*C*	7.1%	7.9%	2.7%
86°/30°	0.6%	0.8%	0.08%
90°/32°	0%	0.03%	0%
95°/35°	0%	0%	0%

The probability of daily mean temperature exceeding these reference temperatures increases markedly over the course of this century, under both RCP 4.5 and 8.5. By 2080, reference temperatures would be exceeded at least 11.5% of the time and up to 30.1% of the time, using the 10th percentile of RCP 4.5 as a lower bound and the 90th percentile of RCP 8.5 as an upper bound.

[6] Daily average temperature

The projected shift toward warmer temperatures in Central Park, for example, is illustrated in Table 6.

Table 6 ■ Current and projected probability of exceeding key ambient reference temperature (average temperature) for high-priority assets (Historical data are for 1976 to 2005 in Central Park. Projected probabilities of exceedances are included for the range of the 10th percentile of RCP 4.5 to the 90th percentile of RCP 8.5)

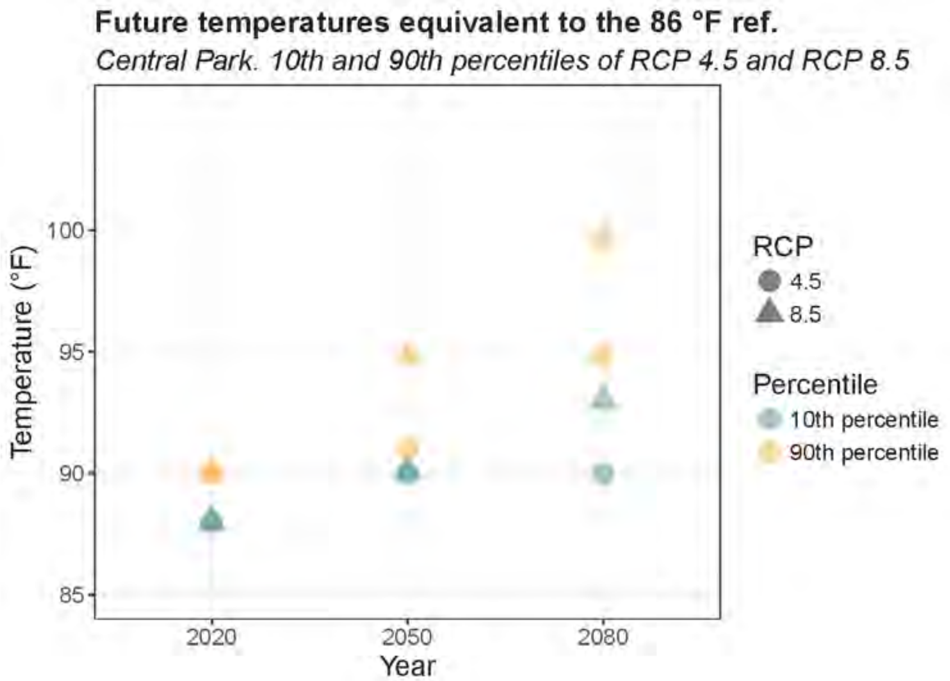
Ambient reference temp[7] °F/°C	Number of historical annual exceedances	Historical daily probability of exceedance	Projected probability of exceedance by		
			2030	*2050*	*2080*
79°F/26°C	26 days	7.1%	8.8%–15.3%	11.5%–22.2%	11.5%–30.1%
86°/30°	2 days	0.5%	1.1%–3.8%	1.9%–7.1%	1.9%–16.2%
90°/32°	0 days	0.0%	0.1%–1.1%	0.3%–3.0%	0.5%–8.2%
95°/35°	0 days	0.0%	0.0%–0.0%	0.0%–0.3%	0.0%–3.0%

If transformers become derated due to increasing temperatures, the most significant impact to Con Edison would be financial. When the capacity of the system is decreased, Con Edison must make investments to replace that capacity. The decrease in capacity is approximately 0.7% per °C (0.38% per °F) for substation power transformers and 1.5% per °C (0.8% per °F) for overhead transmission conductors (Sathaye et al., 2013). To identify the potential cost implications of derating these assets, we chose to identify the range of future ambient temperatures that are expected to be exceeded the same percentage of the time that reference temperatures were exceeded historically. This method then includes the historical tolerances for some climate variability. For example, the temperature value of the 0.6% "event" in Central Park (historically 86°F) becomes 90°–94.8°F by 2050 (using the 10th percentile of RCP 4.5 as a lower bound and the 90th percentile of RPC 8.5 as an upper bound). This range of the potential new ambient temperatures equivalent to the current 86°F reference is shown in Figure 10, for representative time periods (centered on 2020, 2050, and 2080). Under all climate scenarios, the reference temperature of 86°F daily average temperature might need to be increased to 90°F sometime between the 2020 and 2050 time periods.[8]

[7] Daily average temperature

[8] As further discussed in Section 8, in the near-term, Con Edison's existing annual process of updating asset ratings and load forecasting using historic weather data should enable infrastructure operations and system capacity to keep pace with gradual changes in temperature. However, it will become more critical to proactively integrate climate projections into Con Edison operations and processes. It is important to note that near-term projections (e.g., for 2020) are based on statistical representations using a 30-year time slice, centered on the beginning of each decade (Appendix 1.A – Climate Model Information).

Figure 10 ■ Future temperatures equivalent to the 86°F reference temperature.



To better understand the potential impact of future temperatures on the Con Edison system due to operational changes in the rating of a range of assets, the Study team calculated the overall reduction in system capacity for 2030, 2050, and 2080. These near- and mid-term time horizons are useful for informing Con Edison's long-range plan, while the end-of-century information is relevant to the entire useful life of a long-lived asset replaced today. Using the projected temperatures that are expected to be exceeded the same percentage of time in future decades as in the past (illustrated in Figure 10) the capacity could be reduced by as little as 285 MW to as much as 693 MW by 2050.[9] This combined reduction in capacity (compared to the overall system capacity) is illustrated in Figure 11. This could potentially result in an additional capital cost of $237 million to $510 million compared to the 86°F reference temperature, as shown in Figure 12.

[9] For this analysis, reductions in capacity and the associated costs were calculated for overhead transmission, switching stations (including transmission and substation functionality), area station and subtransmission, and transformers (network).

Figure 11 ■ Potential capacity reduction and associated cost increases over time

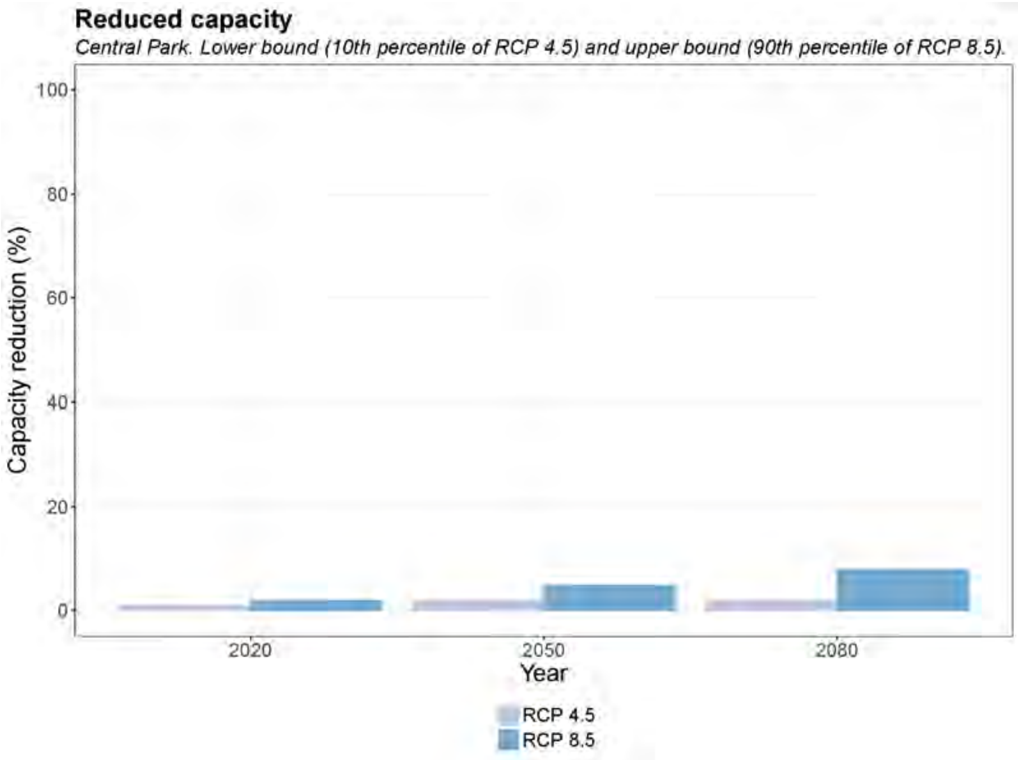
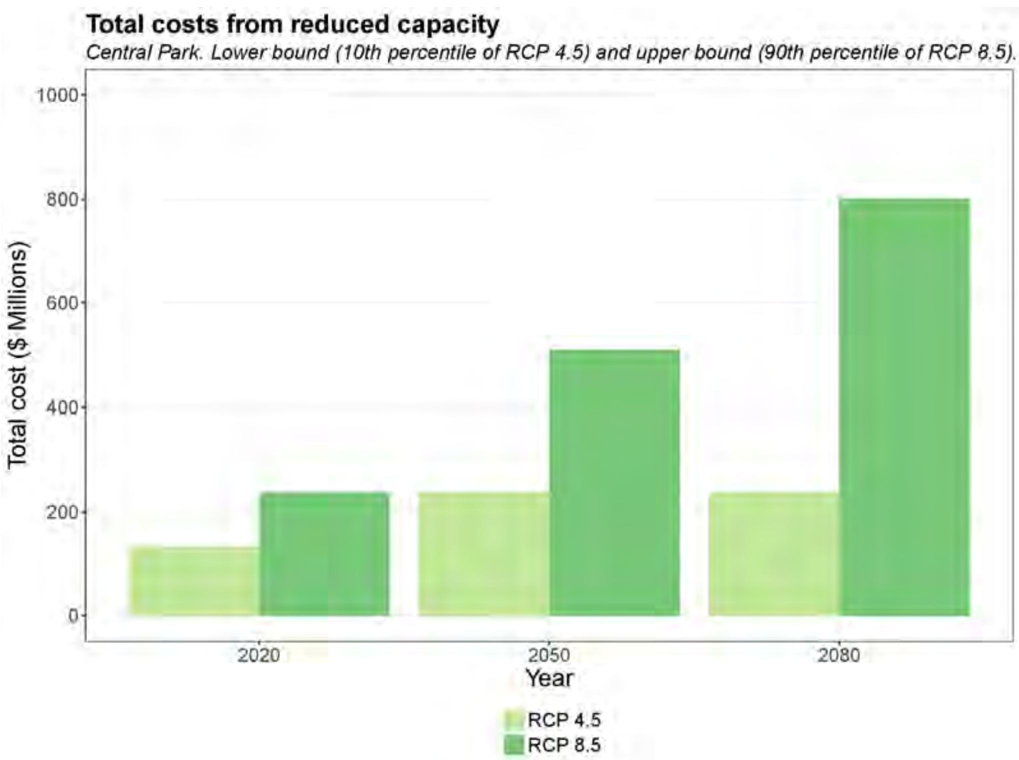


Figure 12 ■ Potential costs from capacity reduction over time



Load Relief Planning

Load relief planning relies on annual updates to asset ratings and load forecasts as inputs to develop a 10- and 20-year load relief investment plan (see Figure 13 and Figure 14). This plan specifies how Con Edison will invest to meet changes in load on each network. While temperature is not a direct input into the load relief planning process, it factors into both the asset ratings and load forecast inputs. In general, the appropriate investment option in the load relief plan is identified by running a cost-benefit analysis to determine the long-term tradeoffs of the various investment options. For example, installing cooling to increase the capability of a transformer may not be cost-effective if the load forecast shows increased demand in subsequent years, above and beyond the increase in capacity that cooling might provide. However, if the relatively low-cost option of installing cooling can defer the need for a larger investment for a significant period of time, it may be the most cost-effective option.

Figure 13 ■ Current 20-year load relief planning process

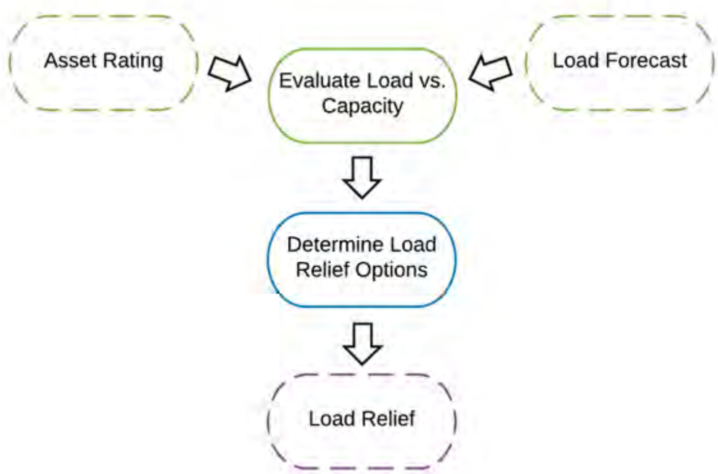
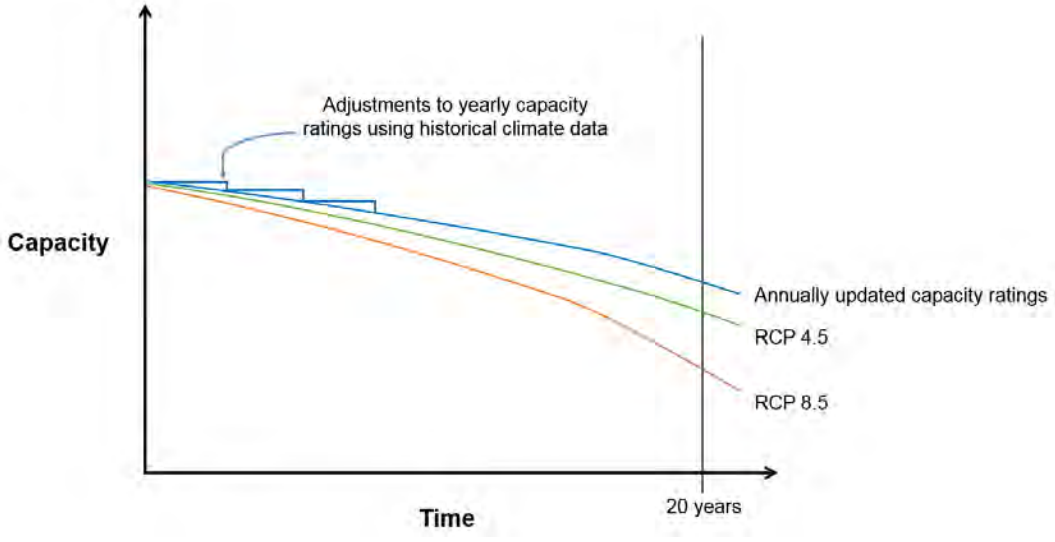


Figure 14 ■ Adjustments in capacity due to increases in temperature under RCP 4.5 and RCP 8.5, compared to rating capacity using historical climate data



Load Forecasting

Load forecasting, which is a component of load relief planning, relies on a historical set of daily temperature variable (TV) data, a combination of dry- and wet-bulb measurements over a 3-day period. Since this forecasting incorporates humidity, this is addressed in Appendix 2 of this report.

6. Adaptation Options

The Study team identified potential temperature adaptation options to address the identified physical vulnerabilities, and the operations and planning practices that consider temperature.

6.1. Adaptation Options for Physical Vulnerabilities

Area Substations

Install thermometers at substations to allow for location-specific ratings. As discussed, a transformer's capacity depends on the ambient temperature experienced at the site. This temperature is often very different from the ambient temperature component included in a nameplate rating (general industry guideline of 30°C) and the typical rating temperature (which for transformers is based on historical temperatures in Central Park, which tend to be cooler—due to the effect of trees and grasses—than other parts of New York City). Con Edison could consider installing thermometers at area substations and reporting the temperature data to a central database. Over time, this will allow ratings to be set based on location-specific data that account for factors such as urban heat islands.

Overhead Transmission Conductors

Track overhead lines with sag/clearance issues and adjust vegetation management practices, replace lines, remove obstacles, or, as a worst case, raise towers. Overhead lines can experience increased line sag when temperatures rise. To address this issue, limiting cable sections could be replaced with cable with higher ratings. Measures can also be taken to avoid the risk posed by sagging lines (such as clearing out vegetation, contouring terrain, or raising towers). Given how critical overhead lines are to the operation of the electric system, there is a preference for these options over derating assets. Con Edison should continue to track line sag and areas of vegetation and development changes via LiDAR flyovers to identify new segments that may require adaptation.

Update the temperature data used for transmission line ratings. Overhead transmission lines are rated based on the 1995 New York Power Pool *Final Report on Tie-Line Ratings*, which relies on weather data from 1983 through 1992. This historical data set does not account for the full range of natural variability, or the increases in temperature over the last 26 years. Con Edison could consider updating the tie-line ratings study and committing to updating it on a regular basis (e.g., incorporating new data every 5–10 years).

Underground Assets

Make ground temperature data more accessible and track increases over time. The degree to which long-term increases in air temperatures will alter ground temperatures is currently unclear. Key uncertainties include lack of data, importance of soil moisture, and dependence on locally varying differences in soil characteristics and surface land cover. To better understand how air temperature may impact ground temperature, Con Edison could:

- Make existing ground probe temperature data more accessible across groups.

- Determine if additional ground temperature data collection points would be useful to identify if detrimental conditions were developing.
- Track ground temperature over time to:
  - Determine ground temperature relationship to air temperature in different areas of the Con Edison territory
  - Determine if ground temperature approaches a reference temperature past which impacts would occur on below-grade infrastructure.

6.2. Adaptation Options for Operational and Planning Vulnerabilities

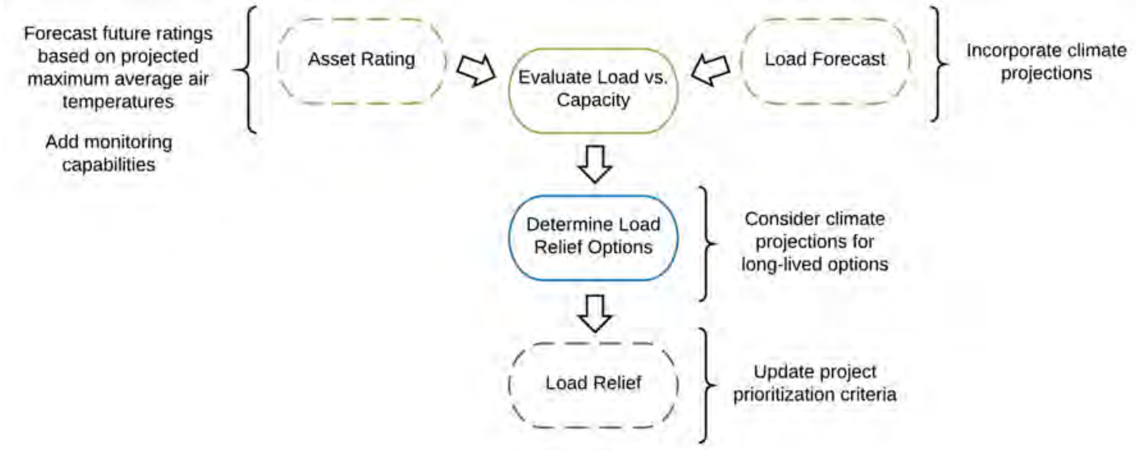
Asset Ratings

Routinely review asset ratings in light of historical observed temperatures and utilize a consistent ambient reference for developing ratings. Across assets, there are varied approaches to reviewing and updating ratings. The temperatures used for the ratings should be included in routine reviews to ensure they are in line with recent historical observed temperatures. For each equipment type, the process for conducting this review and the frequency with which it takes place should be specified and agreed upon.

Assess future asset ratings using temperature projections and incorporate results into the load relief planning process. As shown in Section 5, future changes in ratings due to gradually increasing temperatures will likely have a nontrivial impact on network capacity. In order to maintain capacity over time, the impact of future changes in temperature on equipment ratings should be incorporated into the load relief planning process (see Figure **15**). To facilitate this change in planning, the applicable engineering groups should use their various rating software to calculate a time series of future equipment ratings using projected temperature data. These future rating data should be supplied to the load relief planning group to prepare the load relief plan.

Monitor climate science and update climate projections at least every 5 years. Climate science continues to evolve, and the future should become more certain as we move forward in time. It is therefore important for Con Edison to continue to update climate change projections used for asset design and operations/planning according to the best available science. Updating projections more frequently than every 5 years is likely unnecessary because it takes time for new climate projections to become available in light of existing model development cycles and changes in projections generally evolve gradually. However, Con Edison should monitor climate science in case advances of particular relevance would warrant additional updates.

Figure 15 ■ Load relief planning process with potential adaptation options overlaid



Load Forecasting

Incorporate climate change projections into load forecasting. In addition to affecting equipment capacity, changes in temperature may also affect Con Edison's load (e.g., increased summer temperatures may increase cooling demand). To better understand future changes in load due to future changes in climate, the Con Edison Load Forecasting group should incorporate climate projections into load forecasting. Because the climate data used in load forecasting should include humidity information, this idea is explored more thoroughly in Appendix 2.

Load Relief Planning

Develop a load relief plan that integrates future changes in climate and other critical factors. As discussed above, climate change projections can feed directly into asset ratings and load planning, which are primary inputs to the annual load relief planning process. To meet changes in capacity and load, Con Edison currently relies on an extensive list of load relief options.

Several physical adaptation measures could be implemented to increase network capacity or reduce demand, depending on the projected gap in capacity to meet the load, site constraints, potential for energy efficiency, and other considerations specific to the system location. The least costly of these is to add capacitor banks or upgrade limiting components (such as circuit breakers, disconnect switches, and/or buses). At increasing cost, transformer cooling could be installed, additional transformers could be added, or limiting transformers could be replaced. The most expensive of these options would be to establish a new area substation, and possibly a new switching station. Operations may also offer relief. The range in capacity and unit costs for these options are:

- Add capacitor banks.
- Upgrade limiting components (such as circuit breakers, disconnect switches, and/or buses).
- Install transformer cooling.
- Add transformers or replace limiting transformers.
- Utilize distributed generation.
- Establish a new area substation or switching station.

In addition to these options related to physical assets, load relief can be provided through operational or program changes. These include:

- Transfer the load to an existing substation that has capacity.
- Implement additional or expanded energy efficiency, demand response, or other demand-side management programs.

Con Edison often uses a combination of load relief options to meet projected changes in capacity and load. For example, to meet growing load in the Brownsville Load Area, Con Edison proposed using a range of operational measures, traditional utility infrastructure measures, non-traditional customer-side measures, and non-traditional utility-side measures to defer the construction of a $1 billion substation construction project (Con Edison, 2014).[10]

These load-relief options are not expected to change in a warming climate, although it is possible that non-wires solutions—a portfolio of energy efficiency, demand-response, and distributed energy resources, etc.—may become less dependable because they are more sensitive to uncertainty in load and temperature. Non-wires solutions tend to be implemented just in time to counteract load growth (i.e., they "follow the curve" of load growth) which means they provide little buffer for unanticipated changes in load. More traditional solutions have the benefit of providing excess capacity in the system after installation, which ensures the utility has the capacity to absorb higher rates of load growth and temperature change. On the other hand, non-wires solutions may be very appropriate for addressing gradual increases in load due to gradually increasing temperature. In addition to the increases in capacity, non-wires solutions provide the benefit of reducing electricity use, which has a positive carbon impact.

While adding cooling, a new transformer, or a new substation would provide load relief and reliability benefits, a new substation may also increase reliability. Alternatively, non-wires solutions could be implemented at the customer and/or utility level to help reduce network load affecting an area substation.

Long-Term Planning

Track temperature-related costs and impact thresholds over time. With gradual changes in temperature, it can be difficult to understand how significant the impacts are and how exactly they are changing over time. To help understand the costs associated with changes in temperature, the Work Expenditures group could tie expenditures (e.g., repair/maintenance costs, outage costs, and increased customer service calls) to specific reference temperatures to allow for tracking and correlation of damage from temperature.

Grid Modernization

Continue to invest in grid modernization to increase resilience to climate change. One of the objectives of Con Edison's grid modernization program is to increase the resilience of the grid to extreme weather and climate change. For example, efforts include distribution automation, grid edge sensing (environmental, AMI), asset health monitoring, conservation voltage optimization, and targeted system upgrades. The combined result will be a grid with added insights on the driving factors of load on the system, including the effect of climate conditions. It will also facilitate informed response strategies to maintain high reliability and resiliency under changing conditions.

[10] For more information on the implementation specifics of this program, see the *Brooklyn Queens Demand Management Demand Response Program Guidelines,* 2016. Available at: https://www.Con Edison.com/-/media/files/Con Edison/documents/business-partners/business-opportunities/bqdm-demand-response/bqdm-dr-program-overview.pdf

7. Costs and Benefits of Adaptation Options Under a Range of Possible Futures

The Con Edison load relief planning process considers the costs and benefits of different options. To ensure that Con Edison incorporates considerations of future climate change resilience into planning, the process should consider a range of possible climate futures and should incorporate metrics for resilience.

Con Edison currently considers costs and benefits to evaluate response options through the Reforming the Energy Vision (REV) benefit-cost analysis framework (Con Edison, 2016), which promotes innovative, decentralized, and less energy-intensive load relief options. Prominent among these is the unit cost of a particular option per MW of delivery capacity, as well as an option's "social cost." Social cost accounts for the monetization of air pollution and carbon dioxide using 20-year forecasts of marginal energy prices, the cost of complying with regulatory programs for constraining these pollutants, and the price paid for renewable energy credits (if applicable). The social cost metric also qualitatively accounts for avoided water and land impacts. Beyond these environmental aspects, social cost accounts for net avoided restoration and outage costs to Con Edison, as well as net non-energy benefits (such as avoided service terminations, avoided uncollectable bills, and avoided noise and odor impacts).

The Study team considered a variety of additional complementary metrics that could be included in the load relief planning process to account for the range of possible increasing temperatures. These fall into two categories: "co-benefits" and "adaptation benefits."

Co-benefit metrics include reputational, safety, and customer financial benefit metrics:

- Reputational—captures the extent to which a response option is valued or opposed by public stakeholders.
- Safety—captures the extent to which a response option avoids injuries or fatalities. This includes Con Edison worker safety and public safety. For example, more modern equipment generally improves safety over the lifetime of the asset, but installation may pose some worker risks.
- Customer financial benefits—captures the extent to which a response option affects customer costs. For example, construction of new large assets may be accompanied by rate increases to offset construction costs, while customers may benefit from rebates due to expanded energy efficiency, demand response, or other demand-side management.

Under a non-stationary climate, co-benefits can help planners more comprehensively evaluate response options in light of additional challenges that climate change can pose on the system.

To support long-term planning under the wide range of possible increases in temperature over the century, it is important to evaluate the adaptability of response options themselves. Adaptation metrics include flexibility, reversibility, robustness, proven technology, and customers' resilience:

- Flexibility—captures the extent to which a response option can be scaled up or modified over time to accommodate increasing needs and accelerated changes in climate.
- Reversibility—captures the extent to which a response option can be removed if it becomes unnecessary or another course of action becomes preferred.
- Robustness—captures the extent to which a response option is effective across a range of climate change futures. In general, the larger increase in capacity achieved by an adaption option, the more likely it is to be robust across possible climate futures.
- Proven technology—captures the extent to which a response option is known to provide the needed response. For example, some new technologies may not be extensively tested under a wide range of conditions, may lack demonstrated feasibility, or may provide uncertain levels of risk reduction.
- Customers' resilience—captures the extent to which a response option increases the customer's own resilience to climate hazards. For example, customer-sided distributed energy resources (e.g., battery storage) and energy efficiency allow customers to maintain basic services for a longer duration during some types of extreme events.

These metrics allow for effective implementation of adaptation measures over time to achieve resilience. Table 7 illustrates an evaluation of the portfolio of capital investment and non-wires solution responses for substation equipment, including transformers and for transmission feeders. Therefore, we have scored the load relief measures by their adaptation value to an uncertain climate future. We have done this simply by weighting the assigned high, moderate, negligible, and negative values (2, 1, 0, and -1, respectively). A higher score suggests the load relief measure would be a better climate adaptation choice given the current range of climate projections. These scores could be incorporated into Con Edison's current benefit-cost analysis.

Table 7 ■ Multi-criteria matrix of response options. For each potential response option, co-benefits and adaptation benefits categories are rated as negative (-1), negligible (0), moderate (1), or high (2).

Load Relief Measure	Adaptation Resilience Score	Co-Benefits			Adaptation Benefits				
		Reputational	Safety	Customer Financial Benefits	Flexibility	Reversibility	Robustness	Proven Technology	Customer's Resilience
Utility distributed generation	*8*	*High* (Investing in distributed generation may be popular with customers)	*Negligible* (No significant benefits)	*High* (May decrease customer costs)	*High* (Con Edison could enter into contracts for additional distributed generation)	*Moderate* (Cost-prohibitive to remove generation sources due to contract obligations)	*Moderate* (Can be scaled to provide benefits under most climate scenarios)	*High* (Known to provide needed benefit)	*High* (Provides benefit if equipment allows for islanding)
Storage (e.g., batteries)	*7*	*High* (Customers are in favor of non-wires solutions)	*Negligible* (No significant benefits)	*High* (Rate structures may provide incentives)	*High* (It is possible to increase programs as needed)	*Moderate* (The system can be turned off or retired in place)	*Moderate* (Can be scaled to provide benefits under most scenarios)	*Moderate* (Technology not as well established as others)	*High* (Provides benefit if equipment allows for islanding)
Implement additional or expanded energy efficiency, demand response, or other demand-side management	*6*	*High* (Customers are in favor of non-wires solutions)	*Negligible* (No significant benefits)	*High* (Customers get rebates and lower bills)	*High* (It is possible to increase programs as needed)	*Moderate* (It is possible to end programs as needed)	*Moderate* (Can be scaled to provide benefits under most scenarios)	*Moderate* (Technology not as well established as others)	*Moderate* (Allows for longer duration sheltering in place during extreme heat events)
Add capacitor banks	*5*	*Negligible* (The customer is not aware of this change)	*Moderate* (Installation may pose risk)	*Negligible* (No significant benefits)	*Moderate* (More capacitor banks could be added as needed, but may be space-constrained)	*Moderate* (Assets can be removed from the rate base)	*Moderate* (Only provides benefits under some climate scenarios)	*High* (Known to provide needed benefit)	*Negligible* (No significant benefits)
Install transformer cooling	*5*	*Negligible* (The customer is not aware of this change)	*Moderate* (Installation may pose risk)	*Negligible* (No significant benefits)	*Moderate* (More cooling could be added as needed, but may be space-constrained)	*Moderate* (Once installed, cooling could be removed)	*Moderate* (Cooling will only provide load relief up until a certain point)	*High* (Cooling is known and tested to reduce transformer temperature)	*Negligible* (No significant benefits)

Load Relief Measure	Adaptation Resilience Score	Co-Benefits			Adaptation Benefits				
		Reputational	Safety	Customer Financial Benefits	Flexibility	Reversibility	Robustness	Proven Technology	Customer's Resilience
Solar	*5*	*High* (Customers are in favor of solar)	*Negligible* (No significant benefits)	*High* (Net metering)	*High* (It is possible to increase programs as needed)	*Negative* (It is difficult to remove solar)	*Moderate* (Can be scaled to provide benefits under most scenarios)	*Moderate* (Technology not as well established as others)	*High* (Provides benefit if equipment allows for islanding)
Conservation voltage optimization	*5*	*High* (Customers are in favor of non-wires solutions)	*Negative* (Infrastructure will need to be built, operated and maintained)	*Moderate* (Rate structures may provide incentives)	*Moderate* (It is possible to increase programs as needed)	High (Equipment settings can be changed)	*Negligible* (Capacity is fairly close to planned need)	*High* (Utilized in previous implementations)	*Negligible* (No significant benefits)
Transfer load to existing substation that has capacity	*5*	*Negligible* (The customer is not aware of this change)	*Negligible* (No significant benefits)	*Moderate* (Cost avoidance of new capacity and use of existing rate based capital)	*Moderate* (It is possible to transfer additional load as needed)	*Moderate* (It may be possible to transfer load to another network)	*Moderate* (Provides benefits under most scenarios)	*High* (Known to provide needed benefit)	*Negligible* (No significant benefits)
Micro grids	*4*	*High* (Customers are in favor of non-wires solutions)	*Negative* (Infrastructure will need to be built, operated, and maintained)	*Moderate* (Could eliminate burden of societal costs in rates)	*Moderate* (It is possible to increase participants within boundaries)	*Negative* (It is difficult to stop supporting micro grids)	*Moderate* (Can be scaled to provide benefits under most scenarios)	*Moderate* (Technology not as well established as others)	*High* (Provides benefit as arrangement relies on islanding with utility backup)
Establish a new area substation or new switching station	*4*	*Negative* (Large new construction project may not be popular with customers)	*Negative* (Installation and subsequent ongoing operation may pose safety risk)	*Negative* (Construction of large assets may be accompanied by rate increases to offset construction costs)	*Moderate* (It is possible to add additional capacity)	*Negative* (It is not practical to remove a station)	*High* (Provides required increase in capacity and future potential)	*High* (Known to provide needed benefit with contingency)	*Negligible* (No significant benefits)

Load Relief Measure	Adaptation Resilience Score	Co-Benefits			Adaptation Benefits				
		Reputational	Safety	Customer Financial Benefits	Flexibility	Reversibility	Robustness	Proven Technology	Customer's Resilience
Add transformers or replace limiting transformers	*3*	*Negligible* (The customer is not aware of this change)	*Moderate* (Installation may pose risk, but overall new equipment will provide long-term safety benefits by being modernized)	*Negligible* (No significant benefits)	*Negative* (Most cost-prohibitive option and highly space-constrained)	*Moderate* (Transformer can be removed from rate base.)	*Moderate* (Provides load contingency benefits under most scenarios)	*High* (Known to provide needed benefit with contingency)	*Negligible* (No significant benefits)
Upgrade limiting components (e.g., circuit breakers, disconnect switches, and/or buses)	*2*	*Negligible* (The customer is not aware of this change)	*Moderate* (Installation may pose risk, but overall the new equipment will provide long-term safety benefits)	*Negligible* (No significant benefits)	*Negative* (Upgrades will only provide benefits up to a certain point)	*Negligible* (No significant benefits)	*Moderate* (Upgrades will only provide benefits up to a certain point)	*High* (Known to provide needed benefit)	*Negligible* (No significant benefits)

8. Implementation of Temperature Adaptation Options Over Time

As noted in the report, supporting flexible solutions and adaptive implementation pathways will allow Con Edison to manage risks from a changing climate. As described in Section 5 of this appendix, Con Edison already has an iterative process in place to guide the implementation of load relief options over time. Con Edison has a 20-year load relief plan, which informs (and is informed by) its 20-year strategic plan. These 20-year plans are updated frequently (e.g., about every 4 years). Con Edison's 10-year load relief plan is updated annually, based on current capacity and forecasted load, and is used to inform budgets.

To strengthen Con Edison's planning process against risks posed by increasing temperatures, and the ranges of temperatures, the Con Edison Load Forecasting group could plan for projected loads that incorporate projected climate conditions (e.g., corresponding to the 50th percentile of RCP 8.5).

Con Edison's long-term plan extends nearly to 2040, which is just before when projections from RCP 4.5 and RCP 8.5 begin to diverge substantially (e.g., by 2050). Although this planning period is mostly before the divergence in greenhouse gas emissions scenarios, plans made for this period can have longer-term implications. This is particularly true for energy sector infrastructure, where many assets have long lifespans.

Con Edison could use signposts to adjust planning as we approach 2030, 2040, and 2050. Signposts are metrics that can be tracked to understand how conditions are changing over time. Con Edison already uses signposts to track the assumptions in its long-range plans, including forecasts of the local economy, employment, demographics, and shifts in energy use patterns. For example, these include different assumptions of U.S. GDP growth, employment growth, population growth, and change in energy efficiency and conservation (in terms of peak reduction).

An indicator—the actual measure of information being tracked, which may relate to a particular threshold of change—for a signpost can be integrated in the adaptive implementation pathways approach and assist decision-making regarding which climate projection to plan for (e.g., RCP and percentile, or range thereof) because it is most appropriate for local conditions.

The following temperature signposts for our service area may be informative:

- Number of days over specified reference temperatures
- Rate of change in key temperature climate variables
- Estimated reduction in system capacity due to increases in temperature projected for 1, 5, 10, and 20 years from present
- Average change in asset service life from extreme temperatures

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Appendix 1.A – Climate Model Information

Data Processing

For each global climate model (GCM) and temperature climate variable, the nearest land-based grid box covering the station of interest was extracted. Of the 32 GCMs used, only 5 of the models used multiple (2) grid boxes.

As a first step, histograms of the observed data were compared to histograms of the model output for the associated station over the common time period of 1976–2005 to correct bias between the simulations of historical climate by the GCMs and the observed historical climate. Bias correction is necessary for a variety of reasons: most fundamentally, the spatial extent of GCM grid boxes is approximately 10,000 km^2, leading to a scale mismatch with station data. This reflects the fact that features such as the elevation and surface properties at the GCM scale are different from those at the station level. Bias correction can also address any systematic errors in the models, such as a tendency for baseline temperatures to be too warm, or too low, in individual models at a given point in the distribution, even in comparison to the same spatial scale in observations. As expected, this analysis revealed significant mean differences between the observations and the model projections, as well as differences in measures of the distribution of the data, such as variance.

We next compared each GCM's baseline (1976–2005) temperature histogram to the same GCM's histogram for a future time period when greenhouse gas forcing was high (e.g., 2080 under RCP 8.5). As in the preliminary analyses outlined in the previous paragraph, we found strong evidence that the differences (here, the amount of warming; in the previous preliminary analysis, the bias) were not consistent across the entire distribution of temperatures. As one example, in some models the hottest days are projected to warm more than the summer mean in the same model.

As a result of these two steps, we experimented with several bin sizes for the bias correction, ultimately settling on 1 percentile bins, representing a middle ground between (1) capturing rich information about how both bias and warming can differ across the distribution of temperatures, and (2) including a sufficient number of days per bin (over 100 days across the 30-year period) to minimize the role of random variability associated with small sample sizes.

For each GCM and RCP, a 30-year time slice was created, centered on the beginning of each decade, from 2020 to 2080. For example, projections for 2030 contained model outputs from 2016 to 2045. The observed data and outputs were further divided into seasons, based on the climatological definitions of winter (December, January, February), spring (March, April, May), summer (June, July, August), and fall (September, October, November). For each 30-year time period, model, RCP, season, and station, the bias correction and downscaling approach was conducted as follows:

- Each observed day between 1976 and 2005 was assigned a temperature percentile. The same procedure was applied separately to the GCM data in the base period and in a future period. For example, if October 8, 1984, was in the 33rd percentile of fall days in the observations, the warming experienced in the GCM at the 33rd percentile of temperatures in the two time periods (e.g., 4°F) was applied to the observed day. The resulting dataset can be thought of as a synthetic time series, based on the sequence of weather experienced at the station historically, but modified by the amount of warming projected by each GCM in the temperature percentile associated with each day.
- The synthetic time series was next used to calculate the temperature metrics sought by Con Edison (e.g., the number of days per year above 100°F). To inform risk management, these

metrics were provided for the 10th, 25th, 50th, 75th, and 90th percentiles of the distribution of climate projections per RCP. For example, the 90th percentile can be thought of as the result for which approximately 10% of the models produced a higher total (of days above 100°F), and 90% provided a lower total.

Key Uncertainties

Observed data may contain errors and do not reflect conditions across all the Con Edison service region. RCPs represent possible futures, not most likely outcomes. Climate models are imperfect and may not sample the full range of possible outcomes in terms of overall warming and the distribution of temperature extremes. For example, models may fail to simulate key processes that could change with climate change, such as potential changes in the jet stream or in soil moisture. Future changes in microclimatic features, such as the urban heat island or coastal sea breezes, also are not captured through our GCM-based approach. Because our approach anchors the projections on the observations experienced during a 30-year period, it may miss potential outcomes that could have been experienced during those 30 years; this is especially likely for extremely rare events, such as the 1-in-100 year heat event. However, given potential natural variability on decadal to centennial timescales, which is not fully understood, the basic statistics of even more common extremes could differ somewhat in the future independent of the influence of climate change. For all the above reasons and more, it is critically important that the model-based projections be treated as just that: model-based distributions, rather than estimates of actual predictions of occurrence.

Comparison to New York Panel on Climate Change

Key differences between this approach and that of the New York Panel on Climate Change (NPCC) 2015 assessment[11] include (1) our use of three stations (NPCC considered only Central Park), (2) application of warming factors from the GCMs based on daily (our analysis) rather than monthly (NPCC analysis) data, (3) bias correction through the application of 1 percentile bins (our analysis) rather than universally across the entire distribution (the delta method), and (4) calculation of an expanded set of temperature metrics.

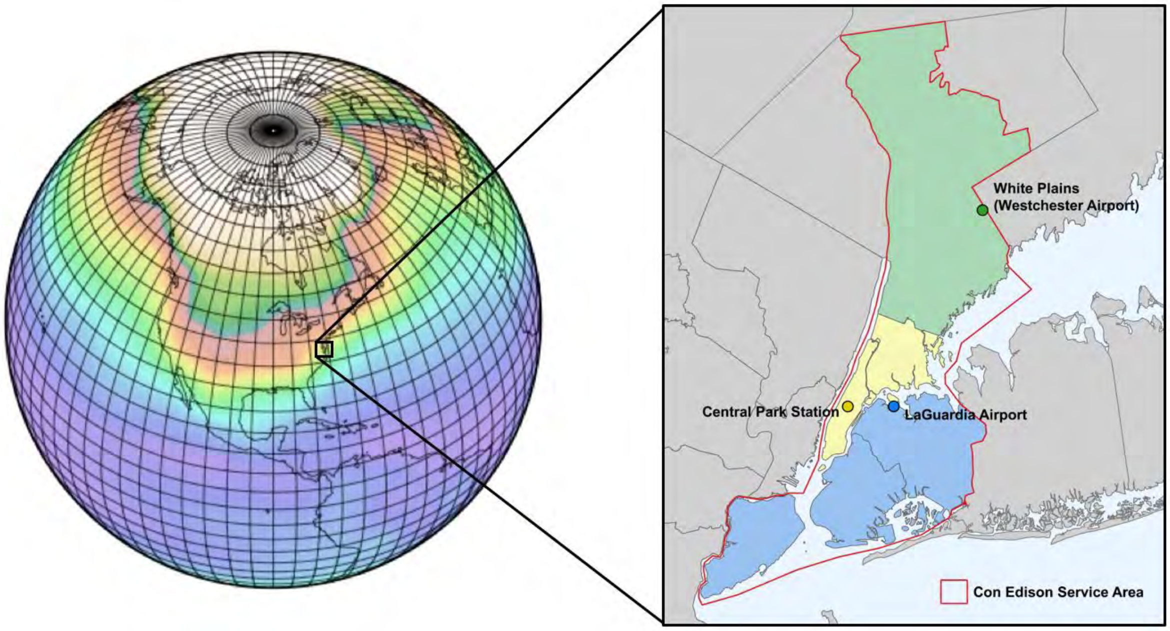
Table 8 lists the GCMs (Global Climate Models) used in the study, along with model institute information.

[11] Horton, Radley, et al. "New York city panel on climate change 2015 Report. Chapter 1: Climate observations and projections." *Annals of the New York Academy of Sciences* 1336.1 (2015): 18-35.

Table 8 ■ 32 Global Climate Models (CMIP5) used in the study analysis

Model Name	Institute ID	Modeling Center (or Group)
ACCESS-1.0	CSIRO-BOM	Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia
ACCESS-1.3	CSIRO-BOM	Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia
BCC-CSM1-1-M	BCC	Beijing Climate Center, China Meteorological Administration
BCC-CSM-1	BCC	Beijing Climate Center, China Meteorological Administration
BNU-ESM	BNU	Beijing Normal University
CanESM2	CCCMA	Canadian Centre for Climate Modelling and Analysis
CCSM4	NCAR	National Center for Atmospheric Research
CESM1-BGC	NSF-DOE-NCAR	Community Earth System Model Contributors
CESM1-CAM5	NSF-DOE-NCAR	Community Earth System Model Contributors
CMCC-CM	CMCC-CM	CMCC
CMCC-CMS	CMCC-CMS	CMCC
CNRM-CM5	CNRM-CM5	CNRM-CERFACS
CSIO-Mk3-6-0	CSIRO-QCCCE	Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence
EC-EARTH	EC-EARTH	EC-EARTH consortium
FGOALS-g2	FGOALS-g2	LASG-CESS
GFDL-CM3	GFDL-CM3	NOAA GFDL
GFDL-ESM2G	GFDL-ESM2G	NOAA GFDL
GFDL-ESM2M	GFDL-ESM2M	NOAA GFDL
HadGEM2-AO	NIMR/KMA	National Institute of Meteorological Research/Korea Meteorological Administration
HadGEM2-CC	MOHC (additional realizations by INPE)	Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)
HadGEM2-ES	MOHC (additional realizations by INPE)	Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)
INMCM4	INM	Institute for Numerical Mathematics
IPSL-CM5a-LR	IPSL	Institut Pierre-Simon Laplace
IPSL-CM5a-MR	IPSL	Institut Pierre-Simon Laplace
IPSL-CM5B-LR	IPSL	Institut Pierre-Simon Laplace
MIROC5	MIROC	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
MIROC-ESM-CHEM	MIROC	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
MIROC-ESM	MIROC	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
MPI-ESM-LR	MPI-M	Max-Planck-Institut für Meteorologie (Max Planck Institute for Meteorology)
MPI-ESMMR	MPI-M	Max-Planck-Institut für Meteorologie (Max Planck Institute for Meteorology)
MRI-CGCM3	MRI	Meteorological Research Institute
NorESM1-M	NCC	Norwegian Climate Centre

Figure 16 ■ Global climate model, adapted from Carleton College, 2017



Appendix 1.B – Glossary

This glossary defines key terms used throughout Appendix 1.

Derate – A decrease in the available capacity of an electric generating unit, commonly due to:

- A system or equipment malfunction
- Environmental, operational, or reliability considerations. Causes of generation capacity deratings include high cooling water temperatures, equipment degradation, and historical performance during peak demand periods. In this context, a derate is typically temporary and due to transient conditions.

The term derate can also refer to discounting a portion of a generating unit's capacity for planning purposes (U.S. EIA).

Impact – Effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes (IPCC, 2014).

Load relief – Application of capacity improvement or load reduction measures to address projected increases in asset loading that exceed design parameters (e.g., capacity improvement with transformer cooling or load reduction through customer energy efficiency).

Non-wires solutions – Actions or strategies such as energy efficiency measures or demand response programs that could help defer or eliminate the need to construct or upgrade a transmission system and distribution substations (DOE, 2012).

Reference temperature – Reference temperatures are used for planning and operations and provide an indicator of where individual climate variables become problematic for an asset or system.

Risk – The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard (IPCC, 2014).

Sensitivity – The degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise) (IPCC, 2014).

Vulnerability – The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC, 2014).

Appendix 1.C – Asset Information

Table 9 provides the asset and variable combinations that were rated as of highly sensitivity by Con Edison subject matter experts. These ratings were used in the asset prioritization process to determine the assets at highest risk from temperature-related hazards.

Table 9 ■ Asset and temperature climate variable combinations with high sensitivity, as rated by Con Edison subject matter experts

Functional Area	Asset	Variable(s)
Transmission Feeders	Transmission line/Conductor Cables	Average Air Temperature, Maximum Air Temperature
	Underground Feeder	Ground Temperature
	Pumping Station	Average Air Temperature
Substation, Transmission & Area	Transformer	Average Air Temperature, Maximum Air Temperature
	Bus, SF6	Average Air Temperature, Maximum Air Temperature
	Bus, Open Air	Average Air Temperature, Maximum Air Temperature
	Bus, Metal Clad	Average Air Temperature, Maximum Air Temperature
	Cable, Underground	Ground Temperature
	Relays, Controls	Average Air Temperature, Maximum Air Temperature
	Disconnect Switch	Average Air Temperature, Maximum Air Temperature
	Circuit Breaker	Average Air Temperature, Maximum Air Temperature
	CCPD	Average Air Temperature, Maximum Air Temperature
	Capacitor Bank	Average Air Temperature, Maximum Air Temperature
	Insulator	Average Air Temperature, Maximum Air Temperature
	Communication Systems	Average Air Temperature, Maximum Air Temperature
	Battery Equipment	Average Air Temperature, Maximum Air Temperature, Nighttime Temperature, Diurnal Temperature Range
	Ventilation/HVAC (both noncritical and critical)	Average Air Temperature, Maximum Air Temperature
	Surge Arrestors	Average Air Temperature, Maximum Air Temperature

Functional Area	Asset	Variable(s)
Distribution, Underground	Primary Feeder	Ground Temperature
	Underground Cables/Conductors	Ground Temperature
	Switches	Average Air Temperature
	Transformer	Average Air Temperature
Distribution, Overhead	Cables/Conduits	Average Air Temperature, Maximum Air Temperature, Nighttime Temperature
	Transformer	Average Air Temperature, Maximum Air Temperature
Steam Generation	Coolant – Generator	Average Air Temperature, Maximum Air Temperature
	Motors (designed to 40°C)	Average Air Temperature, Maximum Air Temperature
	Power & Light	Average Air Temperature, Maximum Air Temperature
	Gas Turbines	Average Air Temperature, Maximum Air Temperature
	Emergency Generator	Average Air Temperature, Maximum Air Temperature
	Boiler	Average Air Temperature, Maximum Air Temperature
	Heat Exchanger (air)	Average Air Temperature, Maximum Air Temperature
	HRSG	Average Air Temperature, Maximum Air Temperature, Nighttime Temperature
Steam Distribution	Remote Monitoring	Maximum Air Temperature
	Condensate Cooling Chamber	Average Air Temperature, Ground Temperature
Customer Steam Station	Ventilation	Maximum Air Temperature
	Flow Computer	Maximum Air Temperature
Liquefied Natural Gas Plant	Heat Exchanger (air)	Average Air Temperature, Maximum Air Temperature, Nighttime Temperature, Diurnal Temperature Range
	Control Room	Maximum Air Temperature, Extreme Cold
	Security	Average Air Temperature, Maximum Air Temperature, Nighttime Temperature, Diurnal Temperature Range, Extreme Cold
	Vaporizer [MOV] (designed to 100°F or 110°F)	Maximum Air Temperature, Nighttime Temperature, Ground Temperature, Extreme Cold

Functional Area	Asset	Variable(s)
Substation, Unit	Transformer	Average Air Temperature, Maximum Air Temperature, Nighttime Temperature, Diurnal Temperature Range
	Bus, Open Air	Average Air Temperature, Maximum Air Temperature
	Bus, Metal Clad	Average Air Temperature, Maximum Air Temperature
	Cable, Underground	Ground Temperature
	Relays, Controls	Average Air Temperature, Maximum Air Temperature, Nighttime Temperature, Diurnal Temperature Range
	Disconnect Switch	Average Air Temperature, Maximum Air Temperature
	CCPD	Average Air Temperature, Maximum Air Temperature
	PTs	Average Air Temperature, Maximum Air Temperature
	Insulator	Average Air Temperature, Maximum Air Temperature
	Communication Systems	Average Air Temperature, Maximum Air Temperature, Nighttime Temperature
	Battery Equipment	Average Air Temperature, Maximum Air Temperature, Nighttime Temperature, Diurnal Temperature Range

Table 10 lists reference ambient temperatures for selected assets.

Table 10 Reference ambient temperature for selected assets

Group	Asset	Ref. Ambient Average Temperature °F/°C[12]	Note
Transmission	Overhead Transmission Conductor	86°F/30°C	Normal conductor design limit of 80°C. Emergency conductor operating limit of 100°C. Line sag, conductor annealing. Transmission lines rated for normal, Long-Term Emergency (LTE = 4 hours) and Short-Term Emergency (STE = 15 minutes)
	Underground Transmission Line	95/35	On forced cooled feeders, capacity loss is due to reduced cooling plant efficiency. Cooling plant rated at 35°C ambient
Substation	Power Transformer	92.1/33.4	Temperature is daily average ambient. Highest historical peak temperature variable (TV) day = 33.4°C, July 6, 1999. IEEE C57.91 assumes 30°C
	Bus Conductor (Indoor & Outdoor)	95/35	
	Disconnect Switch (Indoor & Outdoor)	95/35	
	Circuit Breaker (Indoor & Outdoor)	95/35	
Generation	Simple Cycle	59/15	
	Combined Cycle	59/15	
	Steam, Package		
	Steam, Cogeneration		
Distribution	Overhead Wire (Primary Feeder, Secondary Main & Secondary Service)	95/35	
	Overhead Transformer	86/30	Temperature is daily average ambient
	Network Transformer	78.8/26	Temperature is daily average ambient
	Underground Cable (Primary Feeder)	86/30	Temperature is earth temperature
	Underground Cable (Secondary Main)	77/25	Temperature is earth temperature
	Underground Cable (Secondary Vault Tie)	104/40	Temperature is vault temperature.

[12] Daily mean temperature

Table 11 lists all medium-risk assets and their associated reference temperatures. The table includes information on impacts if reference temperatures are exceeded, along with potential adaptation responses.

Table 11 ■ Reference temperatures, impacts, and adaptation options for medium-risk assets

Asset	*Known Reference Temperature and Impact if Exceeded*	*Adaptation Response*
Overhead Distribution Cables	35°C	• Derate the lines • Replace limiting cable sections
Underground Transmission Line	25°C ground temperature; performance; medium impact	• Derate the lines • Replace limiting cable sections
Underground Distribution Cables	30°C ground temperature; If exceeded performance issue with medium impacts	• Derate the lines • Replace limiting cable sections
Underground Transformer	26°C	–
Overhead Transformer	Unknown	–
Transmission Pumping Station	41°C ambient air temperature; medium impact	–
Ventilation and HVAC	Average air temperature: 95°F inside Maximum air temperature: 105°F	• Increase insulation • Add air conditioning
Steam Generation River Water Coolant	River water over 80°F may lead to discharge over max allowed by SPDES permit (95°F)	–
Steam Generation Heat Exchanger	Unknown; decreased efficiency when air temperatures are high. Rely on internal air.	• Add air conditioning
Steam Generation Gas Turbines	60°F average air temperature is the industry standard. Decreased output at temperatures that exceed the reference temperature. Currently experience significant derating in summer months but demand for steam is low in those months	• Cool the inlet air with air conditioning • Derate the turbines
Customer Steam Ventilation	100°F; Exceeding this temperature limits workers' ability to operate in the space	• Customer is responsible for cooling the space (increased ventilation or air conditioning)
Customer Steam Flow Computer	175°F; low likelihood of exceedance, but if this reference temperature was exceeded, there would be significant impacts at the site	• Customer is responsible for cooling the space (increased ventilation or air conditioning)

Table 12 list the assets that were rated as medium-risk to gradual changes in temperature. These ratings were calculated using the Risk Workbook.

Table 12 ■ Medium-risk assets

Functional Area	Asset	Variable	Probability of Exceeding Reference Temperature	Impact if Reference Temperature Exceeded	Consequence of Impact: Safety	Reliability	Financial Costs	Environmental Damage
Transmission Feeders	Pumping Station	Average air temperature	High	Medium	Low	Medium	Medium	Low
Substation, Transmission & Area	Ventilation/HVAC (Critical Facility)	Average air temperature Maximum air temperature	High	Low	Medium	High	Medium	Low
Distribution, Underground	Transformer	Average air temperature	High	Medium	Low	Medium	Medium	Low
Distribution, Overhead	Cables/conduits	Average air temperature Maximum air temperature	High	Medium	Low	Low	Medium	Low
Distribution, Overhead	Transformer	Average air temperature Maximum air temperature	High	Medium	Low	Medium	Medium	Low
Steam Generation	Coolant-Generator	Average air temperature Maximum air temperature	High	Low	Low	Medium	Medium	High
Steam Generation	Gas Turbines	Average air temperature Maximum air temperature	High	Medium	Low	Low	Low	Low
Steam Generation	Heat Exchanger (air)	Average air temperature	High	Medium	Low	Medium	Medium	Low

					Consequence of Impact			
Functional Area	Asset	Variable	Probability of Exceeding Reference Temperature	Impact if Reference Temperature Exceeded	Safety	Reliability	Financial Costs	Environmental Damage
		Maximum air temperature						
Steam Distribution	Remote Monitoring	Maximum air temperature	Low	High	High	Low	Low	Low
Customer Steam Station	Ventilation	Maximum air temperature	High	Low	High	Low	Low	Low
Customer Steam Station	Flow Computer	Maximum air temperature	Low	High	Medium	High	Medium	Low

Asset Prioritization Methodology

To prioritize assets for further analysis, the Study team assessed risk by screening for potential worst-case impacts of increasing temperature. This included using the projected annual values for each reference temperature, all three station locations (the station with the highest percentage change from historical records was ultimately used), RCP 8.5, the 2080 time period, and 90th percentile in the Risk Workbook. Using the upper range in projected temperature climate variables is a conservative approach that is appropriate for this risk screening step.

The Study team used climate information provided by CCSR to determine the probability of exceeding the reference temperature previously identified by SMEs (see Part 4. Risk-Based Prioritization of Asset Types) for each asset and variable combination. Because the reference temperatures previously identified by SMEs might not exactly match the available climate information, the Study team mapped the available climate information to the relevant reference temperatures and entered the climate information into the Risk Workbook wherever possible (see Table 13).

Table 13 ■ Mapping of climate information to Risk Workbook variables

Risk Workbook Variable	Climate Variable	Justification
Average Air Temperature	(Max Temp + Min Temp)/2	Variables are equivalent
Maximum Air Temperature	Maximum Temperature	Variables are equivalent
Nighttime Temperature	Minimum Temperature	Best match available
Extreme Cold	Cold Wave Frequency	Consistent with Heat Wave variable used
Ground Temperature	—	No corresponding variables
Diurnal Temperature Range	Maximum Temperature – Minimum Temperature	Derived via computation

To best match the climate information (i.e., probability of exceedance values) with the SME-identified reference temperatures, the Study team used the following approach:

- For variable and asset combinations with a specified asset reference temperature that matches a calculated climate variable temperature (i.e., the temperatures listed in Table 1), the Risk Workbook is populated with the corresponding climate information.
- For variable and asset combinations with no specified reference temperature, the Risk Workbook is populated with a master climate value. The master climate value is the SME-identified reference temperature that is most commonly cited in the Risk Workbook for the given climate variable (Average Air Temperature: 95°F; Maximum Air Temperature: 104°F; Nighttime Temperature: 15°F; Heat Wave Frequency or Duration: 86°F; and Extreme Cold: 15°F). Note that the SME-identified reference temperatures did not match any available climate information for Nighttime Temperature, hence the Study team chose a reference temperature based on a reasonable value.
- For variable and asset combinations with a SME-identified reference temperature that does not match any available climate information, the Study team manually populated the corresponding Risk Workbook row with the climate information for the nearest climate variable (either above or below). In some cases where reference temperatures were very high (e.g., a maximum air temperature reference of 175°F for Customer Steam Station Flow Computers), the Study team manually adjusted the climate information reference temperature rating to low, as it is highly unlikely this reference temperature will be exceeded under any future conditions.

Finally, the probability of exceedance values were categorized as high, medium, or low based on an even breakdown of values up to 100% (i.e., low, less than 33.3%; medium, 33.3% to 66.7%; high, greater than or equal to 66.7%).

The Study team then used the Risk Workbook to calculate the highest-risk assets. The overall climate risk score was calculated using probability of impact scores and consequence of impact scores. Probability of impact is scored based on ratings for probability of exceeding the reference temperature and the impact if the reference temperature is exceeded. Consequence of impact is scored based on ratings for safety, reliability, financial costs, and environmental damage consequences.

Appendix 1.D – Climate Information

Table 14 provides a comparison of localized constructed analogs (LOCA) data and data provided by Columbia University. The table compares average annual temperature, average summer temperature, average annual maximum temperature, average summer maximum temperature, and average annual minimum temperature across three locations (Central Park, LaGuardia Airport, and White Plains) for RCP 8.5 in 2080.

Table 14 ■ Comparison of two GCM downscaling approaches: Localized constructed analogs (LOCA) and the delta method. Data shown are for RCP 8.5 in 2080.

		Average Annual Temperature (°F)		Average Summer Temperature (°F)		Average Annual Maximum Temperature (°F)		Average Summer Maximum Temperature (°F)		Average Annual Minimum Temperature (°F)	
	Percentile	LOCA	Delta method	LOCA	Delta method	LOCA	Delta method	LOCA	Delta method	LOCA	Delta method
Central Park	10th	61.7	61.0	78.8	80.2	70.6	68.0	87.6	88.2	52.6	53.6
	50th	63.3	63.7	85.2	83.7	71.2	71.4	93.6	91.9	55.5	56.1
	90th	64.2	65.7	87.0	85.8	72.0	73.2	95.8	94.8	56.9	58.5
LaGuardia Airport	10th	61.9	61.2	77.8	80.8	69.2	67.6	86.0	88.0	54.4	54.3
	50th	63.4	63.9	84.8	84.2	70.8	70.9	92.5	91.9	55.9	56.8
	90th	64.3	65.8	87.0	86.4	71.6	72.9	95.2	94.6	57.0	59.2
White Plains	10th	58.4	57.2	75.5	76.8	68.3	64.9	86.2	85.5	48.2	48.9
	50th	60.7	60.1	81.6	80.4	70.0	68.4	91.9	89.4	51.2	51.8
	90th	63.0	61.9	85.3	82.4	71.6	70.0	95.5	91.6	54.9	53.8

Table 15 provides climate variables and key reference temperatures used in the analysis. The table provides data on average annual temperature, average summer temperature, average annual maximum temperature, average annual minimum temperature, average annual number of days with average temperature exceeding 86°F, and average annual number of days with average temperature exceeding 95°F. Values are shown for each time-slice (centered on 2020–2080) for both RCP 4.5 and RCP 8.5. Data provided by Columbia University.

Table 15 ■ Climate variables and key reference temperatures used in the analysis for the 30-year time-slices, 10-year increments from 2020–2080, both RCP 4.5 and RCP 8.5, and 3 locations (Central Park, LaGuardia Airport, and White Plains)

RCP	Location	Year	Percentile	Daily mean temperature (°F)	Daily mean temperature (Summer) (°F)	Daily maximum temperature (°F)	Daily maximum temperature (Summer) (°F)	Daily minimum temperature (°F)	Average annual number of days with average temperature exceeding 86°F	Average annual number of days with average temperature exceeding 95°F
RCP 4.5	Central Park	2020	10th	56.1	75.6	63.5	83.7	48.7	4	0
			50th	57.0	76.5	64.6	84.6	49.5	5	0
			90th	57.7	77.4	65.3	85.3	50.2	8	0
		2030	10th	56.5	75.6	63.9	84.2	49.3	4	0
			50th	57.7	77.2	65.3	85.3	50.0	7	0
			90th	59.0	78.1	66.2	86.4	51.3	11	0
		2040	10th	57.0	76.8	64.4	84.7	49.8	6	0
			50th	58.3	77.9	66.0	86.0	50.7	10	0
			90th	59.9	79.2	66.9	87.3	52.3	13	0
		2050	10th	57.4	76.8	64.8	84.7	50.2	7	0
			50th	59.2	78.4	66.7	86.9	51.6	12	0
			90th	60.4	79.5	67.8	87.8	53.1	17	0.1
		2060	10th	57.4	76.8	64.8	84.6	50.2	7	0
			50th	59.5	79.0	67.1	87.1	52.0	13	0
			90th	61.0	80.2	68.2	88.5	54.0	19	0.7
		2070	10th	57.7	77.2	65.1	85.1	50.4	7	0
			50th	60.1	79.3	67.5	87.4	52.3	14	0
			90th	61.3	80.8	68.7	89.1	54.5	22	1
		2080	10th	57.9	76.8	65.3	85.1	50.4	7	0

RCP	Location	Year	Percentile	Daily mean temperature (°F)	Daily mean temperature (Summer) (°F)	Daily maximum temperature (°F)	Daily maximum temperature (Summer) (°F)	Daily minimum temperature (°F)	Average annual number of days with average temperature exceeding 86°F	Average annual number of days with average temperature exceeding 95°F
			50th	60.1	79.7	67.6	87.6	52.7	15	0
			90th	61.5	80.8	68.9	89.2	54.7	23	2
	LaGuardia Airport	2020	10th	56.3	76.1	63.1	83.5	49.5	5	0
			50th	57.2	77.0	64.0	84.4	50.2	6	0
			90th	57.9	77.7	64.9	85.3	50.9	9	0
		2030	10th	56.7	76.1	63.5	84.0	50.0	5	0
			50th	57.9	77.7	64.9	85.3	50.7	8	0
			90th	59.2	78.6	65.8	86.4	52.0	12	0
		2040	10th	57.2	77.4	64.0	84.7	50.5	7	0
			50th	58.5	78.4	65.7	86.0	51.4	10	0
			90th	59.9	79.7	66.6	87.3	53.1	15	0.1
		2050	10th	57.6	77.4	64.4	84.6	50.9	8	0
			50th	59.4	79.0	66.4	86.7	52.3	12	0
			90th	60.6	80.1	67.3	87.8	53.8	19	0.3
		2060	10th	57.6	77.4	64.4	84.6	50.9	8	0
			50th	59.7	79.5	66.6	87.1	52.7	14	0
			90th	61.2	80.8	67.8	88.5	54.7	21	1
		2070	10th	57.9	77.7	64.8	85.1	51.1	8	0
			50th	60.1	79.9	67.1	87.4	53.1	15	0.1
			90th	61.5	81.3	68.4	88.9	55.2	24	1
		2080	10th	58.1	77.4	64.9	85.1	51.1	8	0
			50th	60.3	80.2	67.1	87.6	53.4	17	0.1
			90th	61.7	81.3	68.5	89.1	55.4	25	2
	White Plains	2020	10th	52.3	72.1	60.4	81.0	44.1	0.7	0
			50th	53.2	72.9	61.5	81.9	44.8	0.9	0

RCP	Location	Year	Percentile	Daily mean temperature (°F)	Daily mean temperature (Summer) (°F)	Daily maximum temperature (°F)	Daily maximum temperature (Summer) (°F)	Daily minimum temperature (°F)	Average annual number of days with average temperature exceeding 86°F	Average annual number of days with average temperature exceeding 95°F
			90th	54.0	73.8	62.2	82.8	45.7	2	0
		2030	10th	52.7	72.1	60.8	81.5	44.6	0.8	0
			50th	54.0	73.9	62.4	82.8	45.7	2	0
			90th	55.2	74.8	63.1	83.7	46.8	3	0
		2040	10th	53.2	73.4	61.5	82.0	45.1	1	0
			50th	54.5	74.5	63.0	83.5	46.2	2	0
			90th	56.1	75.7	64.0	84.7	47.8	4	0
		2050	10th	53.8	73.4	61.7	82.0	45.7	1	0
			50th	55.4	75.2	63.7	84.2	46.9	3	0
			90th	56.7	76.1	64.8	85.1	48.4	6	0
		2060	10th	53.8	73.4	61.9	82.0	45.7	2	0
			50th	55.8	75.7	64.2	84.6	47.5	3	0
			90th	57.2	76.8	65.3	85.8	49.3	8	0
		2070	10th	54.0	73.8	62.2	82.4	45.9	2	0
			50th	56.1	76.1	64.6	84.9	47.8	4	0
			90th	57.7	77.4	65.8	86.4	49.8	8	0
		2080	10th	54.0	73.4	62.2	82.6	45.9	2	0
			50th	56.3	76.3	64.6	85.1	48.0	5	0
			90th	57.7	77.4	65.8	86.5	50.0	9	0.2
RCP 8.5	Central Park	2020	10th	56.1	75.6	63.5	83.5	48.7	4	0
			50th	57.2	76.6	64.8	84.7	49.6	6	0
			90th	58.1	77.5	65.5	85.6	50.7	9	0
		2030	10th	56.7	76.3	64.0	84.2	49.3	6	0
			50th	57.9	77.5	65.3	85.8	50.4	9	0
			90th	59.2	78.6	66.6	86.7	51.8	14	0

RCP	Location	Year	Percentile	Daily mean temperature (°F)	Daily mean temperature (Summer) (°F)	Daily maximum temperature (°F)	Daily maximum temperature (Summer) (°F)	Daily minimum temperature (°F)	Average annual number of days with average temperature exceeding 86°F	Average annual number of days with average temperature exceeding 95°F
		2040	10th	57.6	77.0	64.8	84.9	50.2	7	0
			50th	58.8	78.6	66.6	86.7	51.4	12	0
			90th	60.6	80.1	68.0	88.2	53.1	18	0.4
		2050	10th	58.6	78.1	66.0	86.0	51.3	10	0
			50th	60.1	79.9	67.6	88.0	52.7	16	0.1
			90th	61.7	81.5	69.3	90.0	54.5	26	1
		2060	10th	59.4	79.0	66.4	86.7	52.2	14	0
			50th	61.3	81.1	68.7	89.4	54.0	23	0.5
			90th	63.0	82.9	70.9	91.4	55.8	36	4
		2070	10th	59.9	79.7	66.9	87.4	52.9	16	0
			50th	62.6	82.2	70.2	90.7	55.2	31	1
			90th	63.9	84.2	72.0	93.0	57.2	44	8
		2080	10th	61.0	80.2	68.0	88.2	53.6	18	0.1
			50th	63.7	83.7	71.4	91.9	56.1	40	3
			90th	65.7	85.8	73.2	94.8	58.5	59	11
	LaGuardia Airport	2020	10th	56.3	76.1	63.0	83.5	49.5	5	0
			50th	57.4	77.2	64.4	84.7	50.4	7	0
			90th	58.3	78.1	65.1	85.6	51.4	10	0
		2030	10th	56.8	76.8	63.7	84.2	50.0	7	0
			50th	58.1	78.1	64.9	85.6	51.3	9	0
			90th	59.4	79.2	66.0	86.7	52.5	15	0.1
		2040	10th	57.7	77.5	64.4	84.9	50.9	8	0
			50th	59.0	79.2	66.0	86.7	52.2	13	0
			90th	60.6	80.6	67.6	88.2	53.8	21	0.6
		2050	10th	58.8	78.6	65.5	85.8	52.0	11	0

RCP	Location	Year	Percentile	Daily mean temperature (°F)	Daily mean temperature (Summer) (°F)	Daily maximum temperature (°F)	Daily maximum temperature (Summer) (°F)	Daily minimum temperature (°F)	Average annual number of days with average temperature exceeding 86°F	Average annual number of days with average temperature exceeding 95°F
			50th	60.3	80.4	67.1	88.0	53.4	18	0.1
			90th	61.9	82.0	68.9	90.0	55.2	29	2
		2060	10th	59.5	79.5	66.0	86.7	52.9	15	0
			50th	61.5	81.7	68.4	89.2	54.7	26	0.7
			90th	63.0	83.5	70.3	91.2	56.5	39	5
		2070	10th	60.1	80.2	66.6	87.3	53.6	18	0.1
			50th	62.8	82.8	69.8	90.5	55.8	35	2
			90th	64.0	84.7	71.6	92.8	57.9	46	8
		2080	10th	61.2	80.8	67.6	88.0	54.3	20	0.2
			50th	63.9	84.2	70.9	91.9	56.8	43	3
			90th	65.8	86.4	72.9	94.6	59.2	62	12
	White Plains	2020	10th	52.2	72.1	60.4	80.8	44.1	0.7	0
			50th	53.4	73.2	61.7	82.0	45.0	1	0
			90th	54.3	74.1	62.4	83.1	46.0	2	0
		2030	10th	52.9	72.9	61.0	81.5	44.6	1	0
			50th	54.1	74.1	62.4	83.1	45.9	2	0
			90th	55.4	75.2	63.5	84.2	47.1	5	0
		2040	10th	53.8	73.6	61.7	82.2	45.7	2	0
			50th	55.0	75.2	63.5	84.2	46.8	3	0
			90th	56.8	76.6	64.9	85.6	48.4	6	0
		2050	10th	54.9	74.7	63.0	83.3	46.6	2	0
			50th	56.5	76.5	64.6	85.3	48.2	5	0
			90th	57.9	78.1	66.4	87.4	49.8	10	0.1
		2060	10th	55.6	75.6	63.5	84.0	47.5	4	0
			50th	57.6	77.7	65.8	86.7	49.3	9	0

RCP	Location	Year	Percentile	Daily mean temperature (°F)	Daily mean temperature (Summer) (°F)	Daily maximum temperature (°F)	Daily maximum temperature (Summer) (°F)	Daily minimum temperature (°F)	Average annual number of days with average temperature exceeding 86°F	Average annual number of days with average temperature exceeding 95°F
			90th	59.2	79.5	67.8	88.7	51.3	14	0.8
		2070	10th	56.1	76.3	64.0	84.7	48.2	5	0
			50th	58.8	79.0	67.1	88.2	50.7	13	0.1
			90th	60.1	80.8	69.1	90.0	52.5	20	2
		2080	10th	57.2	76.8	64.9	85.5	48.9	6	0
			50th	60.1	80.4	68.4	89.4	51.8	19	0.3
			90th	61.9	82.4	70.0	91.6	53.8	28	3

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APPENDIX 2

Humidity, Temperature Variable, & Load

1. Introduction

This appendix addresses climate variables that have a direct effect on system loads and reliability and are specifically addressed in specifications and procedures associated with upgrading system capacity and maintaining system reliability. The climate variables considered in this appendix start with humidity as expressed through wet bulb temperature and extend to include heat waves, cooling degree days, heating degree days, and the combination of projected changes in wet and dry bulb temperatures. When viewed in combination, temperature and humidity can affect the heat index and can have a significant impact on Con Edison's design guideline reference, temperature variable (TV).[1] Several Con Edison operational standards and load planning processes rely on TV, which is a custom variable calculated from wet and dry bulb temperatures and has historically correlated with load.[2]

As described in the report introduction, the analysis for this appendix involves a decision-first and risk-based approach, applying the best available climate science to produce flexible and adaptive solutions. The process was designed to be transparent and interactive so that it can be replicated and institutionalized. This appendix draws upon the most current climate science projections for the Con Edison service territory, over intermediate- (2050), and long-term (2080) time horizons.

The work covered in this appendix has three main objectives:

1. Develop an understanding of projected future heat wave and humidity conditions, and the resultant changes in load, for the Con Edison service territory.
2. Complete a risk assessment of potential impacts of heat waves, TV-driven changes in load, and humidity-related changes on operations, planning, and infrastructure.
3. Establish a portfolio of effective measures to improve resilience to heat wave and humidity conditions, and the resultant changes in load, with a focus on high-priority assets and relevant processes.

The Study team assessed the potential impact of a wide range of gradual temperature change-related variables, including humidity, heat index, TV, cooling degree days, heating degree days, and heat wave frequency and duration. Potential impacts from extreme events will be addressed in another appendix.

This appendix is organized as follows:

- Section 2 provides an overview of the appendix highlights.
- Section 3 describes the screen of operations, planning, and asset types for sensitivity.
- Section 4 provides an overview of relevant climate information.
- Section 5 reviews the risk-based prioritization of distribution networks.
- Section 6 details priority vulnerabilities to humidity-related variables and associated adaptation options.

[1] It is common practice in the industry to consider temperature and humidity together in the load forecasting and planning process. Temperature variable is Con Edison's approach to the practice.

[2] In the summer months, TV for the electric system is calculated as the 3-day weighted sum of the maximum rolling 3-hour average of wet and dry bulb. The current day is weighted at 70%, the prior day at 20% and the next prior day at 10%. The calculations for other TVs (e.g., other months, gas, and steam) can be found in Appendix 2.A – Climate Information.

- Section 7 details secondary vulnerabilities to humidity-related variables and associated adaptation options.
- Section 8 analyzes the costs and benefits of adaptation options under a range of possible futures.
- Section 9 discusses the implementation of adaptation options over time.
- Appendix 2.A provides climate information and equations used in this appendix's analyses.
- Appendix 2.B provides greater detail on secondary vulnerabilities and the related adaptation strategies.

2. Highlights

In this appendix, the Study team focused primarily on Con Edison's vulnerability to future changes in heat and humidity through "temperature variable" (TV), because it is a reference to system load used in many aspects of the business. The Study team also identified potential adaptation measures to address those changes in TV and examined other climate variables.

Screening Process to Determine Climate Sensitivity

As a first step, the Study team worked with 45 Con Edison subject matter experts (SMEs) to conduct a high-level screening of operations, planning, and asset types for climate sensitivity. In a workshop and through follow-up requests, the SMEs answered the following questions:

1. Which humidity-related climate variables are relevant to Con Edison operations, planning, and assets?
2. Which assets are highly sensitive to the identified humidity-related variables? The identification of these assets is based on prior impact, along with information from asset specifications or operation guidelines.

In response to the first question, the SMEs identified these relevant humidity-related variables: humidity, heat index, TV, cooling degree days, heating degree days, and heat wave frequency or duration. The Study team then worked with the SMEs to identify highly sensitive assets based on this list of variables. They found that most assets were sensitive to TV through its relationship to load. Table 1 lists these highly sensitive assets.

Historical and Future Climate Projections

Columbia Center for Climate Systems Research (CCSR) provided climate information to support the Study team's analyses. CCSR modeled historical and future conditions for humidity-related variables, including TV, heat index, cooling and heating degree days, and heat wave frequency and duration. CCSR found that the number of days per year at or above the electric TV threshold of 86°F, as well as those within various heat index thresholds, are projected to increase throughout the century. Currently, there are 0.2 to 1 days per year crossing the TV threshold; this is expected to increase to 3 to 52 days per year by 2080. Similarly, while there are currently zero days annually exhibiting a heat index greater than 115°F at LaGuardia Airport and in White Plains, CCSR expects that 2050 might see as many as 5 to 6 such days. With these increases in dry and wet bulb temperatures, CCSR found that cooling degree days are projected to increase, while heating degree days are projected to decrease. Heat waves are also expected to increase in frequency and duration.

Prioritization Process for Underground Networks

While the Con Edison system is comprised of many elements, a primary area of concern for humidity-related climate variables is the network system, which comprises the majority of load. In order to determine potential vulnerabilities to networks from changes in humidity-related variables, the Study team used Con Edison's existing distribution network reliability metric known as the Network Reliability Index (NRI), as calculated in the NRI-DEF model, to estimate future changes in the reliability of Con Edison's underground distribution networks, making minor changes to target the modeling to changes in reliability due to TV. The Study team modeled network reliability under three scenarios: (1) a no-change base case using historical TV data for the period 1998–2017, (2) conditions reflecting projected TV in 2050 under a moderate-emissions scenario (RCP 4.5 10th percentile case), and (3) conditions reflecting projected TV in 2050 in a high-emissions scenario (RCP 8.5 90th percentile case). Through this process, the Study team could pair projections of future climate conditions with a mature, probability-based model of asset risk to discern complexities and vulnerabilities of the system.

NRI is a metric developed by Con Edison for assessing the reliability of its distribution networks. It is a normalized index in which a value exceeding a "per unit" (p.u.) of 1 reflects a probability of failure that exceeds Con Edison's risk tolerance threshold.[3] Networks were prioritized for vulnerability and adaptation analyses based on their modeled NRI values; those with NRI exceeding 1.0 p.u were therefore the focus of these efforts. Con Edison is developing a newer model (NRI-REV) that would allow for the analysis of the impact of additional adaptation options (such as non-wires solutions) on network reliability. For this study, in addition to traditional NRI-DEF solutions, Con Edison tested NRI-REV solutions for additional reference.

Priority Physical Vulnerabilities

Increased heat waves have the potential to increase NRI (and therefore decrease reliability) such that, depending on climate scenario, 11 to 28 of the 65 underground networks may exceed Con Edison's 1 p.u. standard of reliability by mid-century, without intervention or additional investment. For perspective, there are currently zero networks that exceed this standard. Similarly, increased extreme heat events have the potential to decrease the service reliability of Con Edison's non-network circuits, though to a lesser degree.

A heat wave will involve high temperatures and high loads. If, as is present practice, Con Edison designs, builds, and maintains its system to accommodate the highest load anticipated, the effect of load is addressed and we are left with the effect of high temperatures alone.

Priority Operational and Planning Vulnerabilities

The Study team found that due to general increases in TV, summer electric demand will increase. However, demand for heating in the winter is projected to decrease due to increases in winter temperature, which will decrease expected winter loads for steam, gas, and—to a much lesser extent—electric.

Given the projected increases in summer TV, the number of days in which operational strategies are put in place to avoid negative impacts of high heat (voltage reductions and summer work restrictions) could increase if the system design criteria (TV 86°F) does not change. Similarly, more days with TV conditions are expected that exceed threat-level elevation thresholds (also related to

[3] Con Edison previously performed an analysis to determine the risk tolerance, which is approved by the regulator.

the design criteria TV 86°F) set by the Corporate Emergency Response Plan Incident Command System.

The frequency of days falling within moderate-to-extreme risk for heat index is projected to increase as well, bringing about a potential for greater risk to workers exposed to the heat.

Adaptation Options

Adaptation options for physical vulnerabilities include:

- Network system: Create primary feeder loops within or between networks to increase redundancy and reliability; continue to consider DER alternative/procurements to help defer localized expenditures and to optimize capital portfolio of work.
- Non-network distribution system: Reduce the number of customers between feeder segments, and increase feeder diversity to increase redundancy and reliability.
- Transmission system: Replace equipment with higher failure rates; install additional transmission paths for selected parts of the system.
- General: Utilize non-wires alternatives such as energy efficiency to manage energy peaks.
- Cooling systems: Upgrade HVAC units and cooling towers at the end of their useful life to ensure sufficient capacity for changes in climate.

Adaptation options for operations and planning vulnerabilities include:

- Peak electric load forecasting: Consult utilities in cities with higher temperatures to refine the load forecast equation for high TV numbers.
- Volume forecasting: Update long-term forecasting to include climate data to account for projected changes in cooling degree days and heating degree days.
- Load relief planning: Develop a load relief plan that integrates future changes in climate and other critical factors.
- Worker safety: Reinforce current safety training regarding "water, rest, shade" guidelines to protect workers and prevent heat-related illness.
- Summer operations and voltage reductions: Routinely update voltage reduction thresholds and hands-off thresholds to account for changes in climate and the changing design of the system.
- Corporate Emergency Response Plan (CERP): Routinely update analysis of CERP thresholds to understand the impacts of warmer conditions on system performance and to update CERP thresholds accordingly.

Costs and Benefits of Adaptation Options Under a Range of Possible Futures

The potential for the design criteria TV to be increased because of climate change could result in higher system peak loads in 2050 on the order of 13%–24% (best to worst cases). This could require capital investments on the order of $1.1 billion to $3.0 billion by 2050. Climate projections can be incorporated into load forecasting so that these investments can be made over time and average $35 million to $96 million year over year.

The Study team also conducted a multi-criteria analysis of the portfolio of network reliability improvement measures, giving each measure scores for co-benefits, such as safety, and customer financial benefits and adaptation benefits, such as flexibility, reversibility, and robustness. The Study team found that incorporating distributed energy resources received a high score based on this analysis, while splitting the network into two smaller networks would be a far less cost-effective solution. This confirms the added value of continuing to develop the NRI-REV model, which can be incorporated into Con Edison's current process for assessing potential strategies.

Implementation of Adaptation Options Over Time

Con Edison uses signposts to track the assumptions in its long-range plans. Con Edison could use additional signposts to aid in tracking load- and humidity-related concerns to ensure that action is taken as necessary to effectively and efficiently create a resilient system that continues to function at Con Edison's high standards. Con Edison could also consider adaptive approaches that include low- and no-regrets actions.

3. Screen of Operations, Planning, and Asset Types for Climate Sensitivity

The Study team used a high-level screening process to answer these questions:

1. Which humidity-related climate variables are relevant to Con Edison operations, planning, and assets?
2. Which assets are highly sensitive to the identified humidity-related variables? The identification of these assets is based on prior impact, along with information from asset specifications or operation guidelines.

Con Edison SMEs (45 SMEs) answered these questions through a workshop and follow-up individual data requests. The relevant humidity-related climate variables identified by the SMEs include:

- Humidity
- Heat index
- Temperature variable
- Cooling degree days
- Heating degree days
- Heat wave frequency or duration

Once the appropriate temperature-related climate variables were identified, the Study team used the information provided by the SMEs to rank the corresponding sensitivity of major asset types as high, medium, or low. To determine assets' sensitivity to projected changes in temperature, Con Edison SMEs were asked to consider each climate variable and asset type combination and to identify to what extent the variable is a factor in asset design or operation, through questions such as:

- What previous significant weather events have impacted assets or operations?
- Is information about the climate variable used in design or operation?
- Is the variable a key input or critical factor to asset design or performance?

Information provided by Con Edison SMEs during the screening process indicated that most assets are not sensitive to humidity alone. Rather, the combination of temperature and humidity, and the resultant influence on load, is more likely to cause impacts to asset performance. Table 1 lists the areas that SMEs identified as most sensitive to humidity-related variables. Section 6.1 presents the priority vulnerabilities of key assets in those areas and discusses adaptation options.

Table 1 ■ Assets with high sensitivity to humidity-related climate variables, as identified by Con Edison SMEs

Functional Area
Transmission Feeders
Substation, Unit, and/or Transmission & Area
Distribution, Underground
Distribution, Overhead

4. Historical and Future Climate Projections

4.1. Background

This section describes historical analyses and projections of the humidity-related variables assessed in this appendix.

The relationship between temperature and humidity is complex and nonlinear; warm air is capable of holding far more moisture than cold air. Put another way, if you warm cold air by one degree, it can only hold a bit more moisture, but if you warm hot air by one degree, it can hold far more moisture. Another complexity stems from the fact that we lack definitions of humidity that are as readily comprehensible as the concept of temperature.

- **Specific humidity** refers to the actual amount of moisture that is in the air.
- **Dewpoint temperature** refers to the lowest possible temperature at which air can retain moisture given how much moisture is actually in the air; this is the temperature at which the air becomes fully saturated with moisture.
- **Relative humidity** is defined as the percentage of the maximum possible moisture in the air for a given temperature that is actually present in the air.
- **Wet bulb temperature** (“wet bulb”) is defined as the temperature that a thermometer will cool to if encompassed in a fully saturated cloth; wet bulb temperature thus reflects how much the temperature of a body can cool due to evaporation, which depends both on the temperature and on the amount of moisture in the air.

In the Northeast U.S. and specifically the New York metropolitan region, the highest maximum temperatures tend to be experienced on days when relative humidity is fairly low. The high temperatures themselves lower the relative humidity (because hot air is capable of holding a lot of moisture), but more fundamentally they reflect the fact that the hottest daytime temperatures are associated with processes that are not consistent with air moisture. Specifically, moist air helps prevent the atmosphere from warming: (1) directly, since some sunlight energy goes toward evaporating water rather than heating, and (2) indirectly through development of sun-blocking cloud cover when the air is sufficiently moist.

Nevertheless, it is common in the New York metropolitan region, and in the U.S. more generally, for dangerous combinations of heat and humidity to occur (Raymond et al., 2017). In fact, indices have been developed for our region and the U.S. that reflect heat humidity metrics of particular relevance. This section describes two such indices. First, TV as defined by Con Edison is based on a formula that reflects combinations of temperature-only (“dry bulb”) and joint temperature and humidity (“wet bulb”). When TV crosses certain thresholds, Con Edison systems face challenges related to load, reliability, and other system components. Second, ”heat index” is a National

Weather Service metric that reflects the "feels like" temperature given a certain combination of heat and humidity, and has consequences for Con Edison's employee and system performance.

Historical Analysis

For each of the two long-term quality-controlled weather stations in the region (LaGuardia Airport and White Plains; Central Park was not included due to an absence of the necessary hourly-scale data), the Study team analyzed historical trends and climatological averages for three wet bulb thresholds: 77 °F (25 °C), 79 °F (26 °C), and 81 °F (27 °C) (see Table 2).[4] The Study team also calculated the wet bulb temperatures corresponding to the once per year, and once per 10-year event for each of the two stations.

As shown in Table 2, there is a steep fall-off in the number of days exceeding each threshold as wet bulb temperature increases; whereas wet bulb temperatures of 77°F (25°C) can be expected several times per summer, wet bulb temperatures of 81°F (27.2°C) occur on average less than once per year. Typical once per year and once per 10-year wet bulb extremes for LaGuardia Airport are 79.7°F (26.5°C) and 81.9°F (27.7°C); for White Plains, they are 79.9°F (26.6°C) and 84.7°F (29.3°C). Differences between the two stations are thus small (although both stations exhibit temperatures at the upper end of the wet bulb spectrum), but White Plains does feature slightly more days surpassing the higher thresholds than LaGuardia.

Table 2 ■ Historical climatology of the number of days per year with the maximum daily wet bulb temperature exceeding critical thresholds.

	LaGuardia	White Plains
Number of days per year with maximum daily wet bulb temperature exceeding 77°F (25°C)	7.2 Days	6.4 Days
Number of days per year with maximum daily wet bulb temperature exceeding 79°F (26°C)	1.8 Days	2.4 Days
Number of days per year with maximum daily wet bulb temperature exceeding 81°F (27°C)	0.5 Days	0.6 Days

Methods

As noted above, historical analysis and bias correction are based on station data from only White Plains and LaGuardia Airport, given significant hourly data gaps at Central Park. LaGuardia data run from 1976–1995 and from 2006–2015; White Plains data are available for 1975–1995 and 2002–2005. Based on the close correlation of Central Park temperature data in Appendix 1 with LaGuardia Airport data it was decided to use LaGuardia data as a surrogate for Central Park in this exercise.

As in Appendix 1, climate model projections were driven by the RCP 4.5 and RCP 8.5 scenarios. Projections here are based on the 26 global climate models (GCMs) for which daily maximum temperature (Tmax) and daily minimum temperature (Tmin), surface pressure, *and* specific humidity are available. Note that because a smaller set of GCMs provided all these variables than provided temperature alone in Appendix 1, and due to different methodological requirements associated with the calculations below, the dry bulb temperature projections below differ slightly from those described in Appendix 1. Both sets of temperature projections can be considered equally plausible from a risk management perspective.

[4] These thresholds were selected because they are wet bulb temperatures that are high enough to have an impact on human health, productivity, and electricity demand, while also occurring frequently enough to allow for historical analysis.

The following steps were used to calculate wet bulb temperature and dry bulb temperature projections,[5] which were then used to build the specific indices (TV and heat index):

1. Download and process daily Tmax, Tmin, surface pressure, and specific humidity from the 26 GCMs under historical, RCP 4.5, and RCP 8.5 scenarios.
2. Calculate observed hourly wet bulb temperature for LaGuardia Airport and White Plains.
3. Calculate modeled daily wet bulb from Tavg = (Tmax+Tmin)/2, pressure, and specific humidity.
4. Calculate the difference of the climatology for each calendar month between the future (RCP 4.5 and RCP 8.5, from 2020 to 2080 by decade, each the center of a 30-year time slice) and historical 1976–2005 for wet bulb and dry bulb.[6]
5. For the RCP 4.5 and RCP 8.5 future projections, the Study team applied the difference of the climatology to the hourly observed wet and dry bulb temperature for the seven 30-year time-slices.

For a more detailed description of the methods and terminology used, see Appendix 2.A – Climate Information.

Global Context

Although joint temperature and humidity extremes have historically received much less attention by researchers than temperature alone, that is beginning to change. A few researchers have reported upward trends in wet bulb temperature extremes in specific regions such as northern Egypt (Matthews et al., 2017) and South Asia (Wehner et al., 2016). Recent modeling studies have also projected large increases in the frequency and magnitude of high wet bulb extremes as the century progresses, both using global climate models (Coffel et al., 2017) and in regional model assessments in the Middle East (Pal and Eltahir, 2016), South Asia (Im et al., 2017) and Southeast Asia (Im et al., 2018). These increases in wet bulb extremes are consistent with theoretical expectations, since a warming atmosphere can hold more moisture, and, relatedly, warming oceans and other water bodies can support more evaporation. Other possible drivers of changes in wet bulb extremes, such as vegetation/soil moisture, and atmospheric dynamics, are active areas of research. Warming of the upper ocean and lower atmosphere and surface are among the most robust climate changes observed to date (IPCC 2014).

4.2. Temperature Variable

Temperature variable, which blends wet bulb and dry bulb temperatures and time-averages to include “memory” in the system, is an index currently used by Con Edison for operational decisions and planning. There are multiple equations used for different sectors of Con Edison and times of year, but the canonical equation for summer is:

Summer electric TV equals .70 * max of rolling 3-hour average wet and dry bulb for current day + .20 * max of rolling 3-hour average wet and dry bulb for prior day plus .10 * max of rolling 3-hour average wet and dry bulb for the next prior day.

Con Edison’s TV has been a reliable indicator of the potential for a peak load on the system but is not a definitive estimator. As shown in Table 3 and Table 4, thresholds that have historically been

[5] The methodology described here was used as a bias correction method to ensure that modeled results would confidently yield reliable projected values. This is a common and standard approach in climate science to strengthen modeling efforts.
[6] This represents the modeled historical (base) period for both stations for data taken from the global climate models. This differs slightly from the observed data.

crossed relatively rarely (such as a TV of at least 86 °F (30 °C), which is crossed at LaGuardia approximately one time per year historically), are projected to become common occurrences within a generation, occurring roughly 4 to 19 times per year, respectively, under RCP 4.5 and RCP 8.5. In addition to these 86 °F (30 °C) events becoming more frequent, they can be expected to be of longer duration. Furthermore, future once per year TV thresholds are projected to be much higher than 86 °F (30°C). This raises the potential for peak loads to occur more frequently and could suggest higher peak loads in the future due to climate change alone.

Table 3 ■ Projected number of days per year at or above electric temperature variable of 86°F

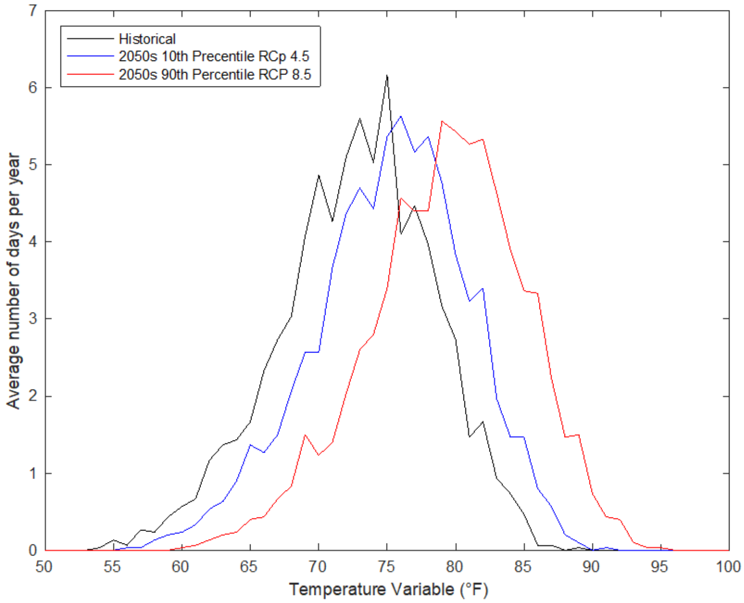
Projection Time Period	LaGuardia		White Plains	
	Lower Bound (RCP 4.5 10th percentile)	**Upper Bound** (RCP 8.5 90th percentile)	**Lower Bound** (RCP 4.5 10th percentile)	**Upper Bound** (RCP 8.5 90th percentile)
2020	2 Days	5 Days	0.8 Days	2 Days
2050	4 Days	19 Days	2 Days	13 Days
2080	5 Days	52 Days	3 Days	42 Days

Note: The historical value for LaGuardia is 1 day per year and for White Plains is 0.2 days per year.

Table 4 ■ The 1-in-3 TV event at LaGuardia Airport under historical and projected future scenarios. (Note that the historical occurrences are of "peak producing TV," i.e., TV that was associated with peak loads)

	LaGuardia Base (Historical)	2030 RCP 4.5 10th percentile	2050 RCP 4.5 10th percentile	2080 RCP 4.5 10th percentile	2030 RCP 8.5 90th percentile	2050 RCP 8.5 90th percentile	2080 RCP 8.5 90th percentile
LaGuardia 1-in-3 TV event (°F)	86.9	88.4	89.4	90.1	90.7	93.5	98.3

Figure 1 ■ Historical and projected values of summer (June–August) daily electric TV values at LaGuardia (top) and White Plains (bottom)



4.3. Heat Index

Heat index projections were developed using the wet bulb and dry bulb temperature projections. The Study team computed heat index values using the equation used by the National Weather Service.[7] In contrast to TV, heat index is not only used by Con Edison, but is employed more widely to assess the public health risks associated with overheating. The results presented here are for a set of thresholds of importance to Con Edison. The threshold of 103°F is also the Occupational Safety and Health Administration's (OSHA's) threshold between moderate and high heat index risk to people working in hot conditions.

Table 5 ■ Historical and projected frequency of occurrences for maximum heat index criteria for 2050

Thresholds	LaGuardia			White Plains		
	Base Period	**Lower Bound** (RCP 4.5 10th percentile)	**Upper Bound** (RCP 8.5 90th percentile)	**Base Period**	**Lower Bound** (RCP 4.5 10th percentile)	**Upper Bound** (RCP 8.5 90th percentile)
Number of days per year with maximum heat greater than or equal to 91°F (33°C) and less than 103°F (39°C)	18 days	29 days	42 days	12 days	21 days	36 days
Number of days per year with maximum heat greater than or equal to 103°F (39°C) and less than 115°F (46°C)	2 days	7 days	20 days	1 day	5 days	14 days
Number of days per year with maximum heat index greater than or equal to 115°F (46°C)	0 days	0.7 days	6 days	0.1 days	0.6 days	5 days

Table 6 ■ Projected maximum values for summer (June–August) heat index

Projection Time Period	LaGuardia		White Plains	
	Lower Bound (RCP 4.5 10th percentile)	**Upper Bound** (RCP 8.5 90th percentile)	**Lower Bound** (RCP 4.5 10th percentile)	**Upper Bound** (RCP 8.5 90th percentile)
2020	108.8°F (42.7°C)	113.8°F (45.4°C)	107.1°F (41.7°C)	112.3°F (44.6°C)
2050	113.2°F (45.1°C)	125.2°F (51.8°C)	111.7°F (44.3°C)	124.0°F (51.1°C)
2080	115.2°F (46.2°C)	143.0°F (61.7°C)	113.9°F (45.5°C)	142.3°F (61.3°C)

Note: The historical maximum value for LaGuardia is 106.1°F (41.2°C) and for White Plains is 104.2°F (40.1°C).

As shown in Table 5, both weather stations experience extreme humid heat in the baseline climate. For all heat index thresholds, the frequency of occurrence is expected to increase dramatically as the century progresses. Only through dramatic societal decreases in greenhouse gas emissions, consistent with RCP 4.5, are the two weather stations projected to experience less than 1 day per year each during the 2050 time-slice, with heat indices above 115°F (46.1°C)—a level experienced on just a single day at LaGuardia over the 30-year period and experienced only 3 days at White Plains over the 25 years with data. Under RCP 8.5, both stations are projected to experience several days per year above this extreme threshold.

[7] The National Weather Service provides greater detail on its heat index equation here: https://www.wpc.ncep.noaa.gov/html/heatindex_equation.shtml

Just as the frequency of occurrence of these extreme heat index values is projected to increase, so too is the magnitude of extreme heat index values. For example, as shown in Table 6, the most extreme heat index value is projected within a generation to exceed 120°F (48.9°C) at both weather stations under the RCP 8.5 scenario. By 2080, under a worst-case scenario, values over 140°F (60°C) cannot be ruled out. It should be noted that such values exceed what has been experienced in the U.S. to date; heat index is non-linear and was designed to correspond to humid heat combinations experienced historically in the U.S. Thus, while specific numbers such as 140°F (60°C) should not be emphasized, it is important that the unprecedented nature of these humid heat combinations be appreciated.

We next describe two indices that reflected longer-term seasonal integration of humid heat (cooling degree days) and cold temperatures (heating degree days).

4.4. Cooling and Heating Degree Days

Cooling degree day projections were based on the wet bulb and dry bulb projections described above. The specific Con Edison formula for a cooling degree day (CDD) is:

- CDD calculations use a dry/wet bulb average of 57.5°F as a reference point. The CDD calculation subtracts this reference point from the mean of the 24-hour average hourly dry bulb temperatures and hourly wet bulb temperatures for a given calendar day (i.e., a day's average of average dry and average wet bulb temperatures of 62.5°F – 57.5°F = 5). If the average of the average 24 hourly dry bulb temperatures and the average 24 hourly wet bulb temperatures is less than 57.5°F, the CDDs are zero.
- In contrast, heating degree days (HDD) are based on dry bulb temperature only. The Con Edison formula is: A reference point of 62°F determines HDD. The HDD calculation uses a 24-hour average of any given day's hourly dry bulb temperatures. This calculation is simply done by subtracting the average 24 hourly dry bulb temperatures from the reference point (e.g., 62°F – 60°F = 2). If the average 24 hourly dry bulb temperatures is greater than 62°F, the HDDs are zero.

Even though HDD is based on temperature only, the projections are based on the methods used to calculate dry bulb temperatures for Appendix 2, not Appendix 1. This approach ensures consistency between HDD and CDD methods, with CDD methods requiring the Appendix 2 approach to downscaling heat and humidity. Note that there are distinct HDD reference temperatures for the electric, gas, and steam sectors (62°F for electric and gas and 56°F for steam (see Volume Forecasting in Appendix 2.B for further information on calculations).

Table 7 ■ Historical and projected values for heating and cooling degree days for 2050

Metric	LaGuardia			White Plains		
	Base Period	**Lower Bound** (RCP 4.5 10th percentile)	**Upper Bound** (RCP 8.5 90th percentile)	**Base Period**	**Lower Bound** (RCP 4.5 10th percentile)	**Upper Bound** (RCP 8.5 90th percentile)
Cooling Degree Days (April–November)	1,670	1,935	2,577	1,160	1,436	2,000
Heating Degree Days (Electric/Gas) (November–April)	3,783	3,240	2,539	4,532	3,927	3,212
Heating Degree Days (Steam) (November–April)	2,754	2,281	1,648	3,476	2,934	2,261

As shown in Tables 7, 8, and 9, CDDs, which are higher in the baseline climate at LaGuardia than in White Plains, are projected to increase substantially as the century progresses, especially under the high-end scenarios associated with higher greenhouse gas emissions. HDDs for electric/gas and steam are both projected to decrease dramatically as the century progresses, especially under the high scenario.

Table 8 ■ Percentage change in cooling and heating degree days by decade for LaGuardia Airport

Projection Time Period	Cooling Degree Days		Heating Degree Days (Steam)		Heating Degree Days (Electric)	
	Lower Bound (RCP 4.5 10th percentile)	**Upper Bound** (RCP 8.5 90th percentile)	**Lower Bound** (RCP 4.5 10th percentile)	**Upper Bound** (RCP 8.5 90th percentile)	**Lower Bound** (RCP 4.5 10th percentile)	**Upper Bound** (RCP 8.5 90th percentile)
2020	7%	23%	-10%	-20%	-9%	-17%
2030	10%	35%	-14%	-25%	-12%	-21%
2040	16%	46%	-15%	-35%	-13%	-29%
2050	20%	60%	-17%	-40%	-14%	-33%
2060	21%	79%	-17%	-46%	-14%	-38%
2070	23%	99%	-20%	-54%	-16%	-45%
2080	24%	119%	-21%	-57%	-17%	-49%

Table 9 ■ Percentage change in cooling and heating degree days by decade for White Plains

Projection Time Period	Cooling Degree Days		Heating Degree Days (Steam)		Heating Degree Days (Electric)	
	Lower Bound (RCP 4.5 10th percentile)	**Upper Bound** (RCP 8.5 90th percentile)	**Lower Bound** (RCP 4.5 10th percentile)	**Upper Bound** (RCP 8.5 90th percentile)	**Lower Bound** (RCP 4.5 10th percentile)	**Upper Bound** (RCP 8.5 90th percentile)
2020	8%	27%	-10%	-19%	-9%	-16%
2030	12%	41%	-13%	-22%	-11%	-19%
2040	19%	55%	-14%	-31%	-12%	-26%
2050	24%	73%	-16%	-35%	-13%	-29%
2060	25%	95%	-15%	-40%	-13%	-34%
2070	28%	120%	-18%	-47%	-15%	-40%
2080	29%	144%	-19%	-51%	-16%	-43%

4.5. Heat Wave Frequency and Duration

Just as the time-integration over a season/year of temperature and humid heat are important for Con Edison, so too is time-integration over a shorter duration of temperature extremes. This section describes projected changes in the frequency and duration of heat waves. Multi-day temperature extremes are important, because health impacts, demand for air conditioning, and stress on electrical systems and other infrastructure all increase with duration of exposure. Because this heat wave analysis focuses on temperature alone, rather than humid heat, it uses the methodology described in Appendix 1 for daily temperature extremes.

Heat waves were defined as 3 or more days with average temperatures exceeding 86°F. Events longer than 3 days are counted as separate heat waves (e.g., 6 consecutive days are considered as two heat waves). The length of the heat waves is defined using the length of the longest event of each year. Results presented are the 30-year average of these longest annual events.

Table 10 ■ Projected number of heat waves per year, where a heat wave is defined as 3 or more consecutive days with average temperatures above 86°F on each day

Projection Time Period	Central Park		LaGuardia		White Plains	
	Lower Bound (RCP 4.5 10th percentile)	**Upper Bound** (RCP 8.5 90th percentile)	**Lower Bound** (RCP 4.5 10th percentile)	**Upper Bound** (RCP 8.5 90th percentile)	**Lower Bound** (RCP 4.5 10th percentile)	**Upper Bound** (RCP 8.5 90th percentile)
2020	0.3	1	0.3	1	0.1	0.1
2050	0.8	5	0.9	5	0.1	2
2080	0.9	14	1	15	0.1	5

The historical values for Central Park, LaGuardia Airport, and White Plains are each 0.2 heat waves per year.

As shown in Table 10, the number of heat waves per year—defined as 3 or more consecutive days each with average temperature above 86°F (30°C)—is projected to increase for all three stations as the century progresses. For all time periods, White Plains experiences fewer such heat waves. Similarly, as shown in Table 11, by 2080, transformative changes in heat wave duration are projected to occur under the high-end scenario. This is particularly true for the warmer Central Park and LaGuardia stations, which could see the average length of the longest heat wave per year reach approximately 15 days by 2080.

Table 11 ■ Projected duration (number of days) of the longest heat wave per year. Heat waves are defined as 3 or more consecutive days with average temperatures above 86°F on each day

Projection Time Period	Central Park		LaGuardia Airport		White Plains	
	Lower Bound (RCP 4.5 10th percentile)	**Upper Bound** (RCP 8.5 90th percentile)	**Lower Bound** (RCP 4.5 10th percentile)	**Upper Bound** (RCP 8.5 90th percentile)	**Lower Bound** (RCP 4.5 10th percentile)	**Upper Bound** (RCP 8.5 90th percentile)
2020	2 days	3 days	2 days	4 days	0.6 days	1 day
2050	4 days	7 days	3 days	8 days	1 day	2 days
2080	5 days	15 days	3 days	15 days	2 days	7 days

5. Risk-Based Prioritization of Distribution Networks

Following the high-level screening for sensitivity, the Study team sought to develop a more detailed understanding of the variable risk of changes in temperature and humidity to Con Edison's distribution networks. The Study team focused primarily on the network system, which is largely underground, because underground electric power equipment in an urban environment exhibits higher failure rates during heat waves than non-network equipment, which is generally open-air. This is due to the greater potential for heat to accumulate underground.[8] Additionally, approximately 87% of Con Edison's distribution capacity is underground.[9, 10]

To conduct the analysis on Con Edison's network system, the Study team relied on Con Edison's existing methods for modeling future changes in the system's reliability, with minor modifications to conduct longer-term model runs that specifically capture changes in reliability due to temperature variable. Con Edison has developed the NRI-DEF model to project and manage the reliability of its network system.[11] The model is run annually to identify vulnerabilities and to assist in planning network improvements. Con Edison is also developing a new model, NRI-REV. The NRI-REV model reflects an updated understanding of the factors that affect network reliability and is capable of modeling distributed energy resources (DER), microgrids, and complex network designs. The reliability projections from both models are reported as a distribution network reliability metric known as the Network Reliability Index (NRI). At present, only NRI-DEF is used for annual reliability assessments and design updates.

NRI is a metric developed by Con Edison for assessing the reliability of its underground distribution networks. It is a normalized index such that a value exceeding 1 per unit (p.u.) reflects a probability of failure that exceeds Con Edison's risk tolerance threshold. The NRI model considers factors including equipment loading, age, known failure rates, and projected TV conditions to project the

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[8] Office of Long-Term Planning and Sustainability, Office of the Mayor, City of New York. 2013. "Utilization of Underground and Overhead Power Lines in the City of New York," p. 13. http://www.nyc.gov/html/planyc2030/downloads/pdf/power_lines_study_2013.pdf

[9] Reilly, G. "Electric Grid Hardening and Resiliency Initiatives." Consolidated Edison Company of New York, Inc. Electric Distribution Engineering. April 17, 2015. https://www.bnl.gov/rsgworkshop/files/talks/Reilly.pdf, slide 2.

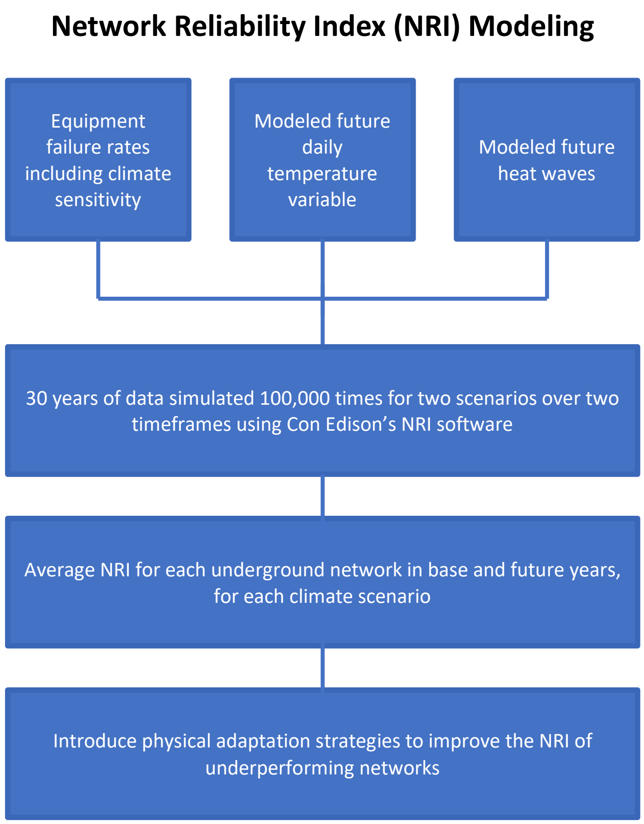
[10] Because Con Edison's distribution capacity for Orange, Rockland, Westchester, and Staten Island is primarily overhead, this analysis does not cover those areas.

[11] NRI is a Monte Carlo simulation used to predict the performance of a network during a heat wave. The program uses the historical failure rates of the various components/equipment that are in the network, and through probability analysis determines which networks are more likely to experience a shutdown.

future reliability of the electric networks. Given these variables, the NRI model forecasts the likelihood of four or more feeders in one portion of a network failing simultaneously. The likelihood of this occurring increases during periods in which the TV is greater than or equal to 80°F (27°C). When four feeders fail simultaneously, there is a threat of cascading feeder failures as a result of overloading on adjacent portions of the grid.[12] Based on the NRI projections for each network, Con Edison develops plans to maintain and improve reliability on a forward-looking basis.

In order to forecast network system reliability under the impacts of climate change, the Study team modeled NRI under various climate scenarios and included the findings in an internal Con Edison report.[13] Figure 2 summarizes the modeling approach and results.

Figure 2 ■ NRI modeling approach for future climate scenarios



[12] Wang, D.Y., Ten-Ami, Y., & Chebli, E., 2008, Evaluation of low-voltage network systems reliability using probabilistic methods [Conference paper], *Proceedings of the 10th International Conference on Probabilistic Methods Applied to Power Systems,* IEEE.
[13] Allen, D., 2018. The effect of heat waves on network reliability under climate change" [Internal Con Edison report].

The model was used to estimate network reliability under three scenarios: a no-change base case using historical TV data for the period 1998–2017, conditions reflecting projected TV in 2050 under a moderate emissions scenario (RCP 4.5 10th percentile case), and conditions reflecting projected TV in 2050 in a high emissions scenario (RCP 8.5 90th percentile case). For the modeling, a heat wave is defined as a day in which the TV is 80°F (27 °C) or more. These heat wave projections are then translated into impacts on network reliability in terms of NRI.[14]

The non-network distribution system's reliability is measured in terms of frequency of failures of supply feeders and SAIFI (System Average Interruption Frequency Index).[15] The Study team compared a base case comprised of historical data for 1998–2017 and a projected case assuming a high-end estimate of climate change (RCP 8.5 90th percentile case) in the years 2050 and 2080, using the non-network feeder model within the NRI-DEF software, to determine the reliability of the non-network system.

The following Section 6 describes the results of these analyses, highlighting the most vulnerable assets as well as the impacts of the adaptation options modeled. The section also describes vulnerabilities found in the transmission and cooling systems, as well as operational and planning vulnerabilities and adaptation options.

6. Priority Vulnerabilities and Adaptation Options

This section provides an in-depth review of the vulnerability of assets and operations/planning practices to changes in humidity-related variables. The assessment of physical vulnerabilities is concerned with the network and non-network distribution systems. The operational and planning practices analyzed include peak load forecasting reliability planning and load relief planning. After discussing the vulnerabilities of these assets and practices to changes in TV and other related variables, the Study team proposed adaptation strategies to address these various concerns.

For information on other, more minor impacts of changes in humidity-related variables on Con Edison's system, see Section 8 – Secondary Vulnerabilities.

6.1. Physical Vulnerabilities and Adaptation Options

Based on the screen of physical sensitivities to identify assets most sensitive to humidity-related climate variables (Section 3), the analysis of physical vulnerabilities and adaptation options focused on the electric network system and non-network systems.

Network System

Con Edison's underground network electric distribution system includes 65 second contingency networks and 19 first contingency networks spread across all boroughs of New York City and

[14] These simulations capture the fact that failure rates increase with increasing values of the average of wet and dry bulb (AWD) temperature variable in heat waves and feeder failure rates decline as heat waves re-occur over the course of any summer. Only fault failures of cable sections, joints, and transformers are addressed. Feeder outages involving the opening of substation breakers occasioned by substation problems (e.g., the failure of feeder breakers to open on demand on a feeder fault) are not considered. The equipment failure rates and outage durations assumed are those that prevailed in 2018; they are those developed and used by Con Edison's Distribution Engineering department. It is also assumed that the existing ratios of feeder peak loads to normal ratings will remain unchanged even if the peak loads increase: that Con Edison will add feeder capacity as required to maintain its existing design criteria.

[15] The number of sustained interruptions per customer per year.

Westchester County.[16] These networks serve approximately 2.6 million customers and include over 96,000 miles of underground cable and over 42,000 underground transformers.

Vulnerabilities

Vulnerability of the network system is measured in terms of impacts to reliability. The NRI metric previously discussed is currently used to assess the current and predicted near-term performance of the network system and to inform current upgrades to the system to meet reliability standards. As mentioned in Section 5, NRI values over 1 p.u. indicate unacceptable levels of reliability for a network and signal a need for investment. Currently, there are no networks that exceed this standard.

As discussed in Section 5, the Study team used the NRI-DEF model to project future NRI values for each underground distribution network. The forward-looking NRI analysis found that given the projections of significantly increased frequency and duration of heat waves by mid-century, between 11 and 28 of the networks may not be able to maintain Con Edison's 1 p.u. standard of reliability by 2050, absent adaptation. Under the higher emissions scenario, projected impacts are relatively severe even by 2030, with 21 total networks projected to exceed the NRI threshold by that year, absent adaptation.

Figure 3 shows the number of networks above the 1 p.u. NRI threshold under a lower (RCP 4.5 10th percentile) and higher (RCP 8.5 90th percentile) climate change scenario, with model results for 2030 and 2050.

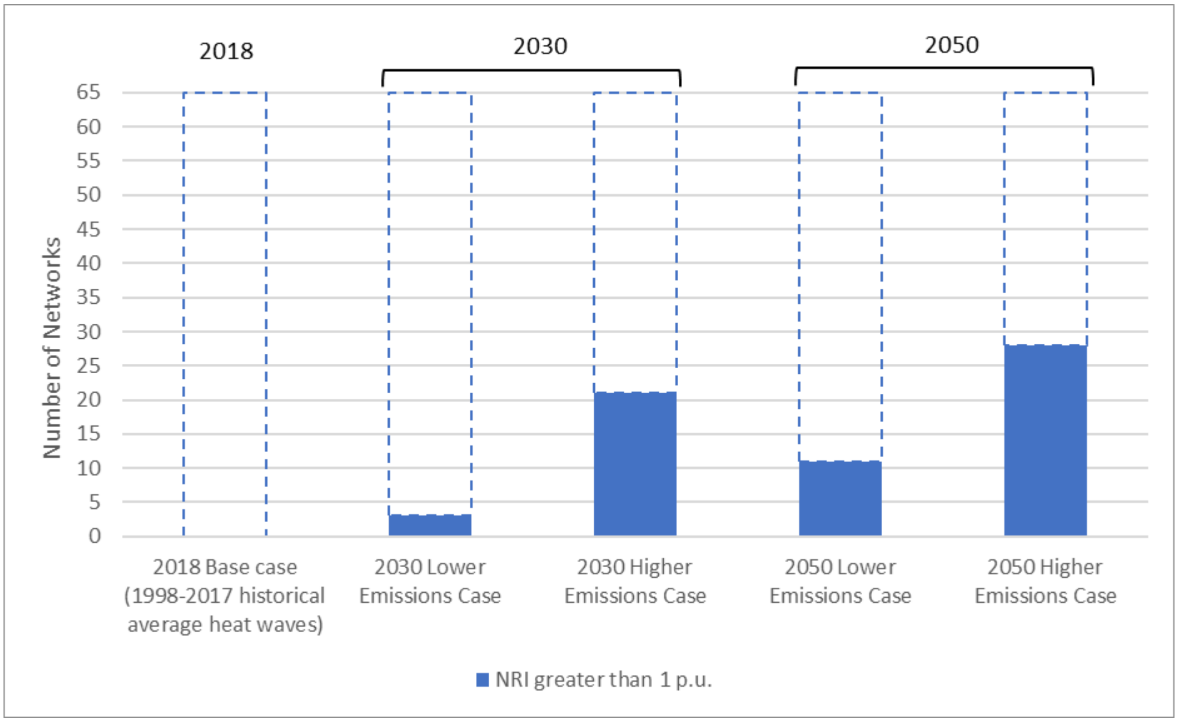
TV-driven increases in NRI are of particular concern in Brooklyn, Queens, and the Bronx due to the large geographic coverage of individual networks (unlike Manhattan, which has relatively small networks) and the correspondingly longer length of supply feeders. Under the worst-case scenario (RCP 8.5), Brooklyn would see 10 out of 12 modeled networks with NRI above 1 p.u. in 2050. Queens would see 6 out of 8, and the Bronx would see 6 out of 6.

As an example of how NRI is projected to change for an individual network, the network with the highest NRI value based on the 1998–2017 historical TV data is 6B in Brooklyn, with a current NRI of 0.314. In 2050, this value is projected to jump to 1.658 under the RCP 4.5 10th percentile, and as high as 5.216 under the RCP 8.5 90th percentile case.

At present, the top 10 highest NRI networks have an average NRI of 0.193. Under the RCP 4.5 10th percentile case in 2050, the NRI values for those same networks range from 0.928 to 1.668. Under the RCP 8.5 90th percentile case in 2050, this same group does not contain any NRI values lower than 3.5.

[16] A first-contingency or second-contingency network can continue operating with its equipment within rating limits despite the loss of one or two supply feeders, respectively.

Figure 3 ■ Projected number of networks with NRI greater than 1 in 2030 and in 2050 under a base case (no temperature change) and lower (RCP 4.5 10th percentile) and higher (RCP 8.5 90th percentile) climate change scenarios. Networks with NRI values exceeding 1 are judged to have an unacceptable probability of feeder failure.



Network System Adaptation Strategies

Currently, Con Edison EO 2152: Distributed Network Reliability Improvements provide "guidance to develop actionable work plans to improve network reliability" through:

- Replacement of paper insulated lead covered (PILC) cable
- De-loading of feeders including de-bifurcation of feeders[17]
- Addition of sectionalizing switches
- Other methods including reducing the size of large networks, replacing thermally sensitive stop joints, targeting feeders with higher failure rates reducing the loading on equipment, and reducing the number of manholes within which common failures can occur

The Study team analyzed the potential of several of these strategies, in addition to others identified as potential adaptation options developed from the beta model NRI-REV.

The Study team used the NRI-DEF software to model replacement of all remaining PILC at a systemwide level by the years 2030 and 2050. As discussed in further detail below, results indicate that PILC replacement is a somewhat effective adaptation strategy under a lower climate scenario, but is insufficient under a high climate change scenario.

[17] Separating feeders currently supplied from a single substation breaker and supplying each of them from an individual breaker.

The Study team also modeled three additional strategies for the Williamsburg (6B) network (the network with the highest predicted NRI value in the RCP 8.5 scenario) in 2050. These strategies were:

- Splitting the network into two
- Creating primary feeder loops
- Installing a distribution substation

In addition, the Study team utilized Con Edison's new, under-development NRI-REV model—capable of considering distributed energy resources (DERs), microgrids, energy efficiency, and complex network designs. The Study team ran the network with the highest NRI values under the RCP 8.5 scenario in each borough—networks 6 Brooklyn (6B), 10 Manhattan (10M), 7 Queens (7Q), and 5 Bronx (5X)—through the NRI-REV model for the year 2050 in these additional analyses.

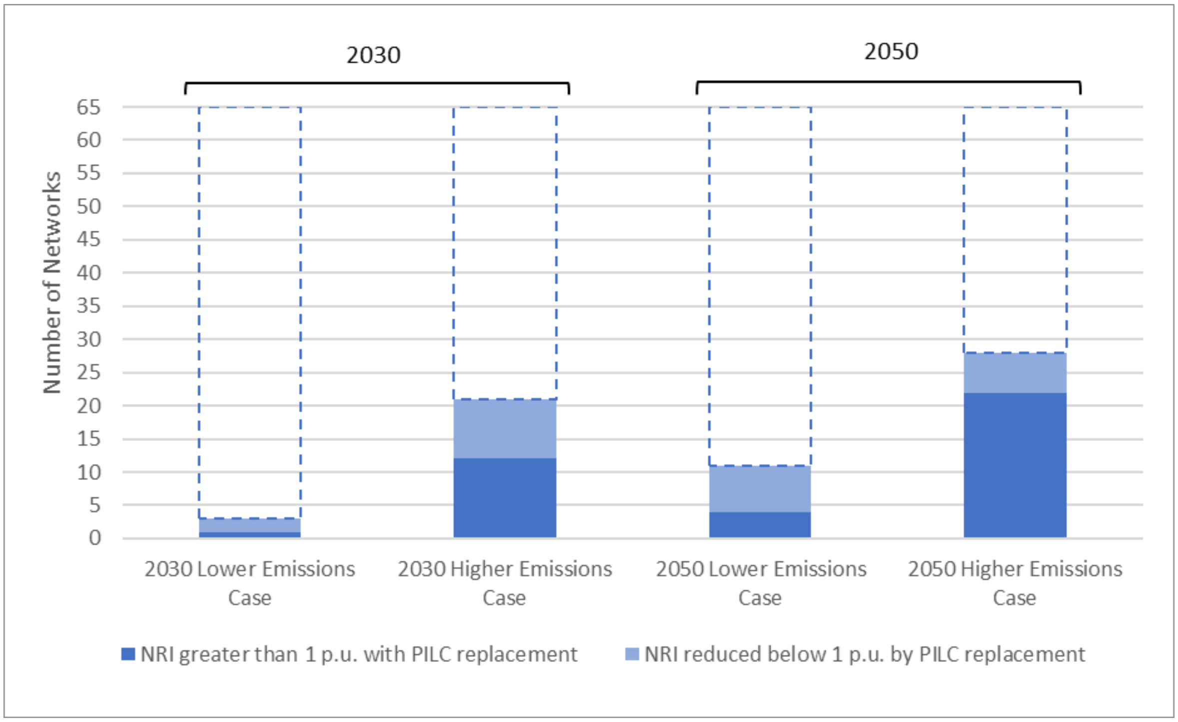
Of the strategies analyzed, several were found to be promising for maintaining reliability as TV changes in the future. **The creation of primary feeder loops** was the one strategy modeled using the NRI-DEF software that was able to reduce NRI below 1 p.u. for 6B under both future climate scenarios and is considered relatively cost-effective. Another possible low-cost and effective strategy is the use of complex network designs that combine DER and feeder loops.

Upon the next revision of Con Edison EO 2152, subject to incorporation of a production version of NRI-REV, Con Edison could consider **feeder loops and non-wire solutions.**

Most of the strategies discussed below (other than building a new substation) are relatively quick to implement. Because of this short timeframe, running the model every year with up-to-date climate information should allow Con Edison to identify and improve reliability as needed. Certain easily implemented strategies—such as complete PILC replacement and splitting the network in two—were shown to be effective under the lower climate scenario (RCP 4.5 10th percentile) but not sufficient under the higher scenario (RCP 8.5 90th percentile). Annual modeling could provide more precise guidance on whether the strategies are likely to suffice, given updated climate information. Additionally, it could be useful to shift the climate data used in annual NRI runs so that Con Edison uses a blend of past and projected data (for example, 20 years past and 10 years projected). This approach would help ensure that Con Edison doesn't fall behind or get too far ahead, as it takes a while for changes in climate to express themselves in the historic trends, and climate projections are dependent on global actions.

Complete PILC replacement. Con Edison currently uses replacement of paper-insulated lead covered (PILC) cable as an effective first line of defense against NRI increases. Typically, when model runs indicate that an underground network may exceed an NRI of 1, the preferred approach to address this issue is to replace PILC cables with newer materials. In order to modernize the grid, Con Edison continues to replace underground PILC cables where possible. This also eliminates failure-prone stop joints. Figure 4 shows the impact of PILC replacement on Con Ed network reliability in each of the modeled scenarios. Under the lower emissions scenario (RCP 4.5, 10th percentile), results indicate that complete replacement of all PILC cable throughout the system will likely be sufficient to keep NRI below the desired threshold in all but one network in 2030 and all but four networks by 2050 (with the additional three networks in 2050 only marginally above the threshold). However, under the higher emissions scenario (RCP 8.5, 90th percentile), the projected increase in the frequency and severity of heat waves will increase the average network NRI value and the number of networks that exceed the 1 p.u. threshold so that the PILC replacement would no longer suffice. Under the higher-emissions scenario, PILC replacement would preserve reliability in an additional 9 networks, but 12 networks would remain with NRI values over 1 p.u. By 2050, PILC replacement would only preserve acceptable reliability for an additional 6 networks throughout the city in 2050, leaving 22 networks still above the threshold.

Figure 4 ■ Impact of PILC replacement (shown in light blue) on number of networks with NRI greater than 1 under lower climate change (RCP 4.5 10th percentile) and higher climate change (RCP 8.5 90th percentile) scenarios in 2030 and 2050.



Based on these results, Con Edison may consider **prioritized PILC replacement in vulnerable networks** in the near term, though this approach is also likely to require supplementation with additional measures within the next decade.

Given the need for additional adaptation measures, the study team also modeled the following strategies for the 6B network in 2050 using the NRI-DEF software. Results are presented in Table 12, with the strategies explained in more detail below.

Splitting the network into two smaller networks. In general, splitting a single network into two independent pieces with a diversity of supply inherently lowers risk of failure. Splitting networks results in shorter feeders and thus in a reduced frequency of multiple feeder contingencies and consequently higher reliability. This strategy may require building new substations unless sufficient empty breaker positions are available in the substation that supplies the existing network or nearby substations. The strategy is intended to reduce primary feeder failure rates, thereby reducing cascading feeder failures. While the strategy is effective in significantly reducing NRI, it is still insufficient on its own to bring NRI below the 1 p.u. threshold in 2050 under the higher emissions (RCP 8.5 90th percentile) scenario.

Creating primary feeder loops within or between networks. The Study team identified the four sets of primary feeders that contributed most to the predicted NRI for network 6B in Williamsburg, the network with the highest modeled NRI for both the base case and future climate scenarios. In the modeling system, fast-acting switches were added to the feeders where necessary, and relevant feeders were joined to create loops. This added redundancy would allow upstream faults in primary feeders to be isolated and would allow the downstream segments of the feeder to remain in service, reducing the load on the feeders remaining in service. Model results indicate that this strategy is effective at reducing NRI in some cases. In the NRI-DEF modeling, it is the only strategy to reduce NRI below the 1 p.u. threshold for network 6B in both future climate scenarios.

Installing a distribution substation. Installing a new distribution substation can serve to increase the diversity of supply points to the network. This strategy involves the installation of a distribution-level substation at a midpoint between the upstream substation supplying the network and the endpoints of the network. The distribution-level substation would serve as a node at which several adjacent feeders connect before continuing. In the event of a fault in a feeder between the upstream substation and the distribution-level substation, the distribution-level substation would allow intact feeders to continue to supply all downstream load. With the assumption of perfect breaker and bus reliability, a distribution substation would somewhat reduce NRI, though not below the 1 p.u. threshold. A distribution-level substation with realistic assumptions as to bus and breaker reliability actually increases projected NRI, since the failure of a bus or breakers at a distribution substation would undo the benefits of bus feeder diversity in the area substation in which the feeders originate (Table 12).

Table 12 ■ NRI predictions (2050) for alternative designs for the Williamsburg (6B) network (NRI-DEF software)

Measure	Present topology with all PILC replaced	Split network with all PILC replaced	Loops with all PILC replaced	Distribution substation with all PILC replaced	
				Perfect distribution substation breaker and bus reliability	Realistic distribution substation breaker and bus reliability
2050 RCP 4.5 10th Percentile	1.536	0.538	0.228	1.606	3.539
2050 RCP 8.5 90th Percentile	4.839	1.882	0.755	3.840	8.429

Incorporating distributed energy resources (DER). Using NRI-REV software, the Study team modeled the effects of DER. The NRI-REV modeling software is in a developmental stage and is being designed to include more factors that influence network reliability. These factors include more complex feeder failure behavior, more granular failure data across a greater number of equipment types including substation buses and breakers, more detail about feeder outage durations and the impact of distributed resources on network reliability. The NRI-REV modeling indicated that DER may be an effective strategy in improving reliability. For example, the 6B network was modeled using the NRI-REV model to determine future NRI in 2050 under the RCP 8.5 90th percentile case. With all PILC replaced and 75 megavolt-amperes of DER NRI was projected to be 0.928.

Designing complex networks that consider combinations of adaptation measures. The Study team used NRI-REV software to model the effects of more complex network designs. This analysis indicated that a hybrid design with both DER and loops could lower NRI (though not below 1 p.u. for network 6B, under the modeled configuration) and that this combination strategy has potential to be a lower-cost alternative to a purely DER-based strategy.

Table 13 ■ Spot NRI predictions (2050) for alternative designs under the RCP 8.5 90th percentile case (NRI-REV software)

Network	NRI With All PILC Replaced and DER
6B	0.928 (3,750 kilovolt-amperes of DER on each of 20 feeders)
7Q	0.979 (2,750 kilovolt-amperes of DER on each of 28 feeders)

Improving fault monitoring capabilities. Although it could not be modeled at this time, for networks with NRI values that are close to but slightly over the existing risk-tolerance threshold of 1 p.u., Con Edison could consider embedding additional sensors in the underground distribution system, inline, within transformers, or in structures. These sensors may provide a low-cost way for Con Edison to identify and respond to incipient fault conditions before larger problems can occur. Additionally, the information collected from the sensors can provide information for the refinement of the NRI predictive modeling capabilities (in either capital planning or operations/response).

Update EO-2152 to include the creation of feeder loops as well as non-wire solutions as accepted strategies. Given the modeled efficacy of these strategies, as discussed above, the Study team suggests institutionalizing them within EO-2152 as accepted strategies.

Non-Network Distribution

Con Edison also has non-network systems that serve parts of Brooklyn, Queens, Staten Island, the Bronx, and Westchester, known as Con Edison's radial grid (on approximately 34,000 miles of overhead cable and accounting for about 14% of Con Edison's distribution load).[18]

The non-network system includes auto-loops, which are traditionally made of two feeders, one or more backup feeders, and automatic switches along the feeder run. During contingencies in which one feeder is lost or one section of the loop is damaged, faults are rapidly isolated via the switches. Backup feeders also serve to restore power upon loss of the main supply feeders. The non-network system also includes 4-kilovolt (kV) grids consisting of supply substations, each of which supply multiple 4-kV feeders that are interconnected into separate grids.

Vulnerabilities

The Study team used the non-network feeder model within NRI-DEF software to measure the effects of climate change on the reliability of the power supply to non-network circuits. The results indicate that the reliability of the non-network system is somewhat vulnerable to heat events. However, climate impacts would be negligible out to 2080.

The Study team compared a base case comprised of historical data for the period 1998–2017 and a projected case assuming both a low-end and a high-end estimate of climate change (RCP 4.5 10th percentile case and RCP 8.5 90th percentile case, respectively) in the years 2050 and 2080. The analysis focused on the loss of feeders supplying auto-loops and 4-kV circuits in Westchester and the Bronx (and their impact on service reliability), as these were the Customer Service Areas with the data required for these simulations.

Impacts to reliability for the non-network system are presented in terms of the frequency of contingencies and subsequent contribution to the System Average Frequency Index (SAIFI).[19] Con

[18] Navigant Consulting, November 2017, REV CONNECT utility profile: Consolidated Edison, p. 4. Available at: https://nyrevconnect.com/wp-content/uploads/2018/01/Con-Edison-Utility-Profile-Revised-Nov2017.pdf.
[19] SAIFI is a measure of customer reliability. It is the average number of times that a customer is interrupted for 5 minutes or more during 1 year.

Edison currently works toward low SAIFI targets for acceptable reliability in non-network areas, which currently are a maximum of 0.45 and a goal of 0.35 interruptions per customer per year.

First contingencies occur when one asset is out of service; a second contingency occurs when another connected asset of the same asset type is out of service while the first is still out; and a third contingency occurs when a third connected asset of that asset type loses power while the first two are still out. Thus, first contingencies are most frequent, and third contingencies are least frequent. In general, a second contingency is required for a loss of power to an auto-loop, whereas third contingencies will be required to causes an outage in configurations where a third feeder is available to provide an alternative power supply through an automatic transfer switch.

Looking at individual non-network system components, none are projected to experience significant impacts to reliability due to climate change. Table 14 shows the average contribution to reliability from auto-loop feeder failures and supply feeder failures (note that these figures are orders of magnitude lower than the overall historical values of SAIFI experienced by non-network customers (0.36 in 2017), and would contribute only up to roughly 8% of the maximum threshold SAIFI of 0.45.)[20]

Similarly, there is a marginal contribution to SAIFI from contingencies involving supply feeders for a 4-kV circuit (Table 14). However, the frequency of contingencies is expected to increase with climate change (more so in Westchester than in the Bronx) for unit substations, supply feeders, and stations supplying a 4-kV grid and the supply feeders supplying unit substations for a 4-kV grid.

Table 14 ■ The effect of climate change on frequencies of contingencies in the non-network system and their subsequent impact on reliability in Westchester

Case	Total Contingency Frequencies (per year)			Average Contribution of a Total Loss of Feeders to SAIFI
	1	2	3	
Base	92.79	00.2041	0	0.00173
RCP 4.5 10th percentile, 2050	99.54	0.2582	0	0.00219
RCP 8.5 90th percentile, 2050	119.43	0.4125	0	0.00349
RCP 8.5 90th percentile, 2080	107.82	0.3472	0	0.00292
Base	202.18	00.71	0.001	0.0276
RCP 4.5 10th percentile, 2050	216.90	0.896	0.00176	0.0230
RCP 8.5 90th percentile, 2050	259.89	1.426	0.00376	0.0363
RCP 8.5 90th percentile, 2080	235.00	1.16	0.0025	0.0327

Adaptation Strategies

Currently, the main strategy for improving non-network reliability is to further sectionalize auto-loops and to diversify feeder supply to unit substations, increasing redundancy and reducing the chance of outages due to loss of supply feeders.

Autoloop sectionalizing: The installation of additional sectionalizing and/or reclosing switches on autoloop feeders will reduce the number of customers per segment between switches and consequently reduce the number of customers interrupted per event.

[20] New York Department of Public Service, June 2018, *2017 Electric Reliability Performance Report*.

Increasing feeder diversity: Given the near-negligible effect of climate change in 2080 on non-network customer reliability (as shown in Table 14 above), there will likely not be a need for further action. However, if the predicted failure rate of non-network feeders is deemed unacceptable, this can be addressed by increasing feeder diversity by installing additional supply feeders to unit substations. The current design provides one or two supply feeders, per station.

Through its Non-Network Reliability program (approximately $30 million annual investment), Con Edison has been Installing additional sectionalizing switches or increasing feeder diversity by installing additional supply feeders. Since the non-network system represents only around 15% of Con Edison load, and the degradation in reliability of the non-network system due to climate change is expected to be minimal, the costs required to provide the marginal performance improvements required would be substantially less than those associated with managing NRI for the network system.

Additional diversity could be supplied by increasing the number of stations supplied with two feeders or even using three-way switches to provide supply from three feeders. Further improvement could be provided if unit substation supplies were reconfigured to be fed from different area substations.

7. Operational and Planning Vulnerabilities and Adaptation Options

As with temperature, discussed in Appendix 1, TV-related variables are relevant to load relief planning and the related planning exercises like load forecasting and load relief planning.

Peak Load Forecasting

Con Edison forecasts peak load annually based on the historical correlation between the load and temperature variables. Because there is a direct correlation between system load and system performance, Con Edison forecasts load to ensure that the system will continue to meet performance expectations in the future. Con Edison designs the electric system to meet a peak demand that would occur approximately once every three years. The TV that corresponds to this peak demand is termed the “1-in-3 peak-producing TV event” and is currently 86°F.

More specifically, Con Edison forecasts peak load annually using historical data for load and weekday TV. There is a strong correlation between system load and TV and therefore, Con Edison uses historical data on weekday TV and daily peak load to forecast expected load based on forecasted TV. Con Edison does not include Friday, Saturday, or Sunday daily TV values in their calculations of average maximum TV and the 1-in-3 TV event, as peak load is not observed on these days. Con Edison performs annual peak load forecasting using recent historical data to account for changes in TV over time. Con Edison also uses TV to estimate winter load, though here average *minimum* TV is used to estimate the peak load needed for heating and only dry bulb temperatures are considered.

Vulnerabilities

Electric Summer Peak Load

The Study team used climate projections of maximum daily summer electric TV over a 30-year time period to develop future peak load projections. Specifically, the Study team calculated the projected 1-in-3 TV event for LaGuardia in 2030, 2050, and 2080 under RCP 4.5 10th percentile and

RCP 8.5 90th percentile. This analysis showed that summer electric demand will increase while winter demand for heating will decrease. Table 15 provides the 1-in-3 TV event.

Table 15 ■ Projected 1-in-3 peak producing TV events under historical and future climate scenarios

Scenario	Year	LaGuardia 1-in-3 TV event
LaGuardia Base (Historical)		86.9
RCP 4.5 10th percentile	2030	88.4
	2050	89.4
	2080	90.1
RCP 8.5 90th percentile	2030	90.7
	2050	93.5
	2080	98.3

Using the existing Electric Weather Adjusted Peak curve and the projection of the future 1-in-3 TV, the Study team also projected future load, as shown in Table 16.

Table 16 ■ Weather-adjusted peak load for projected 1-in-3 peak producing TV events under historical and future climate scenarios at LaGuardia

	LaGuardia Base Case (Historical)	2030 RCP 4.5 10th Percentile	2050 RCP 4.5 10th Percentile	2080 RCP 4.5 10th Percentile	2030 RCP 8.5 90th Percentile	2050 RCP 8.5 90th Percentile	2080 RCP 8.5 90th Percentile
Average Daily Maximum TV	85.7		88.1			92.5	
1-in-3 TV	86.9	88.4	89.4	90.1	90.7	93.5	98.3
Weather-Adjusted Peak Load (MW)	13,572	14,122	14,513	14,774	15,028	16,173	18,306
Percent Change in Peak Load	—	4.1%	6.9%	8.9%	10.7%	19.2%	34.9%

Based on past experience, a second order polynomial is the best fit between TV and load, so the Study team assumed the same shape for the future projection. However, because Con Edison's historical observed data does not fully capture the range of future high TV values, this curve represents an extrapolation. It is possible that a different curve would better fit the shape of higher TV values.

This analysis demonstrates an increase in peak load by 6.9% for 2050 RCP 4.5 10th percentile and 19.2% for 2050 RCP 8.5 90th percentile, as compared to historical scenarios (Table 16). These projected changes in load are due only to the impact of changing TV and do not take into consideration changes in other factors (e.g., population, increased use of air conditioning).

Electric Winter Peak Load

In the winter months (November–March), the Study team projected average winter TV for 2050 under both the base case (using current Con Edison forecasting methods and assuming no climate change) and RCP 8.5 90th percentile. The data represent average TV on Monday– Thursday, 4–6 p.m., as this is the most likely time that electricity is used during winter months. Under the base case, the 1-in-3 TV temperature is 15.3°F. Under RCP 8.5 90th percentile, this value jumps to 22.5°F, a difference of 7.18 degrees. Con Edison estimates that electric load during the winter decreases by 42 MW for every increase by 1 degree TV, indicating that Con Edison might expect winter load decreases of 301 MW in 2050 under RCP 8.5 90th percentile compared to the base case (Table 17).

Table 17 ■ 1-in-3 winter TV and winter peak electric load in 2050 under a base case and the RCP 8.5 90th percentile case

	Base Case	2050 RCP 8.5 90th Percentile
1-in-3 winter TV (°F)	15.3	22.5
Winter electric load change (MW)	--	-301

A decrease in winter peak electric load is noteworthy, as Con Edison is expecting more customers to transition from gas to electric heat to help meet New York City's greenhouse gas emissions-reduction targets. This shift to electric heating could push Con Edison from being a summer-peaking electric system to a winter-peaking electric system. However, the suggested decrease in projected load under climate change due to warmer winter temperatures (as shown in Table 17) could work toward counterbalancing this increase in winter electric heating usage. Extreme cold events are explored in Appendix 5 – Extreme Events.

Gas and Steam Winter Peak Load

The Study team also calculated the change in peak winter load for steam and gas based on changes in winter TV.[21] Although the gas system is designed for a zero degree day for safety reasons rather than to the 1-in-3 TV event, which would be warmer, the change in the 1-in-3 event is still used to estimate changes in peak load.

The Study team projected the changes in the 1-in-3 TV event in 2050 from the base case (assuming no climate change) to the RCP 8.5 90th percentile case. Under the base case for steam, the 1-in-3 TV event is 9.0°F. Under RCP 8.5 90th percentile, this jumps to 16.2°F—an increase of 7.2 degrees. The Study team estimates that for each increase of 1 degree TV, steam load decreases by 124 thousand pounds per hour (Mlb/hr). This indicates that compared to the base case, RCP 8.5 90th percentile is projected to decrease steam load by 891 Mlb/hr in the winter of 2050 (Table 18).

For gas, the base case 1-in-3 TV event in 2050 is 12.7°F, and jumps to 19.9°F under the RCP 8.5 90th percentile. The Study team estimates that for each increase of 1 degree TV, gas load decreases by 20 MDt. This indicates that under RCP 8.5 90th percentile, winter gas load is projected to decrease by 144 MDt in 2050 compared to the base case. Broadly, the increases in winter TV projected under both climate scenarios will likely decrease steam and gas load during winter months due to the decreased need for heating (Table 18).

Table 18 ■ Projected changes in winter steam and gas load in 2050 under RCP 8.5 90th percentile case compared to the base case

	Base case 1-in-3 TV event (°F)	2050 RCP 8.5 90th percentile 1-in-3 TV event (°F)	Unit/TV	Change in winter load by 2050
Steam	9.03	16.22	124 Mlb/hr	-891 Mlb/hr
Gas	12.7	19.88	20 MDt	-144 MDt

[21] For steam, winter TV is calculated as a weighted average of peak hourly dry bulb (the dry bulb for the day between 6 a.m. and 11 a.m., Monday–Thursday) and the 24-hour average dry bulb of the prior day. For gas, TV is calculated as a weighted average of average dry bulb temperature for the gas day and the prior day's gas day (in which a gas day is 10 a.m. to 10 a.m. the following morning).

Adaptation Options

Integrate climate projections into long-term forecasts (e.g., 10 and 20 years) of peak load. Con Edison's current practice for load forecasting consists of a yearly forecast of the 1-in-3 design event using the latest 30 years of historical TV information. Con Edison annually produces forecasts that look out 10 and 20 years. The 10-year forecast is developed via a bottom-up approach considering information such as customer connection requests, while the forecast for 20 years is developed using a top-down approach considering factors including economic forecasts for the service territory. Information on projected load is then used to develop Con Edison's load relief plans, which specify the preferred investments to ensure the capacity of the electric system is able to keep pace with projected increases in load. Supplementing or adapting this yearly analysis to include projections of future TV may assist in anticipating larger changes in load (see Appendix 1 – Temperature for a more detailed discussion).

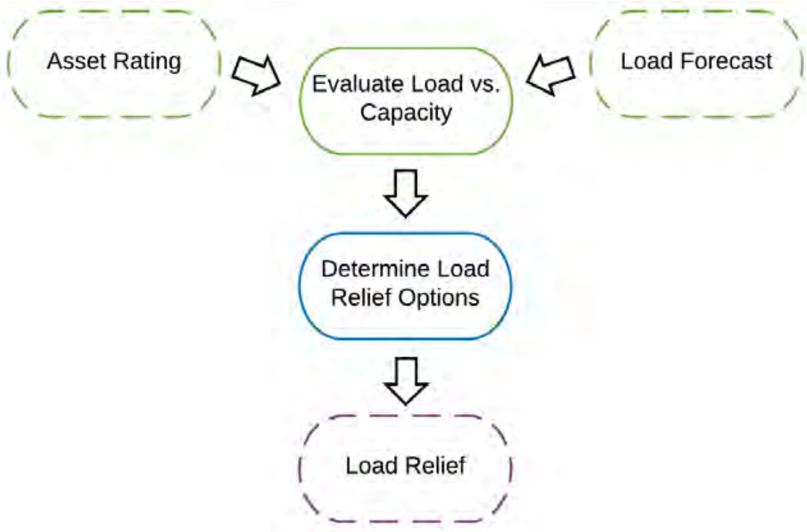
Consult utilities in cities with higher temperatures to refine the load forecast equation for high TV numbers. Con Edison's analysis of future Weather Adjusted Peak Load relies primarily on historical conditions and therefore is constrained when forecasting against unrealized TV and load combinations. As a result, since Con Edison has not previously modeled TV and load relationships above a TV of 89.35 which occurred in 1999, there are some uncertainties in the accuracy of the future relationship. Con Edison could consult utilities in cities with higher temperatures to determine if load curves at higher temperature variables values fit a curve with a different shape. An improved understanding of the projected relationship between high TV and load could improve the accuracy and understanding of future load conditions and necessary adaptations.

Consider changes in winter TV in long-range planning processes. Con Edison's customers may undergo a transition from gas to electric heating in the winter as part of New York City's 80x50 plan while winter temperatures are projected to increase, which would decrease the amount of energy needed for heating. Gaining a firmer understanding of long-term climate projections' influence on winter TV and the city's electrification process will help Con Edison prepare itself for the interactions of these factors on electric load. For gas and steam, tracking winter TV over time could eventually justify moving from a zero-degree-day design standard to a higher standard. However, for the time-being, the science on polar vortices, which would influence peak loads and their future frequency, is still limited.

Load Relief Planning

As discussed in Appendix 1 – Temperature, load relief planning relies on annual updates to asset ratings and load forecasts as inputs to develop a future investment plan (Figure 5). The 10- and 20-year load relief plans specify the preferred investments to meet changes in network loads. The appropriate investments in the load relief plan are identified by running a cost-benefit analysis to determine the long-term tradeoffs of various investment options.

Figure 5 ■ Current 20-year load relief planning process



Vulnerabilities

In Appendix 1 – Temperature, the Study team found that higher average or maximum ambient temperatures can increase the aging rate of insulation in transformers and reduce the carrying capacity of electricity transmission and distribution lines, as well as transformers. As discussed in this appendix, the electric system is also expected to experience higher peak loads due to increases in TV, particularly in the summer. This combination of a greater need but a decreased capacity to fill that need will likely warrant a revision to the load relief planning process in the future.

Table 19 summarizes the combined additional capacity needed due to increased load and decreased capacity in 2050. (See Appendix 1 – Temperature for a more detailed discussion of load relief planning.)

Table 19 ■ The combined impacts of increased load and asset capacity reduction in 2050

Scenario	Total capacity under base and future temperature conditions (MW)	Incremental capacity reduction due to temperature	Peak load during current and future 1-in-3 event (MW)	Incremental load-increase due to changes in TV	Total additional capacity needed under climate scenarios (MW)
Base Case 2050	13,300	0	13,525	-	0
RCP 4.5 10th percentile 2050	13,015	285	14,949	1,424	1,709
RCP 8.5 90th percentile 2050	12,607	693	16,491	2,966	3,659

Adaptation Options

Develop a load relief plan that integrates future changes in climate and other critical factors. This adaptation option is included in Appendix 1 – Temperature. As discussed above (in the section on Peak Load Forecasting), climate change projections could feed directly into peak load forecasting, which is a primary input to the annual load relief planning process. Con Edison relies on an extensive set of physical and operational load relief options to meet changes in capacity and load. For example, physical adaptation measures that could be implemented to increase network capacity or reduce demand include adding capacitor banks, installing transformer cooling, and establishing new substations. Solutions like adding cooling, a new transformer, or a new substation would provide load relief and reliability benefits.

In addition to options related to physical assets, load relief can be provided through operational or program changes, such as transferring the load to an existing substation that has capacity or implanting expanded energy efficiency or demand-side management programs. Overall, these load relief options are not expected to change in a warming climate, although non-wires solutions may become less dependable because they are more sensitive to uncertainty in load and temperature. Non-wires solutions tend to be implemented just in time to counteract load growth and thus provide little buffer for unanticipated changes in load. While more traditional solutions ensure the utility has the capacity to absorb higher rates of load growth and temperature change, non-wires solutions may be a very appropriate solution for addressing gradual increases in load due to gradually increasing temperature or changes in humidity. In addition to the increases in capacity, non-wires solutions provide the benefit of reducing electricity use, which has a positive carbon impact. Non-wires solutions could be implemented at the customer and/or utility level to help reduce network load affecting an area substation.

For a more detailed discussion of adaptation options associated with load relief planning, see Appendix 1 – Temperature.

8. Secondary Vulnerabilities

This section provides an overview of additional analyses the Study Team performed to understand the vulnerability of Con Edison's system to humidity-related variables. Ultimately, these analyses demonstrated a lower-level of sensitivity to humidity-related variables as compared to the priority vulnerabilities outlined in Section 6. The assessment of physical vulnerabilities is concerned with the transmission and cooling systems. The operational and planning practices include summer operations and voltage reductions, the Corporate Emergency Response Plan, volume forecasting, and worker safety. After discussing the vulnerabilities of these assets and practices to changes in TV and other related variables, the Study team proposes a few adaptation strategies. For most of the analyses, additional information can be found in Appendix 2.B – Additional Information on Secondary Vulnerabilities.

8.1. Physical Vulnerabilities and Adaptation Options

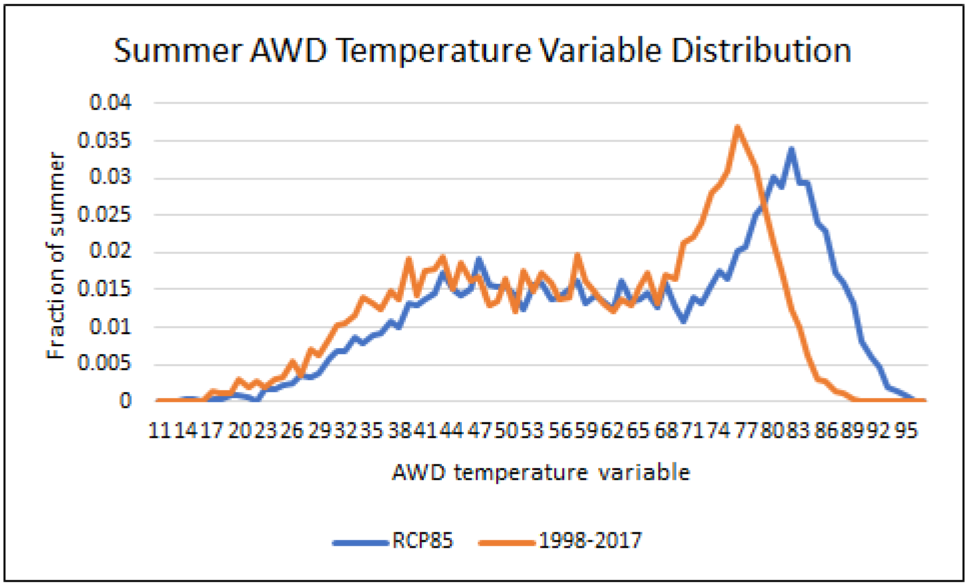
Transmission System

The Con Edison transmission system includes 430 circuit miles of overhead transmission lines and the largest underground transmission system in the United States, with 749 circuit miles of underground cable. The system also includes 39 transmission substations. The high-voltage transmission lines bring power from generating facilities to transmission substations, which supply area substations where the voltage is stepped down to distribution levels.

Vulnerabilities

Con Edison currently designs, builds, and maintains its transmission network for the highest anticipated loads, which ensures that load-drops on hot days due to thermal overloads are very rare. When designing the system, Con Edison assumes a distribution of TV based on historical values, which may not match future profiles of TV distribution. Comparing summer TV data from 1998 to 2017 with those projected under the 2050 RCP 8.5 90th percentile scenario, the Study Team sees both the expected shift to higher values with increasing dry and wet bulb, and increased frequency of days on which loads are close to the peak load (Figure 6). Thus we see a load in excess of 90% of the peak load on 1.5% of summer days historically, and 5.2% of days under the 2050 RCP 8.5 90th percentile scenario.

Figure 6 ■ Summer TV distribution comparing historical to 2050 under RCP 8.5



The projected shift in load pattern, with more frequent exposure to high loads, may affect transmission system reliability even in a system designed for peak loads. To better understand this issue, the Study team selected to use Con Edison's Transmission Probabilistic Reliability Assessment (TPRA) software to project the load-drop frequency expected for a given set of TV and load data. TPRA contains a model of Con Edison's transmission network that includes individual elements and their respective failure rates as influenced by weather, including temperature. The model characterizes reliability as the frequency of load drops per year. It was assumed that system topology remains unchanged in all cases and that Con Edison will strengthen its transmission system as necessary to ensure that its first and second contingency design criteria can be satisfied regardless of the projected load.

The TPRA model was used to estimate transmission system reliability under three scenarios: a no-change base case using historical TV data for the period 1998–2017, conditions reflecting projected TV in 2050 under a moderate emissions scenario (RCP 4.5 10th percentile case) and conditions reflecting projected TV in 2050 in a high-emissions scenario (RCP 8.5 90th percentile case).

The TPRA software projected an approximately 22% increase in the probability of load-drop events to the transmission system during the summer (see Table 20). This small increase is presumed to result in part from a projected increase in the frequency of days on which load approaches system peak load.

Table 20 ■ Simulations of transmission system reliability

Scenario	Summer Load Drop[22] Frequency (per year)	Summer Challenge[23] Frequency (per year)
Historic (2007–2016)	0.0521	5.712
2050 RCP 8.5, 90th percentile	0.0620	6.817
2080 RCP 8.5, 90th percentile	0.0627	6.839

In summary, climate change is likely to result in small increases in the frequency of load drop from the transmission system even if the system is strengthened to accommodate higher loads, due to the change in projected TV distribution (see Figure 6 for a depiction of projected shift in summer TV distribution).

Adaptation Strategies

To ensure this issue is considered alongside other risks to the transmission system, Con Edison could consider **integrating considerations of climate change into the long-range transmission plan.** Both the expected shift to higher TV values with increasing dry and wet bulb, and the increased frequency of days on which loads are close to the peak load could be incorporated into the long-range transmission planning process. While the impacts to summer load drops are projected to be small, they could still be considered alongside other forces impacting the transmission system.

[22] Events, occurring in summer—June to August—in which thermal overloads will force load to be dropped despite any remedial action that might be taken. Remedial action includes voltage reduction and the implementation of demand response measures.
[23] Challenges to the system occurring in summer—June to August—in which thermal overloads would force load to be dropped were there no mitigations.

Cooling Systems

Through conversations with Con Edison SMEs, the Study team identified a select number of assets independent of the network and non-network distribution systems that are sensitive to changes in both humidity and temperature. These include HVAC, air cooling towers, and water cooling towers. Con Edison's cooling system assets include 12 facilities with cooling towers, 255 HVAC systems, 5 facilities that are responsible for cable cooling, 9 gas turbines, and the East River plant.

These cooling systems are sensitive to humidity and temperature changes because as these variables increase, cooling efficiency decreases. Additionally, Con Edison's National Pollutant Discharge Elimination System (NPDES) permit states a temperature threshold for the East River plant's discharge water. As the river water that the plant takes in increases in temperature, the closer the plant is to its NPDES threshold on the discharge.

Vulnerabilities

In order to meet the dry bulb requirements in 2080, Con Edison's HVAC systems will need to increase their capacity by 11% due to projected increases in dry bulb temperature. Similarly, given projected increases in wet bulb temperature, Con Edison's cooling towers will need to increase their capacity by 30% by 2050.

Con Edison's East River plant cooling system relies in part on the river. The plant draws in river water, uses it to cool equipment via heat transfer, and then discharges the water back into the river. The Study team investigated how the East River's water temperature might be affected by climate change and increased TV. As mentioned above, the plant's NPDES permit stipulates that if Con Edison discharges water above a certain temperature back into the river, the company will be fined. If the temperature of the intake river water increases, then it is more difficult for Con Edison to keep its discharge water temperature below the permit threshold.

Based on a review of expert analyses, the Study team concluded that East River water temperature will likely increase as air temperature increases. Quantitatively calculating future river water temperatures requires sophisticated methodologies that are outside of the scope of this project (e.g., artificial neural networks and other forms of machine learning). However, the literature demonstrates that a positive correlation between river water temperature and air temperature does exist (Rabi, 2015; van Vliet, 2011; Toffolon, 2015; Zhu, 2018). In particular, river water temperatures are most sensitive to air temperature during heat waves and droughts and can reach "critically high values" under such conditions (M.T.H. van Vliet 2011). As climate change is projected to increase the frequency and severity of heat waves, river water temperature may be even more strongly impacted by increased air temperatures. Based on the characteristics of the East River (i.e., the river connects the Long Island Sound and the Lower New York Bay, which are both large bodies of water), the East River may likely also experience warming from other sources, including long-term regional ocean warming and transient warming of the shallow ocean.

Adaptation Strategies

Upgrade HVAC systems when undertaking routine replacements. While the Study team expects that Con Edison will need to make updates to HVAC systems by 2080, these systems have a roughly 15-year lifespan. Therefore, Con Edison can wait to make the upgrades until the company undertakes routine HVAC replacements. Doing so will help streamline the upgrade process, and the Study team does not expect there to be a large cost difference to upgrade ($3,500 to $7,000 per unit, for a total of $1.344 million for 157 units.)

Additionally, the group responsible for writing the HVAC dry bulb requirements (ASHRAE) is committed to continuing to update HVAC design data "to reflect changing climate and weather conditions" (ASHRAE 2018). Con Edison can therefore expect these requirements to be updated by 2080. The Study team identified that Con Edison could continue to stay abreast of such updates as it proceeds with the suggested capacity upgrades to its HVAC systems.

Utilize typical building energy efficiency measures. In general, increasing energy efficiency will reduce the burden on cooling systems and allow them to more feasibly meet wet bulb and dry bulb temperature requirements. This is especially important given the projected increases in temperatures throughout the century.

Upgrade cooling towers. In order to meet wet bulb requirements, cooling towers will need to be upgraded to increase their capacity by 30% by 2050. This is expected to incur relatively low costs ($1.14 million total for 19 cooling towers at 12 sites, at $60,000 per cooling tower), which is why the Study team has classified this as a secondary vulnerability. According to ASHRAE, cooling towers have a 20-to-35-year lifespan, depending on material (ASHRAE, n.d.). Therefore, the Study team recommends that Con Edison undertake these capacity upgrades during routine maintenance and replacements between now and 2050.

Monitor river water temperature. Because of the positive correlation between air temperature and river water temperature and projected temperature increases, river water temperature will likely increase. Con Edison monitors river water temperature to track this increase and can use the data to determine if practices need to adapt. This includes monitoring the difference between intake and discharge temperatures and assessing against the National Pollutant Discharge Elimination System (NPDES) limit.

8.2. Operational and Planning Vulnerabilities and Adaptation Options

To identify operational protocols that include TV-based thresholds, Con Edison conducted a keyword search. Based on that review, the following procedures were identified:

- **EOP-5022: Automated Voltage Reduction Program and Demand Response Programs.** This specification specifies the TV at which automatic voltage reduction programs are put in place. The impact of climate change on this specification is discussed below.
- **EOP-5025: Guidelines for Summer Operations of the Distribution System**. This specification specifies the limitations on summer scheduled work based on projected TV. The impact of climate change on this specification is discussed below.
- **EO-2152: Distributed Network Reliability Improvements.** This specification provides guidance on the NRI thresholds at which action needs to be taken to increase reliability and the potential strategies for increasing reliability.
- **EO-4097: Primary Feeder Reliability Work.** This specification specifies the approach to be used for "testing the benefit versus cost of the plans used for improving the reliability of networks and feeders." This specification defines jeopardy as "two feeders in a band *and* two or more feeders in adjacent bands fail when the average of wet and dry bulb (AWD) temperature variable exceeds 80°F."
- **EO-2155: Standardization of Building Models in Poly Voltage Load Flow.** This specification lays out an approach for "creat[ing] models in the Poly Voltage Load Flow (PVL) program to develop a planning case for scheduled reinforcement and replacement of network components." These models are informed by load forecasts, which are set based on a TV threshold of 86°F (85°F for Westchester).

- **EO-4095: Distribution System Operation Under Contingency and/or Elevated Load Conditions.** This specification provides guidance on actions to take in the case of contingencies. This includes voltage reduction, if the level of contingency, NRI, and TV conditions warrant such action.

EOP-5022 and EOP-5025 are reviewed in more detail in the sections, below. Additionally, EOP-2152 was addressed in Section 6 of this appendix.

In addition to these operational considerations, volume forecasting and worker safety are also covered as additional secondary vulnerabilities.

Summer Operations and Voltage Reductions

Con Edison uses a set of procedures to avoid voltage and thermal stresses on their system caused by high temperature and humidity conditions. These procedures stipulate TV thresholds and other conditions that necessitate modifications to standard operating actions, such as voltage reductions and work limitations, to avoid outages and damages to the system as a result of summer weather conditions.[24]

The Study team conducted an analysis to understand how the projected changes in TV would alter the frequency of automated voltage reduction and reduced summer operations. In particular, the Study team wanted to understand:

- If Con Edison continues to design the electric system for *today's* 1-in-3 peak load-producing TV (i.e., TV 86), then how would the frequency of automated voltage reduction and reduced summer operations change?
- If Con Edison updates the design of the electric system to keep pace with changes in the 1-in-3 TV event, how would that change the thresholds for automated voltage reduction and reduced summer operations, and how often would those thresholds be exceeded?

The results demonstrate that if the system is designed/maintained at current levels (i.e., with TV 86 as the design criteria), there could be a significant increase in the number of days with voltage reductions and summer work restrictions. However, if Con Edison continues to invest in the system to ensure operational capacity during the 2050 1-in-3 TV event, then there will actually be a drop in the frequency of voltage reductions and summer work restrictions, relative to today. More information on the analyses and the results are provided in Appendix 2.B – Additional Information on Secondary Vulnerabilities.

[24] Current voltage reduction thresholds associated with operations changes include TV > 85°F for 2 days and TV > 82°F for 2 days. The additional conditions required for these voltage reductions are described in Section 7.

Based on the results of the analysis, the Study team identified two recommended adaptation strategies:

- **Continue designing to the changing 1-in-3 TV event.** In order to avoid significant increases in the frequency of voltage reductions, which might take place if TV increases but the system design does not keep up, Con Edison could continue to regularly update designs to ensure adequate reliability under 1-in-3 TV events.
- **Routinely update voltage reduction thresholds and hands-off thresholds to account for changes in climate and the changing design of the system.** As has been seen in the past, Con Edison's improvements to the distribution system have, over time, resulted in less frequent failures. Our analysis demonstrates that this trend will continue if Con Edison continues to design for the 1-in-3 event. In that case, holding the voltage reduction thresholds constant may result in more voltage reduction days than is necessary, which would be a waste of resources. To ensure this does not occur, Con Edison may consider conducting a statistical analysis to re-evaluate its voltage reduction thresholds, based on actual failure rates, every 5 years.

Corporate Emergency Response Plan

Con Edison also uses TV thresholds to trigger elevated threat levels under its Corporate Emergency Response Plan (CERP). An elevated threat level is associated with a mobilization of the company's Incident Command System (ICS) in preparation to respond to heat-related grid impacts. Con Edison updated the current TV thresholds for threat-level elevation based on a study conducted in 2014 by the Performance and Operational Engineering department within Distribution Engineering.

The Study team conducted an analysis to understand how the projected changes in TV will affect the exceedance of current CERP ICS threat-level elevation thresholds. In a similar analysis for the Summer Operations and Voltage Reduction section, the Study team compared the number of days exceeding the current ICS threat-level thresholds under historical TV conditions, in the RCP 4.5 10th percentile scenario and in the RCP 8.5 90th percentile scenario.

The analysis indicates that TV conditions exceeding current thresholds will increase in both the higher and lower emissions scenarios. The conditions for reaching a "Serious" threat level based on the current thresholds, for example, would increase from 0.4 days on average per summer to 1.8 days under the lower emissions scenario and 12.8 days under the higher emissions scenario (3.108%). While upgrades to both Con Edison's CERP procedures and physical infrastructure are likely to mean that these projections would not translate into a commensurate increase in threat elevations, these data indicate that threat-level elevations are likely to become more frequent, and that careful and frequent revision to thresholds will be necessary. More information on the analyses and the results are provided in Appendix 2.B – Additional Information on Secondary Vulnerabilities.

In light of this, Con Edison could consider **routinely updating analysis of CERP thresholds.** As high-TV conditions become more frequent in a warming climate, system performance throughout the high-TV season may deviate from historical trends. Con Edison should continue to conduct hindcasting studies as TV event frequency increases in order to understand the impacts of warmer conditions on system performance and to update CERP thresholds accordingly.

Volume Forecasting

Volume forecasting is undertaken to estimate the volume of energy that Con Edison needs to purchase, a portion of which is weather-sensitive. Heating degree days (HDD) and cooling degree days (CDD) are used as a primary input to the volume forecast. Heating degree days are calculated for winter months; cooling degree days are calculated for summer months. The calculation for HDD and CDD is straightforward: the difference between a reference temperature and the average 24 hourly temperature of any given day gives the degree days.

The Study team conducted an analysis to understand if changes in HDD and CDD under future climate scenarios could have a meaningful impact on the volume of energy that Con Edison needs to purchase. The results indicate an increase in summertime CDD, which could result in the energy delivery increasing from 43,077 GWh in 2050 under the base case to 43,685 GWh under the RCP 4.5 scenario (a 1.4% increase) and to 45,394 GWh under the RCP 8.5 scenario (a 5.4% increase).

The increase in electric cooling load over the summer months due to climate change is greater than the estimated decrease in electric heating load due to climate change. On the other hand, the steam and gas sectors could experience significant decreases in winter energy sales for heating. There could be up to a 33% decrease by 2050 and a 49% decrease by 2080. More information on the analyses and the results are provided in Appendix 2.B – Additional Information on Secondary Vulnerabilities.

Based on these analyses, the primary recommendation for volume forecasting is to **update long-term forecasting to include climate data**. Given the projected increases in CDD for electricity and the potential losses in HDD and load for gas and steam, it is important to take these changes into account when forecasting volumes. For steam and gas, this may involve lower investment costs as HDD are projected to decline and the electric sector is expected to pick up more of the heating load.

Heat Index and Worker Safety

Heat index is a measure of heat that incorporates both temperature and humidity. In considering worker safety, heat index is a more pertinent measure than temperature alone, as the humidity component also affects how workers feel and how easily the human body can cool off.

Heat index projections were developed using the wet bulb and dry bulb temperature projections. The Study team computed heat index values using the equation used by the National Weather Service. Under a base case assuming no climate change, Con Edison may expect 12–18 days per year to have heat index values between 91°F and 103°F (a "moderate" risk level rating according to OSHA) in the 2050 time-slice. Under the RCP 4.5 scenario, this is expected to increase to 21–29 days. Under the RCP 8.5 scenario, this is expected to increase to 36–42 days. The frequency of very high to extreme risk days (according to OSHA's thresholds) is also expected to increase. Under the base case, there are 0–0.1 days per year in the 2050 time-slice experiencing maximum heat index greater than or equal to 115°F. This frequency is expected to increase to 0.6–0.7 days under the lower scenario and 5–6 days under the higher scenario. More information on the analyses and the results are provided in Appendix 2.B – Additional Information on Secondary Vulnerabilities.

Con Edison has layers of control to ensure job site safety and includes addressing work in high heat conditions starting with the initial job briefing, subsequent job briefings to recognize changes in the work conditions and reinforcement through Job Site Safety Evaluations. The variety of conditions at a work site requires flexibility in how it is performed so that it is done safely and efficiently. Based on monitoring, if projections of more frequent high-heat days become a new normal, Con Edison may decide to **adopt best practices from hotter locations where Con Edison has provided mutual aid, such as Florida and Puerto Rico**. This could include:

- Shift modifications
- Hydration breaks

- Worker rotations
- Modifications to PPE (personal protective equipment)

9. Costs and Benefits of Adaptation Options

9.1. Marginal Cost of Load Increase

Adapting to increases in peak load driven by 1-in-3 TV events of increasing severity will require investment in additional capacity. Based on the calculated increases in load (see Table 19) the Study team calculated the total costs of adapting to climate-driven load increases (see Table 21). These load increases were calculated for 2030, 2050, and 2080 under both climate scenarios (RCP 4.5 10th percentile and RCP 8.5 90th percentile). This calculation followed the same methodology used to calculate the costs of capacity loss as in Appendix 1 – Temperature, using the most recent marginal costs of capacity presented in Rate Case 16-E-0060. These numbers reflect the costs of upgrading the transmission and distribution system to meet climate-driven changes in load. They do not, however, reflect the additional costs of upgrades compensating for capacity losses in transmission and distribution systems due to increased temperature, which are discussed separately in Appendix 1 – Temperature.

Table 21 ■ Total costs of adapting to climate-driven load increases

Scenario		Cost 2030	Cost 2050	Cost 2080
RCP 4.5 10th percentile	Total	$647,910,931	$1,108,516,703	$1,415,979,890
	Annual	$53,992,578	$34,641,147	$22,838,385
RCP 8.5 90th percentile	Total	$1,715,196,938	$3,064,029,695	$5,576,746,089
	Annual	$142,933,078	$95,750,928	$89,947,518

9.2. Multi-Criteria Analysis

To ensure that Con Edison incorporates considerations of future climate change resilience into network reliability improvement planning processes when selecting among load relief options for a particular network, the processes should consider a range of possible climate futures and should incorporate metrics for resilience. Increases in load due to climate change pose a challenge for load relief planning, so incorporating a multi-criteria analysis process can help ensure that selected options will be appropriate for a range of potential futures. In addition, this multi-criteria analysis framework can assist when addressing challenges in networks with an NRI above 1, assisting planners in selecting which NRI-reducing strategy is most appropriate. Table 22 below provides example strategies and how they scored in terms of co-benefits and adaptation benefits.

Con Edison currently considers costs and benefits to evaluate response options to load growth through the Reforming the Energy Vision (REV) benefit-cost analysis framework (Con Edison, 2016), which promotes innovative, decentralized, customer-sided, and less energy-intensive load relief options. Prominent among these is the unit cost of a particular option per MW of delivery capacity, as well as an option's "social cost." Social cost accounts for the monetization of air pollution and carbon dioxide, using 20-year forecasts of marginal energy prices, the cost of complying with regulatory programs for constraining these pollutants, and the price paid for Renewable Energy Credits (where applicable). The social cost metric also qualitatively accounts for avoided water and land impacts. Beyond these environmental aspects, social cost accounts for net avoided restoration and outage costs to Con Edison, as well as net non-energy benefits (such as avoided service terminations, avoided uncollectable bills, and avoided noise and odor impacts).

The Study team considered a variety of additional complementary metrics that could be included in the network reliability improvement planning process to account for the range of possible increases in temperature variable. These fall into two categories: "co-benefits" and "adaptation benefits."

Co-benefit metrics include reputational, safety, and customer financial benefit metrics:

- Reputational—captures the extent to which a response option is valued or opposed by public stakeholders.
- Safety—captures the extent to which a response option avoids injuries or fatalities. This includes Con Edison worker safety and public safety. For example, modern equipment may improve safety over the lifetime of the asset, but installation may pose some worker risks.
- Customer financial benefits—captures the extent to which a response option affects customer costs. For example, construction of new large assets may be accompanied by rate increases to offset construction costs, while customers may benefit from rebates due to expanded energy efficiency, demand response, or other demand-side management.

Under a non-stationary climate, co-benefits can help planners more comprehensively evaluate response options in light of additional challenges that climate change can pose on the system.

In addition to co-benefit metrics, adaptation benefit metrics can support long-term planning under the wide range of possible increases in temperature variable over the century. Evaluating the adaptability of response options themselves can ensure that the portfolio of adaption options are effectively implemented over time to achieve resilience. Adaptation metrics include flexibility, reversibility, robustness, proven technology, and customer's resilience:

- Flexibility—captures the extent to which a response option can be scaled up or modified over time to accommodate increasing needs and accelerated changes in climate.
- Reversibility—captures the extent to which a response option can be removed if it becomes unnecessary or another course of action becomes preferred.
- Robustness—captures the extent to which a response option is effective across a range of climate change futures. In general, the larger increase in capacity achieved by an adaption option, the more likely it is to be robust across possible climate futures.
- Proven technology—captures the extent to which a response option is known to provide the needed response. For example, some new technologies may not be extensively tested under a wide range of conditions, may lack demonstrated feasibility, or may provide uncertain levels of risk reduction.
- Customer's resilience—captures the extent to which a response option increases the customer's own resilience to climate hazards. For example, customer-sided DER (e.g., battery storage) and energy efficiency allow customers to maintain basic services for a longer duration during some types of extreme events.

These metrics allow for effective implementation of adaptation measures over time to achieve resilience. Table 22 illustrates an evaluation of the portfolio of network reliability improvement actions. Therefore, we have scored the measures by their adaptation value to an uncertain climate future. We have done this simply by weighting the assigned high, moderate, negligible, and negative values (2, 1, 0, and -1, respectively). A higher score suggests the adaptation measure would be a better climate adaptation choice given the current range of climate projections. These scores could be incorporated into Con Edison's current benefit-cost analysis.

Table 22 ■ Multi-criteria matrix of response options for load relief to impacts from climate change. For each potential response option, co-benefits and adaptation benefits categories are rated as negative (-1), negligible (0), moderate (1), or high (2)

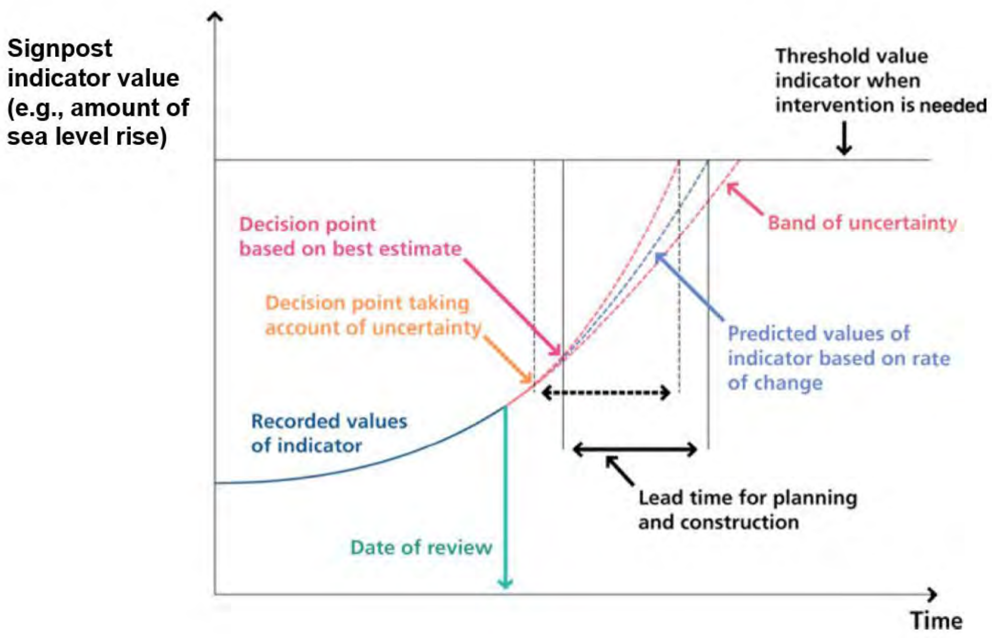
Underground Network Adaptation Measure	Adaptation Resilience Score	Co-Benefits			Adaptation Benefits				
		Reputational	Safety	Customer Financial Benefits	Flexibility	Reversibility	Robustness	Proven Technology	Customer's Resilience
Incorporating distributed energy resources (DER)	*10*	*High* (Supporting investment in DER may be popular with customers)	*Negligible* (No significant benefits)	*High* (May decrease customer costs)	*Moderate* (Con Edison can find contract for additional DERs)	*Moderate* (Cost-prohibitive to remove generation sources due to contract obligations)	*Moderate* (Can be scaled to provide benefits under most climate scenarios)	*Moderate* (Technology not as well established as others)	*High* (Provides benefit if equipment allows for islanding)
Complete PILC replacement	*6*	*Moderate* (Removing lead cables may be popular with customers due to health reasons)	*Moderate* (New cables lead to fewer emergency repairs)	*Negligible* (No significant benefits)	*Negligible* (No significant benefits)	*Negligible* (No significant benefits)	*Moderate* (Replacements will only provide benefits up to a certain point)	*High* (Known to provide needed benefit)	*Moderate* (New cables lead to enhanced network availability)
Creating primary feeder loops within or between networks	*6*	*Negligible* (The customer is not aware of this change)	*Negligible* (No significant benefits)	*Negligible* (No significant benefits)	*Moderate* (It is possible to add additional loops as needed)	*Moderate* (It may be possible to remove loops)	*Moderate* (Loops will only provide benefits up to a certain point)	*High* (Provides required increase in capacity and future potential)	*Moderate* (Diversifies supply to customer base)
Improving fault monitoring capabilities	*5*	*Negligible* (The customer is not aware of this change)	*Negligible* (No significant benefits)	*Negligible* (No significant benefits)	*High* (This low-cost strategy can complement many other future approaches)	*High* (Monitors can be removed)	*Moderate* (The monitors provide useful information under all future conditions)	*Negligible* (Monitoring is a relatively new concept)	*Negligible* (Customers experience no difference in personal resilience)
Splitting the network into two smaller networks	*3*	*Negative* (Large new construction project may not be popular with customers)	*Negligible* (No significant benefits)	*Negligible* (No significant benefits)	*Moderate* (It is possible to add additional capacity)	*Negative* (It is not practical to remove a station)	*High* (Provides required increase in capacity and future potential)	*Moderate* (Efficacy depends on network design)	*Moderate* (Diversifies supply to customer base)

10. Implementation of Adaptation Options Over Time

As discussed in Appendix 1 – Temperature, Con Edison's current long-term plan extends to nearly 2040, representing a planning period that is largely before the time that substantial divergence between climate scenarios RCP 4.5 and RCP 8.5 is expected. Even so, decisions made within this planning period can have longer-term implications, particularly when dealing with long-lived assets.

Given this timeframe for long-term planning and the expectation that current climate conditions are no longer expected to resemble future climate conditions, decision-making will have to allow for uncertainty (Figure 7). One approach for doing so is to start with low- and no-regrets actions. These are decisions that can be put in place now and are able to fit a variety of future scenarios, or are easily reversible. This strategy assumes that these actions are implemented now to meet current and uncertain future needs, whilst further research is conducted to enable more informed flexible pathways to be established for a longer-term perspective.

Figure 7 ■ Current decision-making processes will have to allow for uncertainty, particularly when the lag time between the decision and its implementation allows for further changes in conditions and greater uncertainty.



Appendix 1 – Temperature described signposts as metrics that can be tracked to understand how conditions are changing, which can used by Con Edison to adjust its planning over time. Figure 7, above, shows how decisions must be made based on current signpost information to allow for implementation before the intervention threshold is reached. In the case of humidity-related variables, Con Edison can consider the following signposts:

- Frequency of heat-related contingencies in the network and non-network systems
- Rate of change in TV, cooling degree days, heating degree days, and other key variables
- Number of days over heat index thresholds

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Appendix 2.A – Climate Information

Electric TV	Calculated based on the peak load day	
Summer		Maximum
	70%	Rolling 3-hr (hour) average of wet and dry bulb current day (D)
	20%	Rolling 3-hr average of wet and dry bulb prior day (D-1)
	10%	Rolling 3-hr average of wet and dry bulb next prior day (D-2)
	sum	
April		Maximum
	80%	Rolling 3-hr average of wet and dry bulb current day (D)
	20%	Rolling 3-hr average of wet and dry bulb prior day (D-1)
	sum	
Winter		
	80%	Average dry bulb for 3 hrs 4–6 p.m. (D)
	20%	Average dry bulb for 3 hrs 4–6 p.m. prior day (D-1)
	sum	
Gas TV	Calculated based upon the peak gas day (10 a.m.–10 a.m.)	
Winter		
	70%	Average dry bulb temperature gas day (D)
	30%	Average dry bulb temperature gas day prior day (D-1)
	sum	
Steam TV	Calculated based upon the peak load hour	
Winter		
	60%	peak hour dry bulb (D)
	40%	24-hr average **dry** bulb prior day (D-1)
	sum	

Appendix 2.B – Additional Information on Secondary Vulnerabilities

This section provides additional information on the secondary vulnerabilities identified in Section 8, including volume forecasting, heat index, summer operations and voltage reduction, and the corporate emergency response plan.

Volume Forecasting

Volume forecasting is undertaken in order to estimate the weather-sensitive volume of energy that Con Edison needs to purchase. This effort calculates how much heating and cooling energy Con Edison expects to need in the summer and winter, respectively. Con Edison forecasts the volume over the next 5 years on an annual basis. This allows Con Edison to avoid over-procuring energy while remaining prepared for heavier loads when needed.

Heating degree days (HDD) and cooling degree days (CDD) are used as a primary input to the volume forecast calculation. Heating degree days are calculated for winter months; cooling degree days are calculated for summer months. The calculation for HDD and CDD is straightforward: the difference between a reference temperature and the average 24-hourly temperature of any given day gives the degree days. HDD are calculated in the winter months using 62°F as the reference temperature and dry bulb temperature as the measurement (i.e., winter dry bulb temperatures below 62°F produce heating degree days). CDD are calculated in the summer months, using 57.5°F as the reference temperature and the average of wet bulb and dry bulb average 24 hourly temperatures as the measurement (i.e., average wet/dry bulb temperatures above 57.5°F will produce cooling degree days).

HDD and CDD Definitions: Electric Sector

Heating Degree Day: CECONY uses a reference point of 62°F as its determination of a heating degree day (HDD). The HDD calculation uses a 24-hour average of any given day's hourly dry bulb temperatures. This calculation is simply done by subtracting the average 24 hourly dry bulb temperatures from the reference point (62°F - 60°F = 2). If the average 24 hourly dry bulb temperatures is greater than 62°F the HDDs are zero.

Cooling Degree Day: CECONY uses a reference point that is a wet/dry bulb average of 57.5°F in the calculation of a cooling degree day (CDD). The CDD calculation uses a combination of the averages of the 24 hour average of any given day's hourly dry bulb temperatures plus the 24 hour average of the same day's hourly wet bulb temperatures. This calculation is simply completed by subtracting the reference point from average of the day's average 24 hourly dry bulb temperatures and the average 24 hourly wet bulb temperatures (62.5°F – 57.5°F = 5). If the average of the average 24 hourly dry bulb temperatures and the average 24 hourly wet bulb temperatures is less than 57.5°F the CDDs are zero.

The modeling effort for calculating future heating degree days and cooling degree days under climate scenarios included five main assumptions:

1. The delivery volumes for 2050 and 2080 in the base scenario are set to the levels for 2050 and 2080 in the Unconstrained Case of the CECONY Electric Long-Range Plan.
2. The quarterly distribution for 2019 in the Unconstrained Case of the CECONY Electric Long-Range Plan is used to allocate the annual volumes in 2050 and 2080 to the respective quarters.
3. The weather variables for this analysis are CDD and HDD at LaGuardia.
4. The weather coefficients are those from the CECONY send-out model used in the 2019 Budget.
5. The projections for 2050 and 2080 in the RCP 4.5 and RCP 8.5 scenarios are made relative to the base scenario.

The Study team estimated the impact of a change in CDD and HDD on load using Equation Z below. The impact of changes in CDD and HDD were first determined individually using Equations X and Y, in which CDD_{RCP} and HDD_{RCP} represent the projected values for CDD and HDD, respectively, under either RCP 4.5 or RCP 8.5 (depending on the calculation). CDD_{base} and HDD_{base} represent the projected values for CDD and HDD, respectively, under the base climate scenario. W_C and W_H represent weather coefficients[25] for CDD and HDD. P_{base} is the corresponding quarterly or annual GWh projection of the base case.

$$Equation\ X. CDD\ impact = (CDD_{RCP} - CDD_{base})\ W_C\ P_{base}$$
$$Equation\ Y. DD\ impact = (HDD_{RCP} - HDD_{base})\ W_H\ P_{base}$$
$$Equation\ Z. P_{RCP} = (CDD\ impact) + (HDD\ impact) + P_{base}$$

The study team estimated non-weather sensitive load by calculating total GWh assuming zero CDD and zero HDD quarterly and annually.

Vulnerabilities

The Study team conducted an analysis in order to understand if changes in HDD and CDD under future climate scenarios could have a meaningful impact on the volume of energy that Con Edison needs to purchase.

The Study team first calculated the HDD and CDD projections using Con Edison's standard model. The climate scenarios in this analysis include the 10th percentile of the RCP 4.5 case (a low-emissions scenario) and the 90th percentile of the RCP 8.5 case (a high-emissions scenario). In addition, the Study team ran a base case scenario, which assumes "normal" weather in the future, defined as the 10-year historical average at Central Park. The base forecast is based on the current forecast for 2050 in the Unconstrained Case of the Con Edison Electric Long-Range Plan.

Electric Sector

Based on this analysis, the Study team estimated that the projections of changes in temperature will result in an increase in CDD and a decrease in HDD by 2050 under both climate scenarios, with the changes being more pronounced in the higher-emissions scenario. See Table 23 for a breakdown of the results.

[25] The coefficient for CDD was 0.0002790; that for HDD was 0.0000595.

Table 23 ■ Projections for quarterly and yearly CDD and HDD in 2050 and 2080 under a base case, a lower emissions scenario, and a higher emissions scenario

	Cooling Degree Days 2050 (2080)			Heating Degree Days 2050 (2080)		
	Base	RCP 4.5	RCP 8.5	Base	RCP 4.5	RCP 8.5
Q1	1.1 (1.1)	2.5 (3.0)	12.4 (27.8)	2,325.5 (2,325.5)	2,010.3 (1,951.8)	1,627.2 (1,290.4)
Q2	408.2 (408.2)	508.2 (514.3)	720.7 (961.7)	384.1 (384.1)	272.7 (255.7)	145.8 (75.4)
Q3	1,138.4 (1,138.4)	1,320.2 (1,384.3)	1,695.8 (2,184.2)	13.6 (13.6)	4.8 (4.1)	0.4 (0.0)
Q4	60.9 (60.9)	92.6 (98.7)	179.3 (325.7)	1,318.2 (1,318.2)	1,090.4 (1,076.8)	816.8 (551.6)
Year	1,608.6 (1,608.6)	1,923.5 (2,000.3)	2,608.2 (3,499.4)	4,041.4 (4,041.4)	3,378.2 (3,288.4)	2,590.2 (1,917.4)

The Study team then calculated cooling and heating loads based on CDD and HDD. Given the increase in CDD, Con Edison may expect cooling load to increase from 43,077 GWh in 2050 under the base case to 43,685 under the lower scenario (a 1.4% increase) and to 45,394 GWh under the higher scenario by 2050 (a 5.4% increase) due to the change in cooling load (see Figure 8). The increase in cooling load over the summer months due to climate change is greater than the decrease in heating load due to climate change.

Figure 8 ■ Projected changes in GWh by 2050 under a low and high emissions scenario compared to the base case

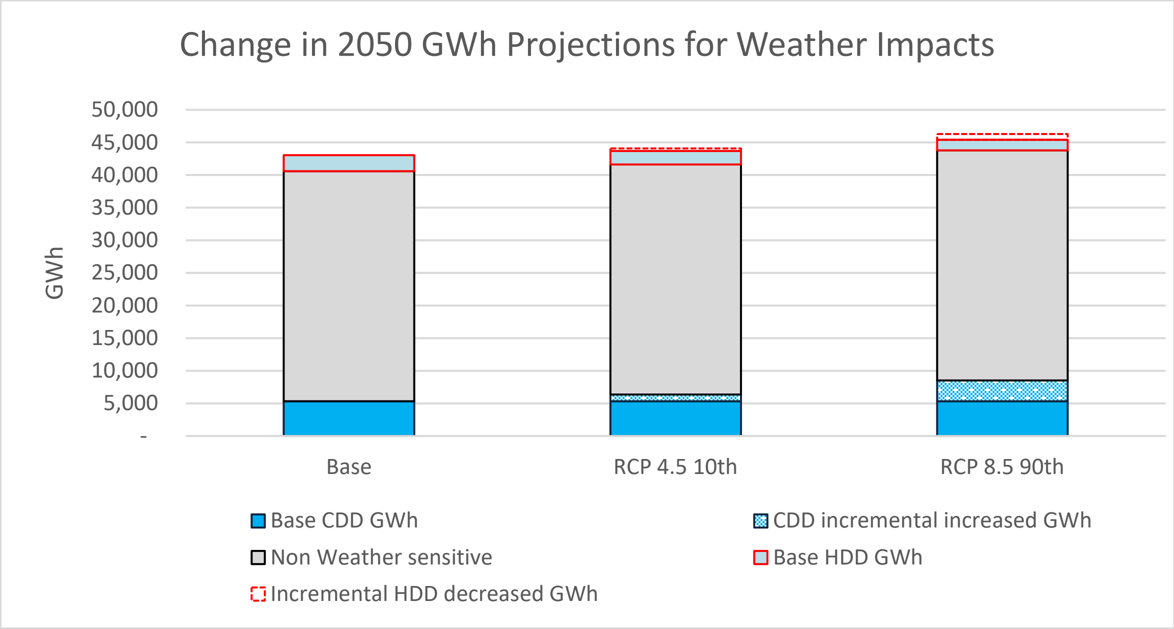
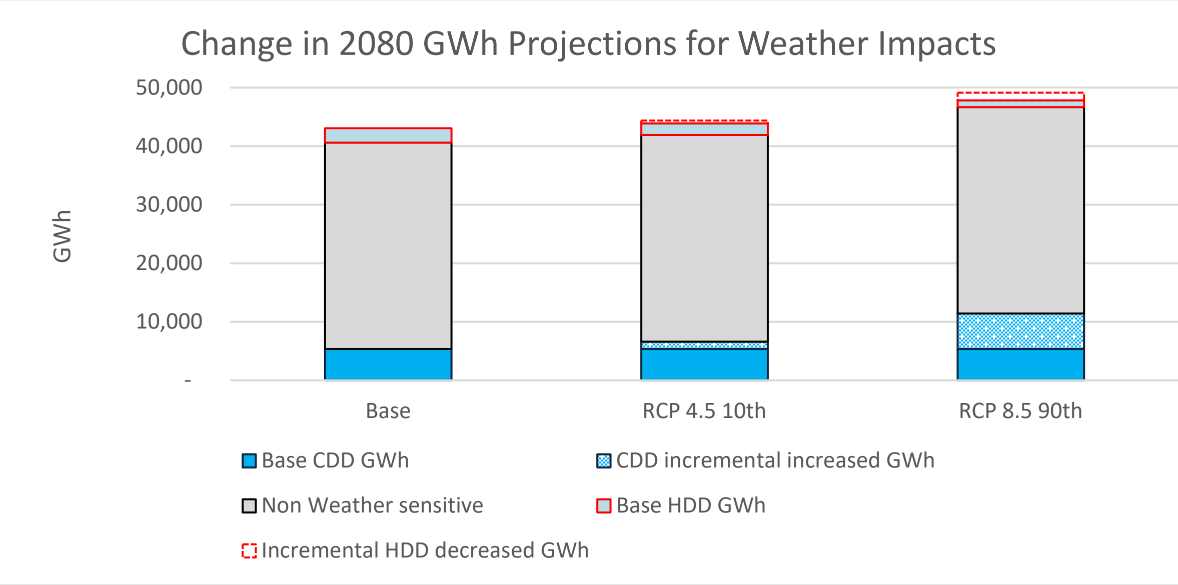


Figure 8, above, shows the change in GWh projections in 2050 due to changes in CDD and HDD. The dark-blue box at the bottom of each bar represents the load based on cooling degree days under the base case (assuming no climate change.) The light-blue box represents the additional cooling degree day-based load assuming a lower scenario and a higher scenario for climate change. The red-outlined box at the top of each bar represents the load based on heating degree days under the base case (assuming no climate change). The orange box represents the load based on heating degree days for each scenario—one can see that this orange box does not fill up the full red outline in either the lower or higher scenario, showing how heating energy is projected to decrease from the base case.

The outlook for 2080 is similar to that of 2050 (see Figure 9). By 2080, Con Edison may expect load to experience a 1.9% increase under the lower emissions scenario and an 11.1% increase under the higher emissions scenario, increasing to 43,894 GWh and 47,837 GWh, respectively.

Figure 9 ■ Projected changes in GWh by 2080 under a low- and high-emissions scenario compared to the base case



In summary, the electric sector is projected to experience only a moderate increase in annual load based on the change in HDD and CDD under both climate scenarios by the mid- and late-century.

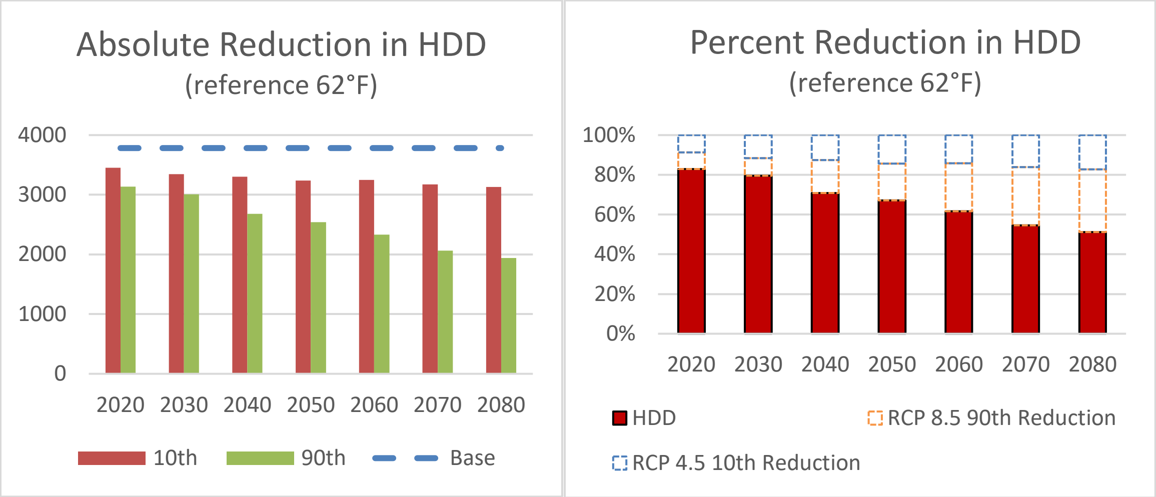
Steam and Gas

The steam and gas sectors could experience significant decreases in energy sales for heating. Table 24 provides the breakdown of the change in HDD and CDD relative to a base case under a low- and high-climate scenario in 2050 and 2080. The table shows up to a 33% decrease by 2050 and a 49% decrease by 2080. This decrease is solely based on climate projections and does not account for other expected changes in load as a result of potential electrification of heat.

Table 24 ■ HDD projections for steam and gas under a lower and higher emissions scenario, related to the base case. Projections are to 2050 and 2080

	HDD Base	HDD 4.5 10th 2050	HDD 8.5 90th 2050	HDD 4.5 10th 2080	HDD 8.5 90th 2080
Gas and Steam	3,782.8	3,239.8 (14% decrease)	2,538.7 (33% decrease)	3,128.9 (17% decrease)	1,938.5 (49% decrease)

Figure 10 ■ Absolute and percent reduction in HDD for the gas and steam, using reference temperature of 62°F



Adaptation Options

Update long-term forecasting to include climate data. Given the projected increases in CDD for electricity and the potential losses in HDD and load for gas and steam, it is important to take these changes into account when forecasting long-term volumes. For steam and gas, this may involve lower investment costs as HDD are projected to decline and the electric sector is expected to pick up more of the heating load.

Heat Index and Worker Safety

Heat index is a measure of heat that incorporates both temperature and humidity. In considering worker safety, heat index is a more pertinent measure than temperature alone, as the humidity component also affects how workers feel and how easily the human body can cool off. Heat index is a commonly used measure for heat exposure and estimating risk to worker safety under hot conditions.

Vulnerabilities

Employees exposed to heat in their working conditions are at risk of heat-related illnesses, though these can be prevented. As heat index increases, so does risk level, and higher protective measures should be taken (Table 25).

Table 25 ■ OSHA's risk table for heat index and worker safety[26]

Heat Index	Risk Level	Protective Measures
Under 91°F	Lower	Basic safety and planning
91°–103°F	Moderate	Implement precautions, raise awareness
103°–115°F	High	Increase precautions
Over 115°F	Very High to Extreme	Greatly increase protective measures

[26] Adapted from https://www.osha.gov/SLTC/heatillness/heat_index/index.html. Accessed September 26, 2018.

Heat illness occurs due to both external environmental conditions and internal body heat from physical labor. When the body cannot lose enough heat to offset the heat experienced from these two factors, heat illness occurs. The severity of heat illness can range from heat rash and heat cramps to heat exhaustion and heat stroke. Progressive loss of body salts and fluid from sweating causes these stages of heat illness. Heat rash occurs when sweat does not evaporate from the skin. Heat cramps occur when there are low salt levels in muscles and can occur during or after work. Heat exhaustion occurs when the body has lost water and salt from heavy sweating and can have more severe physical symptoms, such as nausea, dizziness, weakness, and headache. Heat stroke can be a deadly risk and is always a medical emergency, occurring when the body can no longer regulate its core temperature. Symptoms of heat stroke include confusion, passing out, and seizures.[27]

To better understand vulnerability to heat illness, the Study team assessed future average wet and dry bulb for a given day as a proxy for heat index. Under a base case assuming no climate change, Con Edison may expect 12–18 days per year to have TV values between 91°F and 103°F (a "moderate" risk level rating according to OSHA) in the 2050 time-slice. Under the RCP 4.5 scenario, this is expected to increase to 21–29 days. Under the higher scenario, this is expected to increase to 36–42 days. The frequency of very high to extreme risk days (according to OSHA's thresholds) is also expected to increase: under the base case, there are 0–0.1 days per year in 2050 experiencing maximum heat index greater than or equal to 115°F. This frequency is expected to increase to 0.6–0.7 days under the lower scenario and 5–6 days under the higher scenario (Table 26). Therefore, the Study team expects that more robust worker safety protection measures will be warranted under future climate change.

Table 26 ■ Days per year falling within heat index categories based on TV values by 2050 under a base case and lower and higher climate scenarios. (Lower numbers are for White Plains, while higher numbers are for LaGuardia)

Heat Index Category (via TV)	Base Case =	RCP 4.5 10th (Lower) 2050	RCP 8.5 90th (Higher) 2050
91°F–103°F (Moderate)	12–18 days/year	21–29 days/year	36–42 days/year
103°F–115°F (High)	1–2 days/year	5–7 days/year	14–20 days/year
Over 115°F (Very high to extreme)	0–0.1 days/year	0.6–0.7 days/year	5–6 days/year

Adaptation Options

Scope of work, site conditions and working environment are all factors in job site safety. Con Edison has layers of control to ensure job site safety and includes addressing work in high heat conditions starting with the initial job briefing, subsequent job briefings to recognize changes in the work conditions, and reinforcement through job site safety evaluations. The variety of conditions at a work site requires flexibility in how it is performed such that it is done safely and efficiently.

Job briefings and job site safety evaluations include reviewing environmental conditions whether natural or manmade and establish specific requirements for shade, hydration (water coolers) and breaks or worker rotations. An updated job briefing is expected whenever conditions change that would affect the workers and the work, and this would include changed weather conditions. If these projections of more frequent high-heat days become a new normal Con Edison may decide to

[27] Occupational Safety and Health Administration (OSHA). Occupational heat exposure. U.S. Department of Labor. Accessed September 26, 2018. https://www.osha.gov/SLTC/heatstress/heat_illnesses.html

adopt best practices from hotter locations where Con Edison has provided mutual aid, such as Florida and Puerto Rico. This could include:

- Shift modifications
- Hydration breaks
- Worker rotations
- Modifications to PPE (personal protective equipment)

Summer Operations and Voltage Reductions

Con Edison uses a set of procedures to relieve voltage and thermal stresses on its system caused by high temperature and humidity conditions. These procedures stipulate TV thresholds and other conditions that necessitate modifications to standard operating actions, such as voltage reductions and work limitations, to avoid outages and damages to the system as a result of summer weather conditions. As discussed earlier, there are two primary operational specifications at Con Edison with established TV thresholds for modifications to standard procedures.

- **EOP-5022: Automated Voltage Reduction Program and Demand Response Programs.** [28] This specification sets the TV at which automatic voltage reduction programs are put in place. The voltage reduction and voltage restoration algorithms are decision trees that automate the process for reducing or restoring voltage. Con Edison developed these algorithms by analyzing the system conditions that existed during the historical events when voltage reduction was implemented in the summer of 2010. The analysis considered the TV for 2 consecutive days at the time of voltage reduction, the network/load area load, and the feeders out of service in the network/load area. Upon completion of the analysis, Con Edison developed a computer program to provide recommendations for the implementation of voltage reduction based on various sets of conditions. Voltage reductions are implemented in order to relieve voltage and thermal stresses on the primary distribution cable and prevent a cascading effect of feeder outages. The TV thresholds associated with operational changes include:
  - TV > 85°F for 2 days[29]
  - TV > 82°F for 2 days[30, 31, 32]
- **EOP-5025: Guidelines for Summer Operations of the Distribution System**. [33] This specification provides TV limits for weekday work on electric distribution facilities during the summer period (June 1–August 31). These guidelines are intended to prevent planned outages during extreme heat conditions.

  The TV thresholds associated with operational changes include:

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[28] Con Edison. 2018. Distribution Engineering Department System Program Engineering, Analysis and Reporting Department. Specification EOP-5022 Revision 11. Automated Voltage Reduction Program and Demand Response Programs.
[29] Additional conditions include: Two or more feeders out of service in a second-contingency network OR one or more feeders out of service in a first-contingency load area.
[30] Additional conditions include: Network load > 85% of peak design and more than two feeders out of service in a second-contingency network or more than one feeder out of service in a first-contingency load area.
[31] Additional conditions include: Network load > 85% of peak design and two or more conflicting feeders out of service in a second-contingency network or feeder returning to service after load area peak in a first-contingency design area.
[32] Additional conditions include: Network load ≤ 85% of forecasted summer peak, more than two feeders out of service in a second-contingency network or more than one feeder out of service in a first- contingency load area, and two or more conflicting feeders out of service in a second-contingency network or feeder returning to service after load area peak in a first-contingency design area.
[33] Con Edison. 2018. Distribution Engineering Department System Program Engineering, Analysis and Reporting Department. Specification EOP-5025 Revision 17. Guidelines for Summer Operation of the Distribution System.

- EOP-5025
- TV ≤ 78°F for 2 consecutive days
- TV > 78°F ≤ 79°F for 2 consecutive days
- TV > 79°F ≤ 82°F for 2 consecutive days
- TV > 82°F

As described in the Summer Operations and Voltage Reductions section, the Study team conducted an analysis to understand how the projected changes in TV would alter the frequency of automated voltage reduction and reduced summer operations. This appendix presents the detailed analysis and results of the analysis for White Plains. The detailed analysis is described in the section text.

For White Plains, the results show that if the system is designed/maintained at current levels (i.e., with TV 86 as the design criteria), there could be a significant increase in the number of days with voltage reductions and summer work restrictions. However, if Con Edison continues to invest in the system to ensure operational capacity during the 2050 1-in-3 TV event, then there will actually be a drop in the frequency of voltage reductions and summer work restrictions, relative to today. For example, the historical frequency of meeting condition B is 2.3 days per summer and without changes to the capacity of the system, in 2050, that threshold could be reached 6.7 to 25.4 days per summer (a 193% to 1,016% increase). If the system is modified to meet future peak loads, the frequency of voltage reductions could drop from 4.3 days per summer to 1.4 to 1.7 days (a -33% to -39% change).

Vulnerabilities

The Study team conducted an analysis to understand how the projected changes in TV would alter the frequency of automated voltage reduction and reduced summer operations. In particular, the Study team wanted to understand:

- If Con Edison continues to design the electric system for *today's* 1-in-3 peak load producing TV (i.e., TV 86), then how would the frequency of automated voltage reduction and reduced summer operations change?
- If Con Edison updates the design of the electric system to keep pace with changes in the 1-in-3 TV event (see Table 15), how would that change the thresholds for automated voltage reduction and reduced summer operations, and how often would those thresholds be exceeded?

To begin, the Study team calculated what the future voltage reduction and reduced summer operations thresholds would be if the electric system was enhanced to meet the 2050 1-in-3 TV event for RCP 4.5 10th percentile TV values and RCP 8.5 90th percentile TV values. The thresholds were calculated to trigger action when TV reaches the same probability threshold. Table 27 lists the current and estimated 2050 temperature variable conditions of interest.

Table 27 ■ Current and 2050 temperature variable conditions

	Current conditions (design load of 13,300 MW)	RCP 4.5 10th percentile conditions (design load projection of 14,494 MW)	RCP 8.5 90th percentile conditions (design load projection of 16,491 MW)
A	TV > 85°F for 2 days	TV > 88°F for 2 days	TV > 92.3° F for 2 days
B	TV > 82°F for 2 days	TV > 84.9°F for 2 days	TV > 89.1°F for 2 days
C	TV ≤ 78°F for 2 consecutive days	TV ≤ 80.7°F for 2 consecutive days	TV ≤ 84.7°F for 2 consecutive days
D	TV > 78°F ≤ 79°F for 2 consecutive days	TV > 80.7°F ≤ 81.1°F for two consecutive days	TV > 84.7°F ≤ 85.8°F for 2 consecutive days

E	TV > 79°F ≤ 82°F for 2 consecutive days	TV > 81.1°F ≤ 84.9°F for 2 consecutive days	TV > 85.8°F ≤89.1°F for 2 consecutive days
F	TV > 82°F	TV > 84.9°F	TV > 89.1°F

Next, the Study team calculated the historical and projected number of summer days (June to August) when the current and estimated 2050 threshold conditions are met for LaGuardia and the associated percent changes. The results show that if the system is designed/maintained at current levels (i.e., with TV 86 as the design criteria), there could be a significant increase in the number of days with voltage reductions and summer work restrictions (see Table 28). However, if Con Edison continues to invest in the system to ensure operational capacity during the 2050 1-in-3 TV event, then there will actually be a drop in the frequency of voltage reductions and summer work restrictions, relative to today. For example, the historical frequency of meeting condition B is 4.3 days per summer and without changes to the capacity of the system, in 2050, that threshold could be reached 11.1 to 34.8 days per summer (a 159% to 716% increase). If the system is modified to meet future peak loads, the frequency of voltage reductions could drop from 4.3 days per summer to 2.9 to 3.5 days (a -33% to -18% change).

Table 28 ■ Seasonal (June–August) frequency of days when current and possible future thresholds are met under historical and projected TV for LaGuardia.

		Historical TV	RCP 4.5 10th Percentile TV		RCP 8.5 90th Percentile TV	
Current thresholds		**Frequency (days per summer)**	**Frequency (days per summer)**	**% Change**	**Frequency**	**% Change**
A	TV > 85°F for 2 days	0.8	2.8	232%	16.7	1,908%
B	TV > 82°F for 2 days	4.3	11.1	159%	34.8	716%
C	TV ≤ 78°F for 2 consecutive days	17.8	31.6	78%	61.4	245%
D	TV > 78°F ≤ 79°F for 2 consecutive days	0.5	0.8	60%	0.5	-7%
E	TV > 79°F ≤ 82°F for 2 consecutive days	4.2	6.0	45%	7.0	69%
F	TV > 82°F	7.9	17.1	116%	44.3	460%
	RCP 4.5 10th percentile thresholds	**Frequency**	**Frequency**	**% Change***		
A	TV > 88°F for 2 days	0.0	0.5	-44%		
B	TV > 84.9°F for 2 days	0.8	2.9	-33%		
C	TV ≤ 80.7°F for 2 consecutive days	7.7	16.4	-8%		
D	TV > 80.7°F ≤ 81.1°F for 2 consecutive days.	0.0	0.1	-73%		
E	TV > 81.1°F ≤ 84.9°F for 2 consecutive days.	2.5	4.4	6%		
F	TV > 84.9°F	2.0	6.0	-24%		
	RCP 8.5 90th percentile thresholds	**Frequency**			**Frequency**	**% Change****
A	TV > 92.3° F for 2 days	0.0			0.5	-40%
B	TV > 89.1°F for 2 days	0.0			3.5	-18%
C	TV ≤ 84.7°F for 2 consecutive days	0.9			17.9	1%
D	TV > 84.7°F ≤ 85.8°F for 2 consecutive days.	0.0			0.3	-40%
E	TV > 85.8°F ≤ 89.1°F for 2 consecutive days.	0.4			5.1	22%
F	TV > 89.1°F	0.0			6.8	-14%

* Percent change compares frequency of RCP 4.5 10th percentile thresholds under RCP 4.5 10th percentile TV with historical thresholds under historical TV.

** Percent change compares frequency of RCP 8.5 90th percentile thresholds under RCP 8.5 90th percentile TV with historical thresholds under historical TV.

Adaptation Options

Continue designing to the changing 1-in-3 TV event. In order to avoid significant increases in the frequency of voltage reductions, which might take place if TV increases but the system design does not keep up, Con Edison should continue to regularly update designs to ensure adequate reliability under 1-in-3 TV events.

Routinely update voltage reduction thresholds and hands-off thresholds to account for changes in climate and the changing design of the system. As has been seen in the past, Con Edison's improvements to the distribution system have, over time, resulted in less frequent failures. Our analysis demonstrates that this trend will continue if Con Edison continues to design for the 1-in-3 event. In that case, holding the voltage reduction thresholds constant may result in more voltage reduction days than is necessary, which would be a waste of resources. To ensure this does not occur, Con Edison may consider conducting a statistical analysis to re-evaluate their voltage reduction thresholds, based on actual failure rates, every 5 years.

Corporate Emergency Response Plan

Con Edison also uses TV thresholds to trigger elevated threat levels under its Corporate Emergency Response Plan (CERP). An elevated threat level is associated with a mobilization of the company's Incident Command System (ICS) in preparation to respond to heat-related grid impacts. These TV thresholds are different than those used for voltage reduction or summer work restrictions, and represent TV values at which Con Edison starts to prepare for issues, thereby shortening the response time should an event occur.

Con Edison updated its TV thresholds for threat-level elevation based on a study conducted in 2014 by the Performance and Operational Engineering department within Distribution Engineering.[34] The study assessed the relationship between historical TV and actual incidence of open automatic (OA) incidents in Con Ed distribution feeders.

Table 29 ■ Incident Command System Threat-Level Protocol (2014 updates marked in red)

ICS Level	Systemwide Pre-emptive Action	Systemwide Pre-emptive Action (After Second Non-Consecutive Day of ≥ 83°F Temperature Variable)
ROUTINE No ICS mobilization	• Today's temperature variable predicted to be < 84°F	• Today's temperature variable predicted to be < 84°F
UPGRADED Limited ICS mobilization	• Predicted system load ≥ 11,500 MW or temperature variable ≥ 81°F • After first occurrence of system load ≥ 11,500 MW: • WEEKDAY 81°F ≤ temperature variable ≤ 82°F • WEEKEND temperature variable predicted to be ≥ 82°F	• WEEKDAY temperature variable predicted to be > 84°F for **2** consecutive weekdays • WEEKEND temperature variable predicted to be > 84°F for **2** consecutive weekend days
SERIOUS Full ICS mobilization	• WEEKDAY temperature variable predicted to be ≥ 82°F • WEEKEND temperature variable predicted to be ≥ 82°F for **2** consecutive weekend days	• WEEKDAY temperature variable predicted to be > 86°F • WEEKEND temperature variable predicted to be > 86°F for **2** consecutive weekend days

Analysis of this relationship led to two changes in Con Edison's ICS thresholds. The updated thresholds are marked in red in Table 29, and are described in further detail below.

- **Accounting for annual "first burn" and raising subsequent TV thresholds**
  Previously, Con Edison's thresholds triggered an "Upgraded" threat level upon every exceedance of a predicted weekday TV of 80°F (82°F on a weekend). Historically, however, Con Edison's system tends to experience more OA incidents during the first hot day of the summer, compared to later days with similarly high TV values. This event is known as the "first burn." After this point, the system is more robust to OA events resulting from high TV. Con Edison's analysis of historical data, however, indicates that taking into account "first burn" allows the company to safely elevate this threshold to 81°F (82°F weekend). The updated ICS thresholds account for

[34] Con Ed has recently made additional minor changes to its ICS thresholds; these were not considered for the purposes of this analysis.

"first burn" by triggering an "Upgraded" threat level upon the first projected system load exceeding 11,500 MW, regardless of TV.

- **Accounting for greater TV resilience after several high-TV events**
  Similarly, Con Edison's system becomes increasingly resilient to high-TV events after several such events have already occurred. Prior to the study, Con Edison accounted for this by raising the threat-level TV thresholds after two non-consecutive days of TV greater than or equal to 84°F. At that point, weekday TV thresholds increased from 81°F to 84°F for "Upgraded" threat level and 82°F to 86°F for "Serious" threat level. Con Edison's 2014 study, however, indicated that the precondition for this threshold change could be safely changed to 2 non-consecutive days of 83°F as opposed to 84°F, lowering the overall probability of threat-level elevation.

Con Edison's study concluded that, had its new TV standards been applied from 2006–2013, it could have avoided 13 days in which the ICS threat level was previously elevated.

Vulnerability

The Study team conducted an analysis to understand how the projected changes in TV will affect the exceedance of current CERP ICS threat-level elevation thresholds. In a similar analysis to the one described in the Summer Operations and Voltage Reduction section, the Study team compared the number of days exceeding the current ICS threat level thresholds under historical TV conditions, in the RCP 4.5 10th percentile TV scenario and in the RCP 8.5 90th percentile TV scenario.

As shown in Table 30 below, the analysis indicates that TV conditions exceeding current thresholds will increase markedly in both the higher and lower emissions scenarios. The conditions for reaching a "Serious" threat level based on the current post-first-burn thresholds, for example, would increase from 0.4 days on average per summer to 1.8 days in the lower emissions scenario (342%) and 12.8 days in the higher emissions scenario (3,108%).

Table 30 ■ Seasonal frequency of days on which current ICS threat-level elevation TV thresholds (second column in Table 29) are exceeded under current and projected conditions for LaGuardia

Current Thresholds	Historical TV	RCP 4.5 10th Percentile TV		RCP 8.5 90th Percentile TV	
	Frequency (days per summer)	Frequency (days per summer)	% Change	Frequency (days per summer)	% Change
TV > 84°F for 1 day	3.3	9.1	172%	30.6	817%
TV > 84°F for 2 consecutive days	1.4	5.1	256%	21.5	1,402%
TV > 86°F for 2 consecutive days	0.4	1.8	342%	12.8	3,108%

*For simplicity of comparison, the analysis only addresses weekday thresholds, and does not account for the "first burn" thresholds in the first column of Table 8. It also focuses only on TV data at LaGuardia, whereas ICS threat-level calculations are based on an average of LaGuardia and Central Park data.

While upgrades to both Con Edison's CERP procedures and physical infrastructure are likely to mean that these projections would not translate into a commensurate increase in threat elevations, these data indicate that threat level elevations are likely to become more frequent, and that careful and frequent revision to thresholds will be necessary.

Adaptation Options

Routinely update analysis of CERP thresholds. As high-TV conditions become more frequent in a warming climate, system performance throughout the high-TV season may deviate from historical trends. Con Edison should continue to conduct similar hindcasting studies as TV event frequency increases in order to understand the impacts of warmer conditions on system performance and to update CERP thresholds accordingly. Currently, these updates occur on an ad hoc basis.

APPENDIX 3

Precipitation

1. Introduction

This appendix discusses the potential for climate-driven changes in precipitation in Con Edison's service territory, and the potential impacts of those changes on Con Edison's assets and operations. This appendix focuses only on changes in rainfall and frozen precipitation (i.e., rain, sleet, snow, freezing rain, and hail) and does not consider coastal flooding (addressed in Appendix 4 – Sea Level Rise), lightning, wind, or coastal storms (addressed in Appendix 5 – Extreme Events). Increases in the frequency and intensity of heavy precipitation events are most likely to affect Con Edison's assets and operations. Changes in average precipitation amounts are also considered.

As described in the introduction to the report, the analysis conducted for this appendix involved a decision-first and risk-based approach, applying the best available climate science to produce flexible and adaptive solutions. The process was designed to be transparent and interactive, ensuring that it can be replicated and institutionalized.

This appendix draws upon the most current climate science projections for the Con Edison service territory, over intermediate (2050) and long-term (2080) time horizons.

The work covered in this appendix has three main objectives:

1. Develop an understanding of projected future precipitation for the Con Edison service territory.
2. Complete a risk assessment of potential impacts on assets and operations due to changes in precipitation.
3. Establish a portfolio of effective and cost-efficient measures to improve resilience to future changes in precipitation, with a focus on high-priority assets and relevant processes.

This appendix is organized as follows:

- Section 2 provides an overview of the appendix highlights.
- Section 3 describes the approach to screening operations, planning, and assets for precipitation risks.
- Section 4 provides an overview of relevant climate information, including historical and future projections.
- Section 5 details priority vulnerabilities to precipitation and associated adaptation options.
- Section 6 reviews the costs and benefits of adaptation options.
- Section 7 discusses the implementation of adaptation options over time.
- Section 8 provides references for the appendix.
- Appendix 3.A discusses climate information and the Study team's methodology.

2. Highlights

In this appendix, the Study team focused on Con Edison's vulnerability to precipitation and identified potential adaptation measures to address the associated impacts.

Screening Process to Determine Climate Sensitivity

As a first step, the Study team worked with 45 Con Edison subject matter experts (SMEs) to conduct a high-level screen of operations, planning, and asset types for climate sensitivity. In a workshop and for follow-up requests, the SMEs answered the following questions:

- *How have previous major events affected your assets or operations?*
- *How might longer or more intense events overwhelm your current processes? At what point would additional action be required?*
- *How have you prepared or are planning to prepare for these types of events?*

Findings from this follow-up workshop indicate that the flooding of assets, such as steam mains, gas drip pots, and manholes, in general, was a concern.

Historical and Future Climate Projections

The Columbia Center for Climate Systems Research provided climate projections to support the Study team's analyses of precipitation patterns in the service territory. The Study team drew upon several sources of information to characterize projections of annual and extreme precipitation, including climate models, scientific literature, and historical trends.

The Study team found that over the historical reference period (1976 to 2005), annual precipitation increased 0.50 to 0.83 inch per decade at three weather stations within the New York metropolitan region: Central Park, LaGuardia Airport, and White Plains. Heavy precipitation is also common across the service territory: Each station historically recorded at least 5 days per year exceeding 1.5 inches of rainfall, and the maximum daily rainfall event exceeded 2.60 inches at all three stations.

Looking forward, both average and heavy precipitation are projected to increase throughout the century. By mid-century (2050), annual precipitation is projected to increase by 0% to 15%. The maximum daily rainfall amount is also projected to increase by approximately 0% to 15% through mid-century and by approximately 0% to 20% by 2080. Other literature on extreme precipitation also shows increases throughout the century.

Priority Physical Vulnerabilities

Large quantities of precipitation falling over a very short period cause flooding and present potential risks to Con Edison's gas, steam, and electric systems.

For steam, flooding can create the risk of condensate collection leading to a "water hammer event," where a buildup of condensate interacts with steam in ways that could lead to catastrophic rupture in a steam pipe.

Gas system vulnerabilities to precipitation-driven floods are largely within the gas distribution system. Heavy precipitation can enter low-pressure pipes through joints, causing low gas pressure for customers or interruption in gas service. Once water enters the gas system, it can be very difficult to remove. Under the current gas system design, more frequent heavy rainfall events would likely expand the number of locations with and the frequency of subsurface water intrusions in the gas distribution system.

Con Edison's electric substation containment systems are built to accommodate 6 inches of rain in 24 hours, in accordance with U.S. Environmental Protection Agency (EPA) Spill Prevention, Control, and Countermeasure guidance. While the risk to substations from heavy precipitation is low (it would require three contingencies to occur simultaneously to reach a risk level), an increase in the intensity of the future 25-year precipitation event may necessitate an update to substation design requirements.

For Con Edison's transmission system, the primary concerns related to precipitation events for the purposes of this appendix are from rainfall and the accumulation of radial ice. The latter is harder to predict as winter precipitation may increase at the same time average winter temperatures will be increasing. Radial ice can build up on transmission lines and towers during winter precipitation events. In extreme scenarios, radial ice accumulation can result in unbalanced structural loading and subsequent transmission line failure, especially when accompanied by heavy winds. Radial ice accumulation is also a concern for the overhead distribution system.

The primary concerns for Con Edison's underground distribution system with respect to precipitation events are directly from flooding and indirectly associated with snowfall and ice. Flooding can lead to damage to non-submersible electrical equipment. Salt used to limit snow and ice impacts can infiltrate and damage the underground electric distribution system, leading to manhole events (a safety concern) and customer outages. To a lesser extent, rapid melting of snow and ice might lead to flooding issues.

Priority Operational and Planning Vulnerabilities

Increased precipitation may result in faster growth rate for trees and other vegetation throughout the Con Edison service territory. Contact with vegetation is a primary cause of failures in portions of Con Edison's overhead distribution system. Absent additional efforts to mitigate the impacts of vegetation on Con Edison's overhead distribution system, increased vegetation growth rates, if they occur, are likely to lead to a higher frequency of vegetation-related failures.

Adaptation Options

Overall, Con Edison has many activities underway that support the company's ability to manage risks from precipitation, both currently and in the future. Such activities include pumping water out of steam manholes and into the city sewer in response to rain events, having drip pots installed to collect water at low points in the low-pressure gas distribution system, and meeting the National Electrical Safety Code standard for radial ice.

However, given the projected likelihood for precipitation to exceed key thresholds (such as the amount of rain falling during a 25-year storm) and extreme precipitation, Con Edison could consider a few further adaptation measures. These include:

- Improving collaboration with the City of New York on stormwater design, maintenance, and hardening to identify any potential for localized flooding;
- Implementing monitoring, such as remote monitoring of the steam system (already underway), crowd-sourcing leak detection for steam, and developing a system to allow for remote monitoring of gas system drip pots;

- Increasing current programs, such as building on existing storm hardening to proactively harden sites nearby those prone to inundation, installing additional vent line protectors, accelerating electric transmission and distribution system hardening, and expanding annual spending on vegetation management programs; and
- Hardening system components, such as undergrounding critical distribution lines, raising the height of transformer moats, and installing additional oil-water separator capacity (although all of these will likely rely on monitoring precipitation conditions over time to determine when and where hardening measures are best suited for implementation).

Costs and Benefits of Adaptation Options Under a Range of Possible Futures

Historically, the Con Edison service territory has experienced varying annual precipitation as high as 80 inches, as well as extreme precipitation events where large amounts of rain fall within a short time span. Some Con Edison design standards and operational procedures provide adaptive capacity against the impact of projected precipitation increases. However, other design standards do not reflect recent historical precipitation levels and should be updated to incorporate projected precipitation increases.

At the same time, additional adaptation options would improve the ability of the overall system to mitigate impacts from increasing precipitation and generate associated benefits. For example, improved monitoring capabilities would enable the gas and steam systems to be more proactive and selective in responding to precipitation events. This could save in work-hour commitments to perform manual surveys, while also reducing the risks associated with the timely identification of locations potentially compromised by rainfall.

Implementation of Adaptation Options Over Time

Given that the degree of uncertainty associated with precipitation projections exceeds that for other climate hazards (e.g., temperature), Con Edison could consider a plan to carefully monitor and assess precipitation impacts through time to determine the appropriate point to implement adaptation strategies.

Con Edison could employ indicators and signposts to monitor and assess precipitation impacts through time, including using key existing precipitation thresholds as indicators and monitoring for updates to extreme precipitation projections.

3. Screen of Operations, Planning, and Asset Types for Climate Sensitivity

To rapidly screen the sensitivity of assets to climate variables, the Study team developed a Risk Workbook to collect and organize information on sensitivity, climate, impacts, and consequences for all asset types and all climate hazards.

To populate the sensitivity component of the Risk Workbook, the Study team assigned relative asset type sensitivities (high, medium, or low) to climate hazards and associated climate variables through workshops with Con Edison SMEs. For Appendix 3, the Study team used sensitivity information provided by the SMEs on the following precipitation variables: snowfall, rainfall, ice, hail, average precipitation, maximum precipitation, and storm (flooding).

To determine the appropriate sensitivity rating, Con Edison SMEs were asked to consider each climate variable and asset type combination and identify to what extent the variable is a factor in asset design or operation, using questions such as:

- *What previous significant weather events have impacted assets or operations?*
- *Is information about the climate variable used in design or operation?*
- *Is the variable a key input or critical factor to asset design?*

Assets with initially assigned high sensitivity to precipitation variables were then reconsidered in the subsequent risk-based prioritization process for Appendix 3. Upon refinement, the functional area and variable combinations with high sensitivity are shown in Table 1.

Table 1 Asset and precipitation variable combinations with high sensitivity, as rated by Con Edison subject matter experts

Functional Area	Asset	Variable
Steam Distribution	Steam main, remote monitoring; pumps	Rainfall, maximum precipitation
Gas Distribution	Low-pressure mains; regulator stations	Rainfall, maximum precipitation
Transmission Feeders	Grounding	Rainfall, ice
Substation, Transmission, Area, and Unit	Transformer; bus; underground cable; disconnect switch; circuit breaker; CCPD; PTs; capacitor bank; foundations; grounding; insulators; drainage; surge arrestors	Snowfall, rainfall, ice, maximum precipitation
Distribution, underground	Manhole, service box; underground cables, non-submersible equipment	Rainfall, snowfall, ice (issues surrounding salt)
Distribution, overhead	Primary and secondary cables, wires and splices	Snowfall, ice
Construction	Excavations	Snowfall, rainfall, ice, average precipitation, maximum precipitation
Transmission and Distribution Operations	Vegetation management	Snowfall, rainfall, ice, average precipitation, maximum precipitation
Natural Gas Operations	Valve access and regulator	Snowfall

In a follow-on workshop with the SMEs, the Study team developed an even more nuanced understanding of precipitation-based risks. The Study team asked the SMEs to consider questions such as:

- *How have previous major events affected your assets or operations?*
- *How have you prepared or are planning to prepare for these types of events?*
- *How might longer or more intense events overwhelm your current processes? At what point would additional action be required?*

Findings from this workshop indicate that the flooding of assets, such as steam mains and manholes, was a concern. The screening process identified the key precipitation thresholds that Con Edison currently uses as benchmarks for potentially risky events (see Table 2). These thresholds are a result of the engineering characteristics of the various systems or assets.

Table 2 ■ Key existing precipitation thresholds

Relevant System or Asset	Precipitation Threshold	Timeframe
Gas System	0.5 inch of rain	24 hours
Steam System	0.75 inch of rain	3 hours
Substations	6 inches of rain[1]	24 hours
Electric Distribution – Overhead	6 inches of heavy wet snow	24 hours
Electric Distribution – Underground	6 inches of snow	24 hours
Transmission	None	N/A

4. Historical and Future Climate Projections

"Extreme" precipitation generally refers to the amount of precipitation produced by a storm. For example, Con Edison considers storm totals above 0.5 inch of precipitation as major, while storm totals below 0.5 inch are minor. In contrast, precipitation "intensity" refers to the rate of precipitation. Con Edison considers heavy precipitation greater than 0.5 inch per hour, moderate precipitation between 0.5 and 0.25 inch per hour, and light precipitation less than 0.25 inch per hour. Within this framework, a short-duration intense rainfall may not be extreme if it does not result in flooding. Also, extreme events can intensify over time (i.e., become more extreme).

The Study team analyzed historical precipitation in the Con Edison service territory and projected potential changes in precipitation through the 21st century. The historical reference period is based on daily precipitation observations from 1976 to 2005 collected from three weather stations within the Con Edison territory: Central Park, LaGuardia Airport, and White Plains.

The New York metropolitan region experiences a range of precipitation events occurring over a range of timescales (i.e., durations), including rainfall, downpours, snowfall, and ice. On short timescales, thunderstorms associated with frontal systems can produce intense rainfall lasting minutes to hours. In contrast, tropical cyclones create downpours that can last for multiple days. While heavy rain events occur in all seasons, the combination of intense and short-duration downpours occurs mostly during the warm months of the year. The service territory also experiences frozen precipitation in the form of snow and ice, which can become heavy during events such as extratropical cyclones, known as nor'easters during the cold months.

Climate change is projected to cause heavier precipitation because a warming of the atmosphere holds more water vapor and provides more energy for convection driving strong storms. While predictive models are capable of characterizing long-term precipitation patterns across the service territory, the physical processes governing short-duration, extreme precipitation events are particularly challenging to simulate in global climate models. As a result, the Study team relied on several sources of information to inform projections of extreme precipitation, including climate models, scientific literature, and historical trends. Despite the uncertainties involved in projecting

[1] Aligns with the amount of precipitation associated with the historical 25-year, 24-hour precipitation event. A 25-year precipitation event has a 4% chance of occurring in any given year.

changes in extreme precipitation, it plays a central role in this appendix because extreme precipitation events are projected to intensify and increase faster than seasonal and annual total precipitation, and extreme, short-duration precipitation events may have significant impacts on Con Edison's assets and operations.

Historical Precipitation Summary

The New York metropolitan region receives approximately 48 inches of precipitation per year, on average. There are relatively small regional differences across the Con Edison service territory. For example, White Plains experiences 15% more rainfall than LaGuardia Airport and 5% more than Central Park. These differences likely reflect geographic variations across the service territory: Inland locations generally receive more precipitation than coastal locations. Central Park may also receive more rainfall relative to LaGuardia Airport due to urban amplification (i.e., the tendency for warmer temperatures in urban areas to support greater rainfall amounts) and LaGuardia Airport's proximity to the coastline.

Consistent with the findings in other studies (e.g., Horton et al., 2014), annual precipitation has increased 0.50 to 0.83 inch per decade at the meteorological stations over the observational record (data collection began at Central Park in 1900, LaGuardia Airport in 1940, and White Plains in 1948) (see Figure 1). Seasonal precipitation (i.e., total precipitation during each of the four seasons of the year) also increased at each station, although White Plains experienced a small decrease in winter precipitation over the observational record. Variations among the stations likely represent natural climate variability within the service territory.

The New York metropolitan region experiences nearly uniform precipitation throughout the year (Table 3), which reduces the risk of long-term drought and excess rainfall. However, wintertime precipitation is marginally lower at all three stations.

Table 3 ■ Historical seasonal precipitation at each meteorological station (1976–2005)

Season	Central Park	LaGuardia Airport	White Plains
Winter Precipitation (Dec, Jan, Feb)	10.6 inches	9.4 inches	11.1 inches
Spring Precipitation (March, April, May)	13.1 inches	11.7 inches	13.6 inches
Summer Precipitation (June, July, Aug)	12.3 inches	11.7 inches	12.0 inches
Fall Precipitation (Sept, Oct, Nov)	12.7 inches	10.9 inches	13.5 inches

Excess precipitation can lead to flooding. Flooding is commonly associated with heavy short- or long-duration precipitation events (i.e., sub-daily to multi-day), which can be exacerbated by impervious land cover and small streams within the metropolitan environment. Heavy precipitation is common across the service territory: Each meteorological station recorded at least 5 days per year with 1.5 inches of rainfall, and the annual 99th percentile daily rainfall event exceeded 2.60 inches at all three stations (Table 4). The annual 99th percentile daily rainfall amount characterizes extremely heavy precipitation (within the top 1%) in any given year. The maximum recorded daily rainfall amount over the historical reference period for Central Park, LaGuardia Airport, and White Plains is 7.40 inches, 4.63 inches, and 5.93 inches, respectively. Heavy rainfall can also be very localized, sometimes avoiding parts of the service territory entirely. For example, a large downpour produced more than 13 inches of rainfall in Central Islip, NY (about 50 miles east of New York City), on August 13, 2014, while Central Park saw less than 1 inch.

Table 4 ■ Historical precipitation climatology (1976–2005)

Historical	Central Park	LaGuardia Airport	White Plains
Annual precipitation[2]	48.7 inches	43.7 inches	50.2 inches
Number of days per year with rainfall at or above 0.5 inch	31 days	29 days	32 days
Number of days per year with rainfall at or above 1.5 inches	6 days	5 days	7 days
Annual 99th percentile daily rainfall	2.75 inches	2.60 inches	2.81 inches
Annual 5-day average maximum precipitation total[3]	4.97 inches	4.36 inches	4.89 inches
5-day maximum precipitation total[4]	9.56 inches	8.11 inches	8.28 inches

Historically, Westchester County[5] experiences more frequent snow days and approximately 20% more snowfall per year than Central Park and LaGuardia Airport (Table 5). Differences in snowfall amounts among these locations are due to geographic differences across the service territory. For example, inland locations, such as White Plains, generally experience colder temperatures and more snowfall than areas closer to the coast or in New York City's urban heat island. Freezing rain occurs only twice per year, on average, at the two New York City stations (Table 5), and while no data on freezing rain are available for White Plains, colder temperatures there may lead to a few more days per year with freezing rain compared with the urban stations. Sleet is recorded several times per year at each location. Accumulating sleet and freezing rain are relatively rare throughout the service territory and occur fewer than 5 to 10 days per year. It is important to note that meteorological stations likely underrepresent the occurrence of freezing rain and sleet, in part because they have difficulty registering small-magnitude and short-lived events.

Table 5 ■ Historical frozen precipitation climatology (1976–2005)

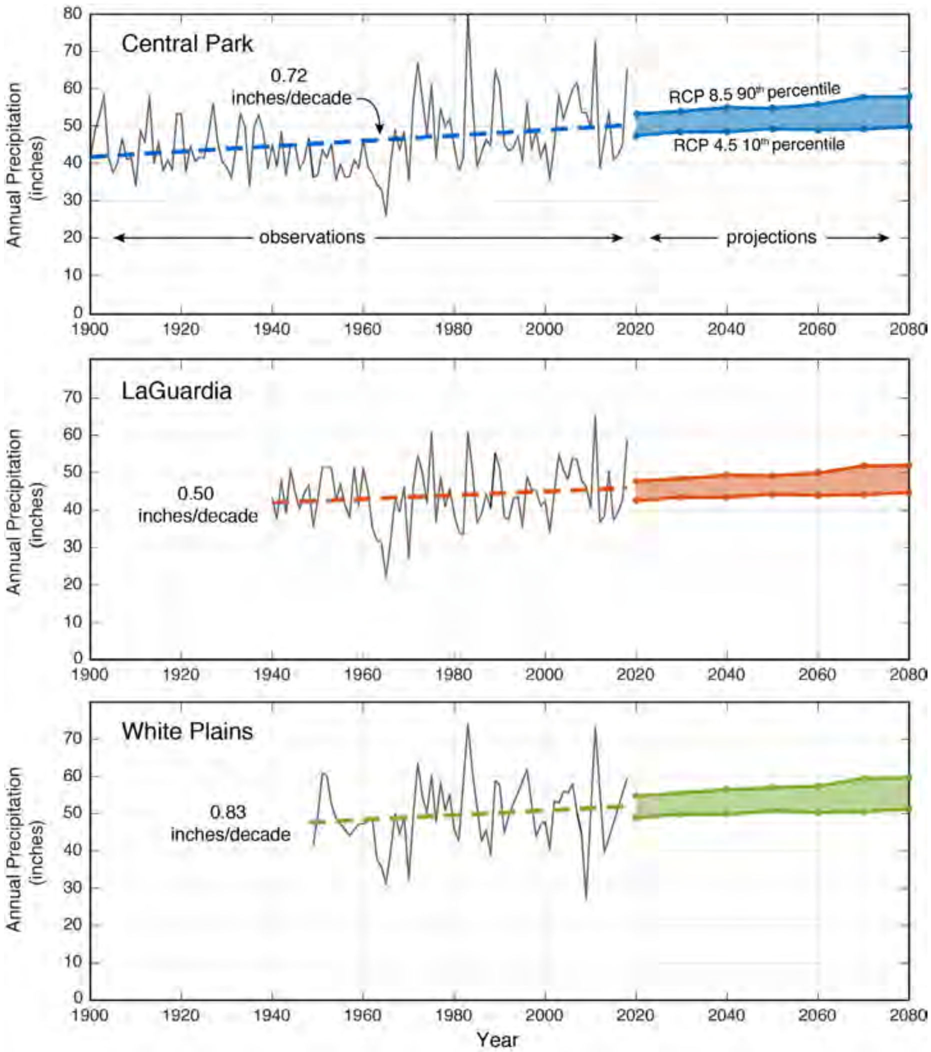
Historical	Central Park	LaGuardia Airport	Westchester
Annual snowfall	25.3 inches	26.3 inches	31.7 inches
Number of days per year with snowfall	14 days	12 days	18 days
Number of days per year with freezing rain	2 days	2 days	N/A
Number of days per year with ice (sleet)	3 days	7 days	5 days

Projections of Future Precipitation

The Study team used a suite of 26 Global Climate Models (GCMs) for which daily precipitation simulations are available to project the range of possible future precipitation across the Con Edison service territory. The GCMs were bias-corrected (i.e., statistically adjusted to bring their simulations closer in line with observed data) using weather station data over the 1976–2005 historical reference period. Details on the methodology are provided in Appendix 3.A. To capture the range of risk posed by increasing precipitation, the Study team accounted for both upper-end estimates using the 90th percentile of RCP 8.5 and lower-end estimates using the 10th percentile of RCP 4.5 (e.g., Figure 1). Projections are drawn from 30-year timeframes centered on the beginning of each decade between 2020 and 2080.

[2] Annual precipitation includes both rainfall and rainfall equivalent from frozen precipitation.
[3] This is the annual average maximum 5-day precipitation over the historical reference period.
[4] This is the maximum 5-day precipitation total over the historical reference period.
[5] Snowfall data for Westchester are from the Dobbs Ferry, NY, weather station. This is the closest station to White Plains with a complete 30-year daily snowfall record.

Figure 1 ■ Observed and projected annual precipitation. Projections are given as decadal 30-year average projections (shown as colored circles) and show the range of potential annual precipitation using the RCP 8.5 90th percentile and RCP 4.5 10th percentile. Projections reveal long-term trends but underrepresent year-to-year variability. Dashed lines show the linear trend though each observational record, with observed precipitation increases given in inches per decade.



Looking forward, both average and maximum precipitation are projected to increase throughout the century. By mid-century (2050), annual precipitation is projected to increase by 0% to 15% at each site (Figure 1 and Table 6). Heavy rainfall projections reveal similar percentage increases. For example, the number of days with precipitation at or exceeding 0.5 inch and the 99th percentile daily rainfall amount are projected to increase by approximately 0% to 13% and 0% to 15%, respectively, through mid-century (Table 7 and Table 8). The maximum precipitation total over a 5-day period is projected to be 11.47 inches in Central Park by mid-century, representing a 17% increase over the historical reference period. Seasonal increases in heavy precipitation (e.g., maximum 3-day precipitation total) will be greatest in summer and spring and less in fall and winter (see Appendix 3.A).

Table 6 ■ Projected annual precipitation at 2050

2050 Projection	Central Park			LaGuardia Airport			White Plains		
	Baseline	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*
Annual precipitation	48.7 inches	49.3 inches	54.8 inches	43.7 inches	44.2 inches	49.1 inches	50.2 inches	50.8 inches	57.0 inches

Table 7 ■ Projected annual days exceeding 0.5 inch of daily precipitation at 2050

2050 Projection	Central Park			LaGuardia Airport			White Plains		
	Baseline	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*
Annual days exceeding 0.5 inch of daily precipitation	31.4 days	32.1 days	35.4 days	28.5 days	29.4 days	32.1 days	31.6 days	32.7 days	36.2 days

Table 8 ■ Projected extreme precipitation at 2050

2050 Projection	Central Park			LaGuardia Airport			White Plains		
	Baseline	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*
Annual 95th percentile daily rainfall	1.53 inches	1.54 inches	1.79 inches	1.36 inches	1.37 inches	1.59 inches	1.63 inches	1.64 inches	1.91 inches
Annual 99th percentile daily rainfall	2.75 inches	2.79 inches	3.26 inches	2.60 inches	2.63 inches	3.08 inches	2.81 inches	2.85 inches	3.33 inches
30-year annual 5-day maximum precipitation total	9.56 inches	9.55 inches	11.47 inches	8.11 inches	8.22 inches	9.58 inches	8.28 inches	8.39 inches	9.79 inches

By late century (2080), annual precipitation is projected to increase by 0% to 20% relative to the historical reference period (Table 9). The number of days associated with different precipitation thresholds is similar to that at mid-century (Table 7 and Table 10). Heavy precipitation will continue to increase relative to current conditions: The 99th percentile daily rainfall amount and maximum 5-day precipitation total are projected to increase by approximately 0% to 17% and 0% to 20%, respectively, by 2080 (Table 11).

Table 9 ■ Projected annual precipitation at 2080

2080 Projection	Central Park			LaGuardia Airport			White Plains		
	Baseline	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*
Annual precipitation	48.7 inches	49.8 inches	57.9 inches	43.7 inches	44.6 inches	51.9 inches	50.2 inches	51.3 inches	59.7 inches

Table 10 ■ Projected annual days exceeding 0.5 inch of daily precipitation at 2080

2080 Projection	Central Park			LaGuardia Airport			White Plains		
	Baseline	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*
Annual days exceeding 0.5 inch of daily precipitation	31.4 days	31.4 days	36.6 days	28.5 days	29.4 days	33.5 days	31.6 days	31.6 days	37.4 days

Table 11 ■ Projected extreme precipitation at 2080

2080 Projection	Central Park			LaGuardia Airport			White Plains		
	Baseline	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*
Annual 95th percentile daily rainfall	1.53 inches	1.55 inches	1.88 inches	1.36 inches	1.38 inches	1.67 inches	1.66 inches	1.64 inches	2.00 inches
Annual 99th percentile daily rainfall	2.75 inches	2.81 inches	3.32 inches	2.60 inches	2.65 inches	3.14 inches	2.81 inches	2.87 inches	3.39 inches
30-year annual 5-day maximum precipitation total	9.56 inches	9.98 inches	11.92 inches	8.11 inches	8.28 inches	9.76 inches	8.28 inches	8.47 inches	9.98 inches

Further Constraints on Future Extreme Precipitation

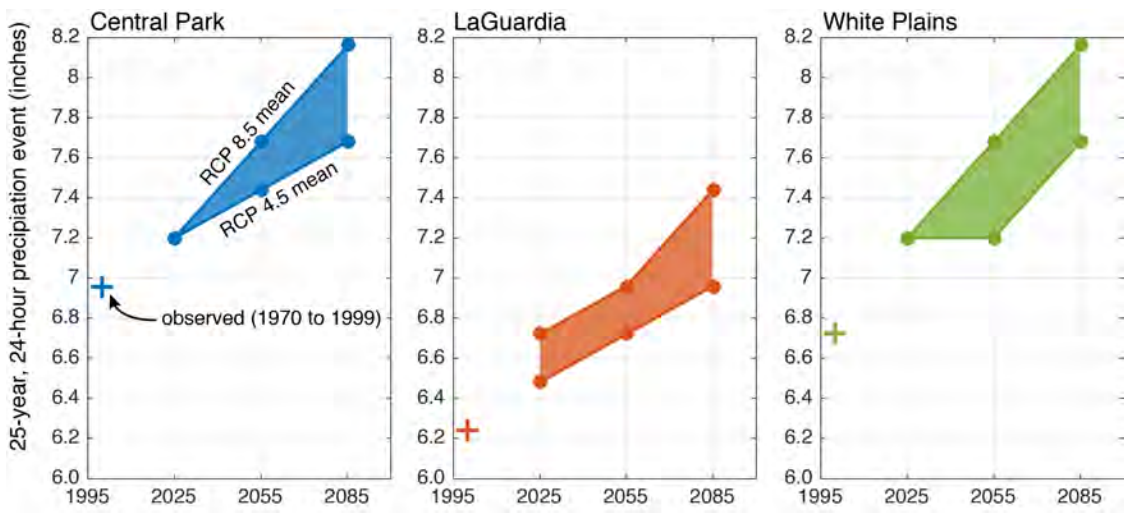
GCMs often have difficulty resolving short-duration, extreme precipitation, such as downpours and strong coastal storms, which pose outsized risks to Con Edison's assets and operations. To address this shortcoming, the Study team used recent scientific literature to help constrain and contextualize future extreme precipitation events in the service territory. Unlike GCMs, the studies used to inform this part of the analysis focus specifically on extreme rainfall events and often use specialized, high-resolution models to resolve individual storms and their projected rainfall amounts in a warming climate.

Several studies have shown significant increases in both the magnitude and frequency of extreme precipitation in the northeastern United States (GCRP, 2017). Between 1958 and 2016, the Northeast experienced a more than 50% increase in 99th percentile precipitation, and similar increases in maximum 2-day and 5-day precipitation totals (GCRP, 2017). These findings complement additional work suggesting that extreme precipitation could increase as much as 7% to 14% per degree Celsius of atmospheric warming (e.g., Lenderink et al., 2015; Zhang et al., 2017). These increases exceed quantitative projections from GCMs described in this appendix, and approximate "plausible worst case scenarios" for Con Edison's system in the future. Ultimately, projections and scientific literature point to a future defined by more frequent heavy precipitation and downpour events, with smaller increases in the number of dry or light precipitation days (GCRP, 2017).

One of the driving forces behind anticipated extreme precipitation increases is projected changes in the energy and track of hurricanes and nor'easters. Projections show that the intensity of precipitation associated with these storms may increase in the future (GCRP, 2017), and some evidence suggests that storm tracks could shift closer to the coast (Colle et al., 2013), creating conditions that are more favorable for extreme precipitation.

The National Oceanic and Atmospheric Administration (NOAA) Atlas 14 Point Precipitation Frequency Estimates database[6] contains up-to-date information on high-intensity precipitation events within the Con Edison service territory. According to this source, the 25-year,[7] 24-hour precipitation amount currently exceeds 6 inches at Central Park, LaGuardia Airport, and White Plains. In addition, data from the Northeast Regional Climate Center[8] show that 25-year, 24-hour precipitation events at Central Park, LaGuardia Airport, and White Plains (Figure 2) are projected to increase by 7% to 14% and 10% to 21%, respectively, by mid- and late-century (Figure 2). The largest increase is projected to occur in White Plains, where the 25-year precipitation event could reach 7.68 inches over a 24-hour period by mid-century.

Figure 2 ■ Observed and projected 25-year, 24-hour precipitation amounts in inches. Projections show the range of potential precipitation amounts using RCP 8.5 and RCP 4.5 ensemble mean values. Crosshairs show observed precipitation amounts over the historical reference period (1970 to 1999). Note that projected time horizons are for 2025, 2055, and 2085, which provide early, mid-, and late-century outlooks, but differ from the decadal projections in the previous section. Unlike LaGuardia Airport, Central Park and White Plains share the same projection at 2025 for both RCP 4.5 and RCP 8.5 ensemble means.



[6] https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=ny
[7] A 25-year event has a 4% chance of occurring in any given year.
[8] http://ny-idf-projections.nrcc.cornell.edu/

Constraints on Future Frozen Precipitation

Projections for changes in snow and ice are less certain than those for rainfall. Snowfall in Con Edison's territory often occurs under relatively mild winter conditions with temperatures close to the freezing point (32°F), in large part due to the moderating influence of the Atlantic Ocean and Long Island Sound. Even a slightly warmer climate may shift winter precipitation from snow to rain more frequently in the future. Given that White Plains will remain relatively colder than more urban areas of Con Edison's territory, it may continue to have a higher likelihood of experiencing ice and snow events in the future, compared with more heavily urbanized areas.

Recent projections reveal a gradual northward migration of the average rain-snow transition zone across the eastern United States. As a result, the Con Edison service territory could experience a 10% to 50% reduction in the frequency of snowfall by the end of century, assuming RCP 8.5 conditions (Ning and Bradley, 2015). While projected temperature increases may reduce the likelihood of snow, future changes in frozen precipitation are also dependent upon changes in winter storm intensity and track.

Opportunities to Improve Climate Projections Relevant to Con Edison

Improved projections of both heavy and frozen precipitation in the Con Edison service territory will require considerable future research (Gonzalez et al., 2019). The Study team highlights some potential research avenues. First, GCM datasets can drive higher resolution Regional Climate Models (RCMs) that dynamically downscale projections to better capture natural variability and precipitation processes within the local climate system. RCMs could incorporate urban features, such as tall buildings, impervious land surfaces, and the urban heat island effect, to represent realistic boundary conditions that influence precipitation patterns in the New York City metropolitan region. Similarly, dynamic downscaling using RCMs could better constrain how rising temperatures manifest changes in frozen precipitation, including snowfall and ice events. RCMs could be coupled with secondary models and datasets to better simulate disruptions to Con Edison's assets and operations. For example, RCM outputs could combine with vegetation models to simulate tree-on-line failures to overhead assets. Finally, future research should focus on understanding changes to strong coastal storms, such as tropical and extra-tropical cyclones. Small changes in storm intensity or storm tracks relative to the Con Edison service territory due to warming sea surface temperatures, stronger coastal temperature gradients, or atmospheric dynamics could have important implications for extreme precipitation in the region.

5. Priority Vulnerability and Adaptation Options

5.1. Physical Vulnerabilities and Adaptation Options

Based on the screen of physical sensitivities to identify assets most sensitive to precipitation-related climate variables, the analysis of physical vulnerabilities and adaptation options focused on Con Edison's steam system, gas system, and the transmission and substation components of the electric system.

Steam

Vulnerabilities

Con Edison's steam system provides service to more than 3 million Manhattan residents, from lower Manhattan to 96th Street. The steam system includes 3,000 manholes within this service area, through which water can enter and come into contact with the steam system. Large quantities of precipitation falling over a very short period present potential risks to Con Edison's steam system via the risk of condensate collection leading to a water hammer event. When water pools around the outside of a steam pipe, for example, if collecting in significant quantities in a manhole, it can cause the steam inside to cool and form condensate. A buildup of condensate can interact with steam in ways that can lead to catastrophic rupture in a steam pipe.

Following the 2007 precipitation-related steam pipe explosion at Lexington Avenue and 41st Street, Con Edison implemented a precautionary monitoring threshold of 0.75 inch of rain falling over the course of 3 hours, defined by Steam Procedure S-11974 as a "rain event." This threshold allows Con Edison to proactively monitor and address water intrusion into the system before it results in a water hammer event.

Con Edison responds to rain events by pumping water out of manholes and into the city sewer. If the sewer system is overwhelmed, or if pumping cannot keep up with the influx of water, Con Edison is forced to take steam mains out of service. Hurricane Irene in 2011 was the first incident in which Con Edison shut down portions of the steam system proactively due to heavy rainfall. Sewer system backups present the greatest concern for the steam system during heavy rain events, as they prevent Con Edison from relying on the sewer to accept condensate from the steam system.

A climate-driven increase in the frequency and severity of heavy precipitation events could increase the frequency and severity of impacts to Con Edison's steam system. Furthermore, sewer system backups could be exacerbated by sea level rise. These events are explored in more detail in Appendix 4 – Sea Level Rise and Appendix 5 – Extreme Events.

Adaptation Options

Con Edison currently addresses precipitation risk to its steam system through the following actions:

- **Deploying a rain patrol during heavy rain events.** During rain event days (triggered when more than 0.75 inch of rain falls within 3 hours), Con Edison sends workers to scout for visible steam vapor at ground level, which indicates that water is in contact with the outside of a steam pipe. These teams also check manholes to ensure that there is no flooding from backups in the sewer system.
- **Opportunistic improvements in waterproofing.** During the normal course of maintenance and upgrades to the steam system, Con Edison replaces system components with improved materials that reduce threats from precipitation. These include hydrophobic insulation, better sealants for steam mains, and sealing around manhole covers.
- **Prioritized hardening of problem locations.** Con Edison keeps track of steam mains that are submerged following rain events and has been systematically re-engineering these locations to reduce vulnerability. Solutions may include raising the main, adding a drain, or installing a pump. The list of priority locations has been reduced from 86 when the program started to fewer than 10 locations today.
- **Remote monitoring of the steam system.** The company is in the final stages of designing a remote monitoring system to monitor manhole water level and steam trap operation for its steam network. The system is planned to be fully operational by 2021.

In the future, Con Edison could pursue (or in some cases, is already pursuing) the following actions:

- **Improve collaboration with the City of New York on stormwater design, maintenance, and hardening.** Con Edison's ability to protect its system from inundation is linked to the City's stormwater management design and maintenance. Improved coordination with the City on design standards and problem locations could reduce risks. Coordination on system hardening with City engineering activities (e.g., addressing steam system issues at the same time as stormwater) could streamline the process. In addition, Con Edison could increase their coordination with the City's flood design innovations to manage increased precipitation, which include strategies such as reducing the use of impervious surfaces, increasing water infiltration where appropriate, and detaining rainwater to delay drainage.

- **Consider hardening at marginal locations.** Building on its existing hardening efforts at problem locations, Con Edison could assess whether locations close to ones that are known to be prone to inundation (e.g., within a certain radius) are more likely to experience problems. This would allow Con Edison to prioritize additional hardening after clear problem locations are addressed.
- **Improve systems for crowd-sourcing leak detection.** Improved public awareness of the signs of steam system risks could allow for earlier detection and prevention of potential steam events. Con Edison may consider a public communications campaign to encourage the public to report visible steam that is not vented out through a stack. One option may be to devise a system for sending photographs of potential steam concerns through the City's 311 smartphone app.

Gas

Vulnerabilities

Con Edison's gas system provides service to approximately 1.1 million customers. The gas distribution system includes approximately 8,000 miles of pipes, with 4,000 miles of local gas distribution lines.[9] The distribution system operates at three pressures: 33% operates at high pressure, 11% at medium pressure, and the remaining 56% at low pressure.

The vulnerabilities of the gas system to precipitation are largely within the gas distribution system. Heavy precipitation events can result in water intrusion into Con Edison's gas distribution system. When the ground becomes saturated, moisture can enter low-pressure pipes through joints, causing low gas pressure for customers (frequently leading to complaints) or interruption in gas service. Once water enters the gas system, it can be very difficult to remove. Cast iron pipes, in particular, are prone to water intrusion. Water can also enter the gas system through open excavations where active work is occurring should standard flood protection measures be compromised.

Con Edison's low-pressure gas distribution system has drip pots installed to collect water at low points in the system. Just over 8,000 drip pots are located throughout Con Edison's system. Drip pots need to be emptied periodically following heavy precipitation events. Con Edison currently uses a conservative threshold of 0.5 inch of forecasted precipitation in 1 day to trigger inspection and pumping of selected drip pots prior to and during the rain event. Con Edison is investigating the viability of a remote monitoring program that could be applied throughout the system. Main technical hurdles involve sensor method, power requirements (i.e., battery life), and communications.

Not all low points in the system have drip pots installed. Where no drip pot is present, water in the system is difficult to locate and remove, and generally requires excavation and construction. When customer complaints indicate water in a main and the problem cannot be located, Con Edison

[9] https://www.coned.com/en/about-us/corporate-facts

typically responds by replacing the relevant low-pressure segment with a medium or high-pressure system.

Climate change is projected to increase the frequency of heavy 1-day precipitation events, potentially resulting in increased frequency of water intrusion into Con Edison's low-pressure gas distribution system. This study measures the projected frequencies of those events based on Con Edison's current 0.5-inch daily precipitation threshold.

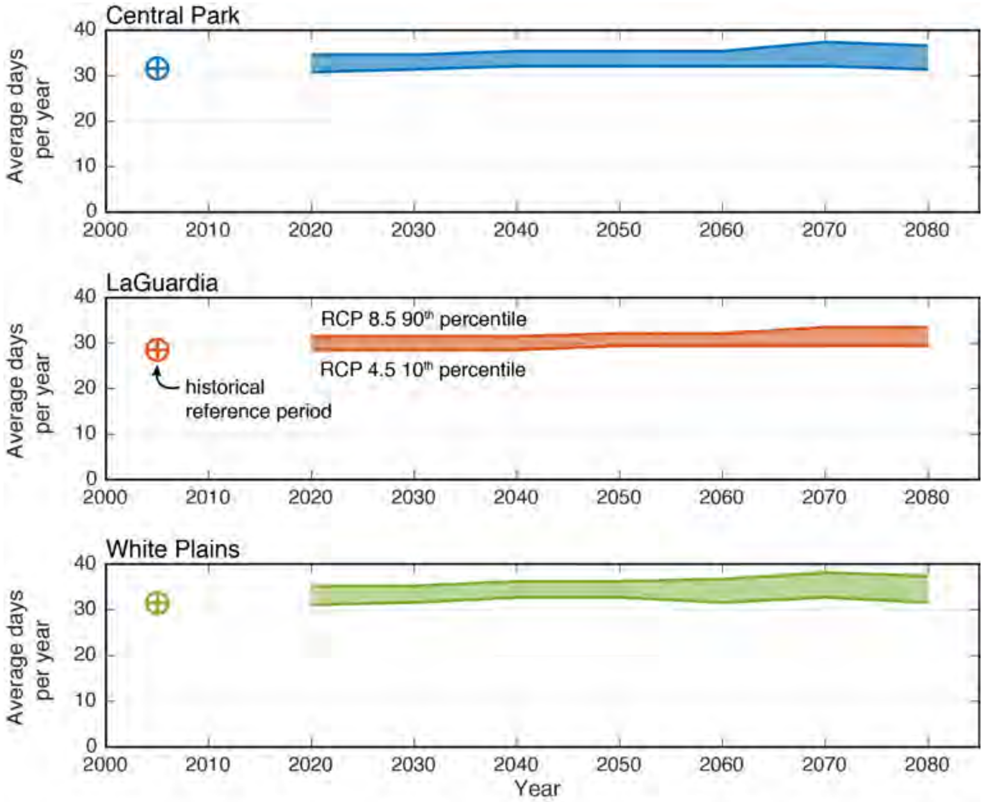
As shown in Figure 3, projections for the RCP 8.5 scenario include nearly 20% more days with precipitation greater than 0.5 inch than have been historically observed, approximately 37 days per year in Central Park by the latter part of the century, compared with approximately 31 days per year over the baseline period.

Under the current gas system design, more frequent heavy rainfall events would likely expand the number of locations in the gas distribution system with subsurface water intrusion issues and would increase the frequency of those events.

Heavy precipitation events may also pose a risk of water intrusion via gas regulator vents. Vents located in a low-lying area surrounded by higher land may be at risk from localized flooding if the vent is not sufficiently elevated to future flood potentials. Water intrusion at these locations would result in higher numbers of customer interruptions.

In addition to heavy rain events, snow events present potential risks to the gas system. Water intrusion risk from snow events is dictated by the rate of melt rather than the rate of snowfall. Looking forward, climate projections suggest that rapid snowmelt events could become more common as temperatures rise, potentially leading to more frequent flooding following snowstorms.

Figure 3 ■ Projected average annual days exceeding 0.5 inch of precipitation by climate scenario and decade through 2080



Adaptation Options

Con Edison currently uses the following strategies to address precipitation-related impacts on its gas distribution system:

- **Drip pots.** As noted above, drip pots are effective—where they are present—in removing water from the system. When daily precipitation is forecasted to exceed the 0.5-inch threshold, Con Edison sends crews to check and empty selected drip pots.
- **Securing open excavations.** When daily precipitation is forecasted to exceed the 0.5-inch threshold, Con Edison sends crews to install surface measures, such as temporary berms, to prevent the flow of surface water into open excavations. In addition, Con Edison performs inspections after every rainstorm.[10] This measure is reasonably effective in preventing water intrusion.
- **Main Replacement Program.** Con Edison is conducting a targeted Main Replacement Program. This program targets 1,900 miles of pipes that are potentially prone to water intrusion, leaks, or other concerns, based on an engineering assessment. Assets prioritized for replacement include low-pressure mains in low-lying areas (i.e., Federal Emergency Management Agency [FEMA] + 3′ flood zones). The present accelerated plan would complete main replacement by 2036.
- **Long-term move to implement leak resistance in the system.** Con Edison is also in the process of progressively transitioning its entire gas system to equipment types that are significantly less vulnerable to precipitation-related intrusion. Outside of Manhattan, Con Edison

[10] Con Edison standard CE-SS-3400, Part 2200 for Excavation & Backfilling.

is replacing its low-pressure systems with medium- or high-pressure systems, both of which are more resistant to water intrusion. In Manhattan, where higher pressure pipes pose too much risk given the density of infrastructure, Con Edison is moving toward low-pressure polyvinyl chloride components, which are significantly less prone to water intrusion compared with cast iron.

- **Elevating gas regulator vent lines above the flood plain.** As described in Appendix 4 – Sea Level Rise, Con Edison has either extended the gas regulator vent line terminus above the FEMA + 3′ elevation or had a vent line protector installed if the regulator is within the FEMA floodplain.[11]

In addition to continuing to implement the above strategies, the company could consider the following strategy for further identifying, prioritizing, and mitigating precipitation-related risks. Con Edison could monitor the changes in precipitation conditions, which should be a factor in the decision to implement a given strategy.

- **Implementing remote monitoring and data analysis.** Con Edison is currently developing a program to better prioritize gas infrastructure replacements using machine learning to identify areas that are likely to be leak-prone. The company is also in the research and development stage of investigating remote monitoring of drip pots. Remote sensors will allow for improved identification of leak-prone areas for prioritized infrastructure upgrades. Drip pot sensors will also facilitate greater efficiency in the periodic emptying of drip pots. Investment in these monitoring efforts will help prioritize the mitigation of increasing precipitation risks in the face of climate change, as well as reduce the effort required to monitor drip pots over the period of planned pipe replacement.
- **Installing additional vent line protectors in regulator locations prone to precipitation-driven flooding.** While this approach is already used within the FEMA floodplain, it could be implemented more broadly in areas that may become flood-prone due to precipitation projections.

Electric

Based on the screening analysis, the Study team found that substations, overhead distribution, underground distribution, and the transmission system were most at risk for precipitation-based hazards. Con Edison's electric system includes 62 area substations and more than 37,000 miles of overhead distribution lines.[12] Con Edison's underground network electric distribution system includes 65 second contingency networks and 19 first contingency networks spread across all boroughs of New York City and Westchester County.[13] These networks serve approximately 2.6 million customers and include more than 97,000 miles of underground cable and more than 42,000 underground transformers. Con Edison also has non-network systems that serve parts of Brooklyn, Queens, Staten Island, the Bronx, and Westchester, known as Con Edison's radial grid (on approximately 34,000 miles of overhead wire and accounting for about 14% of Con Edison's distribution load).

The following section first examines substation vulnerabilities and adaptation options, then those for the transmission system and the distribution system.

[11] In Westchester, Gas Distribution Engineering is also required to check against the National Weather Service Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model, which models storm surge potential. Areas in Westchester that are not at risk from Category 1–3 hurricanes are not required to build to the FEMA + 3′ Base Flood Elevation.

[12] https://www.coned.com/en/about-us/corporate-facts

[13] A first contingency or second contingency network can continue operating with its equipment within rating limits despite the loss of one or two supply feeders, respectively.

Substations

Vulnerabilities

Con Edison's substation secondary containment measures (e.g., moats) are built to accommodate 6 inches of rain in 24 hours, in coordination with U.S. EPA Spill Prevention, Control, and Countermeasure (SPCC) regulatory guidance, which recommends that major projects be built to accommodate 25-year heavy precipitation events. This threshold is incorporated into the basic site and building design requirements for water percolation, capture, and storage.[14] The company's elected rainfall depth was associated with the 25-year heavy precipitation event found in the U.S. Department of Agriculture's *Rainfall Frequency of the United States*, published in 1961. This resource indicated that the 25-year, 24-hour storm for New York City generally yields about 6 inches of rainfall. While this is still the standard used at Con Edison, it is considered to be out-of-date. Using more recent rainfall data,[15] the 25-year, 24-hour storm in New York City produces a total rainfall amount of closer to 7 inches.

Within the substation, the risk stemming from heavy precipitation is from the overflow of water from transformer spill moats, which could result in a release of oil-contaminated water within the substation. Even this risk is low, however, as transformer spill moats are built at a level that is robust to all but a severe and highly improbable conjunction of events. In accordance with New York State code and federal SPCC recommendations, Con Edison's transformers are protected by moats designed to hold water from a 6-inch, 1-day storm event in addition to the gallons of oil that may be released during a spill event, and a further 50,000–60,000 gallons of fire suppression fluid. Based on this standard, Con Edison's substation transformer moats are robust to 6 inches of rain during a catastrophic emergency, and significantly more than that at all other times. At present, Con Edison has pumps installed at all substations to pump water out of moats at approximately 100 gallons per minute. Water is typically pumped into the public sewer after any oil has been separated out. Con Edison also has a "defense in depth" strategy, implemented as part of Con Edison's post-Superstorm Sandy storm hardening effort. This strategy employs "trash pumps" behind flood walls to pump water out of substations as a last resort.

Based on data from the Northeast Regional Climate Center (e.g., Figure 2), the historical 25-year, 24-hour precipitation event at Central Park is projected to increase up to 10% and 17% by mid-century and late-century, respectively.[16] White Plains will experience larger increases of 14% and 21% by mid-century and late-century, respectively. These increases in rainfall totals would cut into the existing Con Edison risk tolerance for substations.

Adaptation Options

If needed, Con Edison may consider several adaptation options to account for increases in the severity of future extreme precipitation events.

- **Update design standards.** While risk to substations from heavy precipitation is low, an increase in the intensity of the future 25-year precipitation event would require an update to substation design requirements for future construction and design upgrades for existing sites. The Study team recommends designing to at least the up-to-date 25-year, 24-hour precipitation amount (from the NOAA Atlas 14 Point Precipitation Frequency Estimates database[17]) and considering the cost implications of designing to the lower return frequency and higher magnitude 50-year, 24-hour precipitation event in order to address the potential for heavier rainfall in the future.

[14] Con Edison specification CD-ES-2002 -21, Figure 6.
[15] https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=ny
[16] http://ny-idf-projections.nrcc.cornell.edu/
[17] https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=ny

- **Raise the height of transformer moats.** If transformer moats were required in the future to meet a significantly higher standard for an extreme storm event, height could be added to the moats of existing transformers at a relatively low cost.
- **Install additional oil-water separator capacity.** If necessary, Con Ed could install additional oil-water separator capacity to more quickly remove water from substation moats.

Transmission

Vulnerabilities

For Con Edison's transmission system, the primary concerns related to precipitation events are from rainfall, high winds, tornadoes, and the accumulation of radial ice. This appendix will focus on rainfall and radial ice, with the other hazards covered in Appendix 5 – Extreme Events.

Radial ice is ice that builds up on transmission lines and towers during winter precipitation events. In extreme scenarios, accumulation of radial ice can result in unbalanced structural loading and subsequent transmission line failure, especially when accompanied by heavy winds.[18] Accumulation of ice on lines can change the wind loading dynamics of those lines and cause them to swing in high winds.[19] Tension towers, which are built to support a lateral bend in line angle, are more robust than suspension towers, which merely support the line in a vertical dimension. The failure of one suspension tower may result in a cascade of multiple suspension tower failures. While Con Edison has not experienced historical impacts from ice-driven transmission tower collapse, similar impacts in other regions have been severe. In Quebec, a 1998 ice storm led to the collapse of a large number of transmission towers, resulting in millions of customer outages.[20]

Con Edison's transmission system meets the National Electrical Safety Code (NESC) standard for radial ice and is fairly robust with regard to ice accumulation. Transmission towers are designed to withstand 1 inch of uniform radial ice combined with 20 pounds force per square foot of wind pressure—a condition understood to reflect a 100-year event.[21] Con Edison Transmission Operations also currently operates a program to strategically reinforce suspension towers such that they act as anchors for other nearby towers, stopping the progression of a cascade of falling towers. The company routinely conducts scenario analysis to determine the system impacts of losing different transmission feeders. In addition, Con Edison has invested in temporary towers and wooden poles that can provide short-term replacement of fallen transmission towers and has the ability to quickly re-stand fallen towers.

Adaptation Options

Given the uncertainty in future icing, the current standards and operational measures are currently sufficient for addressing ice conditions. Con Edison could monitor the frequency and severity of ice accumulation over time. If there is an upward trend, Con Edison may consider the following additional strategies:

- **Undergrounding of critical transmission lines.** Undergrounding critical transmission lines would remove the risk of damage and disruption due to ice accumulation.
- **Accelerated transmission system hardening.** Increasing the rate of transmission system hardening will help Con Edison ensure that the system remains robust in the face of changing

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[18] https://pdfs.semanticscholar.org/4d68/af2b2dd4f0073ed40744e57fcb9c9763899e.pdf

[19] https://www.tdworld.com/features/manitoba-hydro-mitigates-ice-issue-power-lines

[20] http://www.hydroquebec.com/ice-storm-1998/

[21] Con Ed standard CC-SS-2006.

ice conditions. For example, elevating standards for radial ice accumulation will ultimately lead to infrastructure that can withstand greater amounts of ice accumulation.

Overhead Distribution

Vulnerabilities

Similar to the transmission system, the primary concerns for Con Edison's overhead distribution system with respect to precipitation events are also from high winds, tornadoes, and the accumulation of radial ice. This appendix will focus on radial ice, with the other hazards covered in Appendix 5 – Extreme Events. As described in the Transmission Vulnerabilities section, radial ice can build up on lines during winter precipitation events. Currently, Con Edison's distribution system meets the NESC standard, Rule 250B, for an area with "heavy" ice loading of 0.5 inch of radial ice and 40 miles per hour of wind. In addition, Con Edison selects NESC "Grade B" construction, which provides a more robust safety factor than Grade A.

Adaptation Options

- **Undergrounding of critical distribution lines.** Undergrounding of critical distribution lines would remove the risk of damage and disruption due to ice accumulation.
- **Accelerated distribution system hardening.** Increasing the rate of system hardening will help Con Edison to ensure that the system remains robust in the face of changing ice conditions. For example, installing stronger poles, upgrading to breakaway connectors, and replacing open wire with aerial cable may ultimately lead to a distribution system that can withstand greater amounts of ice accumulation.

Underground Distribution

Vulnerabilities

The primary concerns for Con Edison's underground distribution system with respect to precipitation events are directly from flooding and indirectly associated with snowfall and ice.

Flooding can lead to damage of non-submersible electrical equipment. Con Edison designs all underground cables and splices to operate submerged in water. Con Edison also specifies submersible underground distribution equipment (e.g., transformers, switches) for installations in flood zones. For non-flood zones, the company specifies ventilated (non-submersible) designs. After Superstorm Sandy, the company revised its design guidelines to specify submersible equipment for all new installations; however, existing ventilated equipment could be vulnerable to flooding due to increased precipitation, which could include greater amounts of rapid melting of snow and ice.

Salt is spread by the City of New York to minimize ice buildup on roads. Salt can damage the underground system and lead to manhole events (a safety concern) and customer outages. More specifically, when snowmelt and road salt wash into manholes and service boxes, the combination can degrade wire insulation and generate heat, causing the insulation to burn. The sparks and smoke from the burning insulation can ignite gas and cause a manhole fire, or even an explosion.[22]

Adaptation Options

- Retrofit equipment. Retrofitting ventilated equipment with submersible equipment would eliminate the risk of damage due to water intrusion.

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[22] https://www.coned.com/en/safety/safety/energy-safety

- **Replacement programs.** Con Edison's Underground Secondary Reliability program improves system safety and reliability by replacing poorly performing components. This program could be expanded to respond to an increase in manhole events due to increased precipitation and salting.
- **Vented manhole covers.** Con Edison has installed more than 121,000 vented covers on manholes and service boxes that allow gases to escape if underground wiring begins to smoke. The deployment of these covers could be accelerated, if necessary.
- **More resilient cable.** Con Edison also has a program to replace underground cable, adding 833 miles of new, dual-layered and insulated cable, which is more resistant to damage and should reduce the incidence of manhole events.
- **Manhole sensors.** Con Edison has initiated a program to improve the safety and reliability of the underground distribution system by installing sensors in manholes to detect conditions indicating a potential manhole event. This program is estimated to be deployed over a 20-year period and the company has the option of accelerating its deployment, if warranted.

5.2. Operational and Planning Vulnerabilities and Adaptation Options

Vegetation Management

Vulnerabilities

Contact with vegetation is a primary cause of failures in the portions of Con Edison's distribution system that are composed of overhead wires. Climate-driven increases in annual average precipitation, which are projected at 10% to 15% in a high climate change scenario, are likely to lead to increased tree and brush growth. In the northeastern United States (including New York), warming temperatures have lengthened the growing season, which is partially responsible for increases in forest growth (U.S. GCRP, 2018, citing Keenan et al., 2014).

However, the overall effects of climate change on forest growth are more complex. For example, shifting seasonality and warming temperatures will likely lead to earlier insect emergence and a geographic range increase of tree pests (U.S. GCRP, 2018, citing Menzel et al., 2006; Paradis et al., 2008; DeSantis et al., 2013; and Weed et al., 2017). Warmer winters can mean less early winter snowfall, more precipitation falling as rain rather than snow, and earlier snowmelt, which can affect water availability throughout the spring and summer seasons (U.S. GCRP, 2018, citing Notaro et al., 2014, and Demaria et al., 2016).

Absent additional efforts to mitigate the impacts of vegetation on Con Edison's overhead distribution, increased growth rates, if they occur, are likely to lead to a higher frequency of vegetation-related failures.

Adaptation Options

Con Edison conducts ongoing and extensive vegetation management to control vegetation that threatens overhead distribution and transmission infrastructure. The standard tree-trimming cycle is 3 years. Some areas grow faster than others, however, and it is possible that increased rainfall could increase those differences. Con Edison is currently considering shortening or lengthening trimming cycles for different locations based on observed vegetation growth rates.

In addition to standard ongoing vegetation management, Con Edison is piloting a Hazardous Tree Removal Program to strategically target the areas that are most susceptible to vegetation-related damage. Under the pilot program, Con Edison engineers identified the worst-performing feeders in a part of Westchester that had been severely affected by storms. Con Edison then worked with a vendor to identify dead, dying, and diseased trees outside the company's right-of-way that could pose threats to the relevant feeders. Con Edison's vendor then obtained permission from property owners to remove the trees. In 2019, Con Edison expanded the program to additional municipalities, and plans to remove between 800 and 1,000 trees this year. Con Edison is considering an annual allocation of $2 million, on an ongoing basis, in order to remove approximately 1,000 high-threat trees per year.

Under potential climate-driven increases to vegetation growth rates, Con Edison may consider the following strategies:

- **Expand annual spending on the vegetation management programs.** Increasing the scale of Con Edison's well-developed vegetation management program is likely to be an effective counterweight to climate-driven increases in vegetation growth.
- **Expand monitoring and targeting of high-risk vegetation areas.** If locational differences in vegetation growth rates are observed, Con Edison may consider expanding its ability to track problem areas and target them with more frequent and aggressive trimming.

6. Costs and Benefits of Adaptation Options Under a Range of Possible Futures

Projections of future precipitation do not represent a drastic departure from historical conditions. Con Edison has implemented a range of measures to address current risks from precipitation in the service territory, which provides additional adaptive capacity against expected precipitation increases over the coming century. These measures include pumping water out of manholes and into the city sewer in response to rain events, installing drip pots to collect water at low points in the low-pressure gas distribution system, and meeting the NESC standard for radial ice.

Looking forward, some incremental costs associated with additional adaptation options are not expected to be prohibitively high, as current programs and plans already provide a substantial level of protection. As an example, the steam system arranges for appropriate contractor coverage to perform vapor patrolling and pre-emptive flood protection for critical facilities in anticipation of a forecasted rain event. In addition, many of the adaptation options are focused on monitoring and expanding current programs that could be accomplished at manageable costs, such as remote monitoring of the steam system, and expanding vegetation management programs.

Other adaptation options require hardening system components, such as raising the heights of substation moats, undergrounding transmission and distribution lines, and replacing non-submersible equipment with submersible equipment. These actions will rely on monitoring precipitation trends and risks over time to determine when and where hardening measures are best suited for implementation.

At the same time, additional adaptation options and strategies highlighted in the sections above would improve Con Edison's ability to mitigate impacts from increasing precipitation and generate associated benefits. Some benefits would improve operations. For example, because rainfall often surpasses critical thresholds locally and not uniformly throughout the region, an improved monitoring system could more efficiently constrain problem areas for selective responses and determine the specific resources required to address them. This could save in work-hour commitments to perform manual surveys, while also reducing the risks associated with the timely identification of locations potentially compromised by rainfall.

Benefits may also result from new community partnerships with the City of New York. For example, Con Edison could emphasize collaboration with the City on stormwater design, maintenance, and hardening to identify any potential for localized flooding, and find mutually beneficial and cost-effective solutions. Similarly, new investments to improve crowd-sourcing leak detection for steam could raise social awareness of Con Edison's operations and initiatives throughout the City, ultimately increasing positive public exposure for the company.

7. Implementation of Adaptation Options Over Time

Sections 5.1 and 5.2 describe vulnerabilities and adaptation options related to precipitation impacts across Con Edison's system. Given that the degree of uncertainty associated with precipitation projections exceeds that for other climate hazards (e.g., temperature), Con Edison could carefully monitor and assess precipitation impacts over time to determine the appropriate point at which to implement adaptation strategies. For example, while projections of extreme precipitation remain uncertain, small changes in average coastal storm tracks or intensities over time could have significant consequences for the service territory.

Energy planners are increasingly using an approach known as "flexible adaptation pathways" to address uncertainty in future climate hazards and to determine useful timelines for adaptation strategies and investments. A critical component of this model is consistent monitoring of external indicators, such as climate information and observations, asset health, and societal changes. The most recent New York City Panel on Climate Change report endorses a framework through which to view and establish indicators and monitoring strategies relevant to the energy sector in support of flexible adaptation pathways (Blake et al., 2019).

Examples of indicators and signposts for monitoring and assessing precipitation impacts through time could include:

- **Using key existing precipitation thresholds as indicators.** Active monitoring of existing thresholds (e.g., 0.5 inch of rain or 6 inches of snow in 24 hours) can provide a sense of how quickly relevant precipitation indices are increasing relative to current design standards. Con Edison could adopt a standardized format to observe and document precipitation events, their relation to existing thresholds, and concurrent consequences across the territory (e.g., rain event days, substation flooding). In turn, this standardized dataset could be used to determine when adaptation measures may be required. For example, the decision to increase pumping capacity at substations might be prompted by an increase in the number of rain event days above an acceptable threshold (when more than 0.75 inch of rain falls within 3 hours).
- **Updates to extreme precipitation projections.** Projections of extreme precipitation will improve as the research community advances the field of climatology. Improvements may result from more frequent use of dynamically downscaled precipitation projections using Regional Climate Models (RCMs). RCMs are better suited to capture local climatology and weather processes driving downpours, storms, and floods than coarser resolution GCMs. As the research community converges on new projections, findings will be published in periodic peer-reviewed climate assessments, including The New York Panel on Climate Change and National Climate Assessment. Con Edison could consider using new projections to update evaluations of both existing precipitation thresholds and new thresholds established over interim time periods.

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Appendix 3.A: Precipitation Projections

Precipitation projections are based on daily precipitation outputs from a suite of 26 global climate models (GCMs). GCMs divide the globe into grid boxes and represent the climate within those boxes; each grid box typically spans 1 to 2.5 degrees of latitude and longitude (1 degree of latitude or longitude corresponds roughly to a distance of 100 kilometers, or 62 miles).

The Study team selected Representative Concentration Pathways (RCPs) 4.5 and 8.5 as scenarios to be simulated under each GCM. The RCPs, originally developed for use by the Intergovernmental Panel on Climate Change, are a range of scenarios that depict how global greenhouse gas concentrations could evolve over the course of this century based on assumptions about the use of fossil fuels, changes in technology, population growth, and other driving factors. RCP 4.5 represents a moderately warmer future, where radiative forcing contributing to global warming is projected to increase by 4.5 watts per square meter (W/m^2) by 2100. RCP 8.5 represents a much hotter future, where radiative forcing is projected to increase by 8.5 W/m^2 by 2100. The latter scenario represents "business as usual," in which society continues to heavily depend on carbon-intensive fuels and little effort is made to reduce greenhouse gas emissions. To support a risk-based assessment of Con Edison's vulnerability to climate change, the Study drew upon all 26 GCMs for which daily precipitation was available, spanning a large set of possible outcomes.

The following steps were used to calculate daily precipitation projections. First, the Study team extracted the modeled daily precipitation corresponding to LaGuardia Airport, White Plains, and Central Park stations using the nearest land-based grid location covering the station of interest. Next, for each GCM and RCP, a 30-year time slice was created, centered on the beginning of each decade from 2020 to 2080. For each, the Study team calculated the percentage of change in precipitation between each future 30-year time slice and historical baseline reference period (1976–2005) for each percentile bin. Finally, for the RCP 4.5 and RCP 8.5 future projections, the Study team applied the percentage of change for each 30-year time slice to the daily observed precipitation for each percentile bin. Ultimately, these steps provide an ensemble of projected future daily time series (one per each model for each of the two scenarios) from which the precipitation metrics are computed.

The following precipitation metrics were used for analyses in this appendix:

Number of days per year – The number of days per year with daily precipitation that meets or exceeds a specified threshold. The thresholds used in the analysis are 0.75 inch, 1.5 inches, 2 inches, 3 inches, 5 inches, and 6 inches. To calculate this metric, the total number of days over the full time period is divided by the number of years to get the average value. This was computed for the full year (annual) and seasons (DJF, MAM, JJA, and SON).

Daily rainfall – The average amount of rainfall per day on days with precipitation. To calculate this metric, the average of all days with rainfall is taken for the full time period. The result is the average daily precipitation total for the full year for days that have rainfall.

Annual rainfall – The total amount of rainfall in an average year. This is calculated by first finding the annual value for each year in the time period (the sum of all daily precipitation values for that year). Then, the annual average across all years is found (the average of the annual values).

95th percentile – The value of precipitation at the 95th percentile for all days with rainfall. This is found by taking the 95th percentile value of all days with daily rainfall in the full time period.

99th percentile – The value of precipitation at the 99th percentile for all days with rainfall. This is found by taking the 99th percentile value of all days with daily rainfall in the full time period.

3-day period total rainfall – The total amount of precipitation recorded over a 3-day period. For each year, a running total for 3-day precipitation is calculated. The annual maximum of the 3-day totals is found for each year. The average of the maximum 3-day totals for all years in the full time period is presented. This was computed seasonally (DJF, MAM, JJA, and SON).

3-day period maximum total rainfall – The maximum total amount of precipitation over a 3-day period. For each year, a running total for 3-day precipitation is calculated. The annual maximum of the 3-day totals is found for each year. The maximum of the annual maximum 3-day totals for all years in the full time period is found. This was computed seasonally (DJF, MAM, JJA, and SON).

5-day period total rainfall – The total amount of precipitation recorded over a 5-day period. For each year, a running total for 5-day precipitation is calculated. The annual maximum of the 5-day totals is found for each year. The average of the maximum 5-day totals for all years in the full time period is presented. This was computed for the full year (annually).

5-day period maximum total rainfall – The maximum total amount of precipitation over a 5-day period. For each year, a running total for 5-day precipitation is calculated. The annual maximum of the 5-day totals is found for each year. The maximum of the annual maximum 5-day totals for all years in the full time period is found. This was computed for the full year (annually).

The tables below show additional precipitation metrics that support the analyses and conclusions drawn in the main text. The 3-day precipitation changes are shown for both 3-day period total precipitation and 3-day period maximum total precipitation at 2050 and 2080 (see the above explanations for more details). These metrics are calculated seasonally to highlight seasonal variation (Table 12, Table 13, Table 14, and Table 15). In general, 3-day precipitation increases are the same order of magnitude between seasons (~20% by 2080) and are largest in the fall. The tables below also show the number of days per year that meet or exceed various precipitation thresholds at 2050 and 2080. Together, Table 16 and Table 17 reveal increases in heavy precipitation days (e.g., days with more than 1.5 or 3.0 inches), but decreases or smaller increases in light precipitation days (e.g., days with less than 0.75 inch) by both 2050 and 2080. Together, these tables characterize potential precipitation futures in the Con Edison service territory and reveal a future projected to experience more frequent heavy precipitation events and fewer light precipitation and dry days.

Table 12 ■ Projected seasonal 3-day period total precipitation for 2050

2050 Projection	Central Park			LaGuardia Airport			White Plains		
	Baseline	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*
Winter 3-day average maximum precipitation total	2.14 inches	2.16 inches	2.47 inches	1.92 inches	1.94 inches	2.22 inches	2.48 inches	2.51 inches	2.88 inches
Spring 3-day average maximum precipitation total	2.76 inches	2.79 inches	3.21 inches	2.40 inches	2.43 inches	2.79 inches	2.93 inches	2.96 inches	3.40 inches
Summer 3-day average maximum precipitation total	3.21 inches	3.25 inches	3.73 inches	3.14 inches	3.18 inches	3.67 inches	2.97 inches	3.01 inches	3.46 inches
Fall 3-day average maximum precipitation total	3.13 inches	3.16 inches	3.66 inches	2.71 inches	2.74 inches	3.15 inches	3.40 inches	3.44 inches	3.98 inches

Table 13 ■ Projected seasonal 3-day period maximum total precipitation for 2050

2050 Projection	Central Park			LaGuardia Airport			White Plains		
	Baseline	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*
Winter 3-day maximum precipitation total	3.98 inches	4.02 inches	4.66 inches	3.57 inches	3.60 inches	4.19 inches	4.16 inches	4.22 inches	4.86 inches
Spring 3-day maximum precipitation total	5.59 inches	5.68 inches	6.59 inches	5.03 inches	5.08 inches	5.89 inches	6.64 inches	6.72 inches	7.79 inches
Summer 3-day maximum precipitation total	6.20 inches	6.28 inches	7.27 inches	5.61 inches	5.68 inches	6.61 inches	5.50 inches	5.57 inches	6.51 inches
Fall 3-day maximum precipitation total	9.19 inches	9.18 inches	11.09 inches	7.50 inches	7.58 inches	8.79 inches	7.34 inches	7.45 inches	8.66 inches

Table 14 ■ Projected seasonal 3-day period total precipitation for 2080

2080 Projection	Central Park			LaGuardia Airport			White Plains		
	Baseline	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*
Winter 3-day average maximum precipitation total	2.14 inches	2.18 inches	2.59 inches	1.92 inches	1.97 inches	2.33 inches	2.48 inches	2.54 inches	3.00 inches
Spring 3-day average maximum precipitation total	2.76 inches	2.82 inches	3.33 inches	2.40 inches	2.46 inches	2.90 inches	2.93 inches	2.99 inches	3.54 inches
Summer 3-day average maximum precipitation total	3.21 inches	3.28 inches	3.89 inches	3.14 inches	3.21 inches	3.78 inches	2.97 inches	3.04 inches	3.59 inches
Fall 3-day average maximum precipitation total	3.13 inches	3.19 inches	3.78 inches	2.71 inches	2.76 inches	3.28 inches	3.40 inches	3.47 inches	4.11 inches

Table 15 ■ Projected seasonal 3-day period maximum total precipitation for 2080

2080 Projection	Central Park			LaGuardia Airport			White Plains		
	Baseline	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*
Winter 3-day maximum precipitation total	3.98 inches	4.06 inches	4.78 inches	3.57 inches	3.64 inches	4.29 inches	4.16 inches	4.24 inches	5.03 inches
Spring 3-day maximum precipitation total	5.59 inches	5.70 inches	6.78 inches	5.03 inches	5.12 inches	6.14 inches	6.64 inches	6.77 inches	8.06 inches
Summer 3-day maximum precipitation total	6.20 inches	6.32 inches	7.51 inches	5.61 inches	5.73 inches	6.74 inches	5.50 inches	5.62 inches	6.63 inches
Fall 3-day maximum precipitation total	9.19 inches	9.58 inches	11.45 inches	7.50 inches	7.64 inches	9.12 inches	7.34 inches	7.49 inches	8.90 inches

Table 16 ■ Projected number of days per year that meet or exceed precipitation thresholds at 2050

2050 Projection	Central Park			LaGuardia Airport			White Plains		
	Baseline	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*
Annual rainfall days below 0.75 inch	100 days	97 days	100 days	100 days	97 days	100 days	94 days	92 days	95 days
Annual rainfall days at or above 1.5 inches	6 days	6 days	8 days	5 days	5 days	7 days	7 days	7 days	10 days
Annual rainfall days at or above 3 inches	1 day	1 day	2 days	0.6 day	0.7 day	1 day	0.6 day	0.7 day	2 days

Table 17 ■ Projected number of days per year that meet or exceed precipitation thresholds at 2080

2080 Projection	Central Park			LaGuardia Airport			White Plains		
	Baseline	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*	**Baseline**	**Lower Bound** *(RCP 4.5, 10th percentile)*	**Upper Bound** *(RCP 8.5, 90th percentile)*
Annual rainfall days below 0.75 inch	100 days	97 days	100 days	100 days	96 days	100 days	94 days	91 days	95 days
Annual rainfall days at or above 1.5 inches	6 days	6 days	9 days	5 days	5 days	7 days	7 days	7 days	10 days
Annual rainfall days at or above 3 inches	1 day	1 day	2 days	0.6 day	0.7 day	1 day	0.6 day	0.8 day	2 days

APPENDIX 4

Sea Level Rise

1. Introduction

This appendix identifies how changes in sea level may affect operations, planning, and infrastructure across the electric, gas, and steam segments of Con Edison's business. Sea level rise (SLR) will manifest itself as changes in the frequency of tide/nuisance flooding, and as a contributing factor to total water levels (along with storm surge) during storm events. This appendix addresses these impacts while reviewing and building on the work done by the Con Edison Storm Hardening Resiliency Collaborative in response to Superstorm Sandy.[1] Subsequent appendices will address how changes in other storm components (e.g., winds, warming waters leading to an increased frequency in the conditions for hurricanes) affect Con Edison.

As described in the report introduction, the analysis for this appendix involves a decision-first and risk-based approach, applying the best available climate science to produce flexible and adaptive solutions. The process was designed to be transparent and interactive so that it can be replicated and institutionalized. This appendix draws on the most current climate science projections for the Con Edison service territory over near- (2020), intermediate- (2050), and long-term (2080) time horizons.

The work covered by this appendix has three main objectives:

1. Develop an understanding of projected sea level conditions for the Con Edison service territory.
2. Complete a risk assessment of the potential impacts of sea level rise on operations, planning, and infrastructure.
3. Establish a portfolio of effective and cost-efficient measures to improve resilience to sea level rise, with a focus on high-priority assets and relevant processes.

This appendix is organized as follows:

- Section 2 provides an overview of the appendix highlights.
- Section 3 describes Con Edison's response to Superstorm Sandy.
- Section 4 provides an overview of relevant climate information, including historical and future projections.
- Section 5 details priority vulnerabilities to sea level rise and associated adaptation options.
- Section 6 analyzes the costs and benefits of adaptation options under a range of possible futures.
- Section 7 discusses the implementation of adaptation options over time.
- Section 8 provides references for the appendix.
- Appendix 4.A discusses climate information and the Study team's methodology.
- Appendix 4.B provides a glossary of terms used in this appendix.

[1] See Con Edison's Storm Hardening and Resiliency Collaborative Phase Three Report for more information. Available at: http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7B0B9E9CB9-0E0E-434B-91F0-82A58FD77A37%7D

2. Highlights

In this appendix, the Study team focused on Con Edison's vulnerability to sea level rise and identified potential adaptation measures to address its impacts.

Con Edison's Response to Superstorm Sandy

Superstorm Sandy showed that Con Edison's underground coastal electric networks, generating stations, tunnels, and the gas system were all, to some degree, vulnerable when significant flooding occurred. While Con Edison had previously implemented anti-flooding measures, it took immediate hazard mitigation measures in 2013, including updating the company's minimum flood protection design standards to "FEMA plus three feet."[2] The company also developed longer term adaptation measures to implement between 2014 and 2016.

Historical and Future Climate Projections

The Study team analyzed data gathered by the National Oceanic and Atmospheric Administration (NOAA) to assess historical sea level rise. The Study team found that, in Manhattan, the historical relative sea level rise trend from 1856 to 2017 is 2.84 millimeters (mm) per year, with a 95% confidence interval of ± 0.09 mm.

The Study team drew upon recent peer-reviewed decadal sea level rise projections for New York City. Sea level rise is projected to accelerate in the future, compared with historical rates. Under a lower emissions scenario (Representative Concentration Pathway [RCP] 4.5), sea level rise is likely to reach from 0.85 to 1.48 feet, and very likely to reach from 0.62 to 1.74 feet by 2050. Under a high emissions scenario (RCP 8.5), sea level rise is likely to reach from 0.89 to 1.64 feet, and very likely to reach from 0.62 to 1.94 feet by 2050. In the context of these projections, "likely" denotes a 66% probability of occurrence, and "very likely" denotes a 90% probability of occurrence.

Based on these conclusions, the Study team calculated the change in height of future flood return levels in response to sea level rise, as well as the change in frequency of historical return period flood heights. This analysis found that the flood height of the 1% annual chance (100-year) flood increases from 10.9 feet to as much as 15.9 feet under RCP 8.5 by 2100 (an increase of ~50%). The frequency of historically extreme floods is also projected to increase, such that 500-year floods could become 10-year floods and today's annual chance flood could occur at every high tide by the end of the century under RCP 8.5. In the nearer term, today's 10-year flood could occur annually at mid-century.

Priority Design Standard Vulnerabilities for New Infrastructure

Con Edison's current design standard results in infrastructure that will withstand an increase of 1 foot in sea level. Under both RCP 4.5 and RCP 8.5, additional sea level rise may exceed 1 foot as early as 2030 (high-end scenario) or as late as 2080 (RCP 8.5, 5th percentile) to 2090 (RCP 4.5, 5th

[2] This includes the FEMA 1% annual flood hazard elevation, 1 foot for sea level rise, and 2 feet of freeboard (to align with the New York City Building Code for critical infrastructure). The Con Edison flood design basis for generating stations, substations, facility buildings, and service centers is the higher of the FEMA 100-year flood plus 3 feet (FEMA + 3') or Category 2 hurricane storm surge elevation. There are instances where facilities have been designed to a higher standard for highly critical long-life assets.

percentile).[3] In 2050, there is a ~65% (RCP 4.5) to 70% (RCP 8.5) probability that sea level rise will exceed 1 foot.

Priority Physical Vulnerabilities for Existing Infrastructure

To assess Con Edison's physical (asset) vulnerabilities to sea level rise, the Study team mapped FEMA + 5′ (RCP 8.5, 83rd percentile for 2080)[4] to determine assets that would fall into the following categories:

- Asset protection meets or exceeds FEMA + 5′: Prior construction or recent storm hardening exceeds protection for FEMA + 5′
- Asset protection can be upgraded: Existing FEMA + 3′ storm hardening can be modified to meet or exceed FEMA + 5′
- Asset protection requires rebuild: Existing FEMA + 3′ storm hardening must be replaced by new FEMA + 5′ measures because they cannot be extended
- New assets: New assets that would require storm hardening measures

Adaptation Options

The Study team suggests considering the following adaptation options for Con Edison's design standard for future infrastructure:

- Revise design guidelines to consider sea level rise projections and facility useful life (as do the NYC Climate Resiliency Design Guidelines for new projects).
- Continue to build to the higher of the FEMA + 3′ level and the Category 2 storm surge levels at new-build sites, as is current practice. Add sea level rise to the Category 2 maps to account for future changes and a greater flood height/frequency.

The Study team suggests the following adaptation options to address Con Edison's physical vulnerabilities to sea level rise for existing infrastructure:

- Perform coastal monitoring of sea level rise to determine when to act to increase adaptive measures for existing locations.
- Leverage and adjust the existing Con Edison Storm Surge Calculator to plan for impacts from sea level rise and additional storm events in the future.
- Consider how changes in the frequency of smaller flooding events could impact Con Edison assets.
- Leverage new innovations and advancements in flood protections.

Figure 1 shows how Con Edison might implement these measures through a phased approach, with monitoring of storm surge patterns and sea level rise continuously informing updates to the company's Storm Surge Calculator.[5] It also shows how sea level rise and the frequency and impact

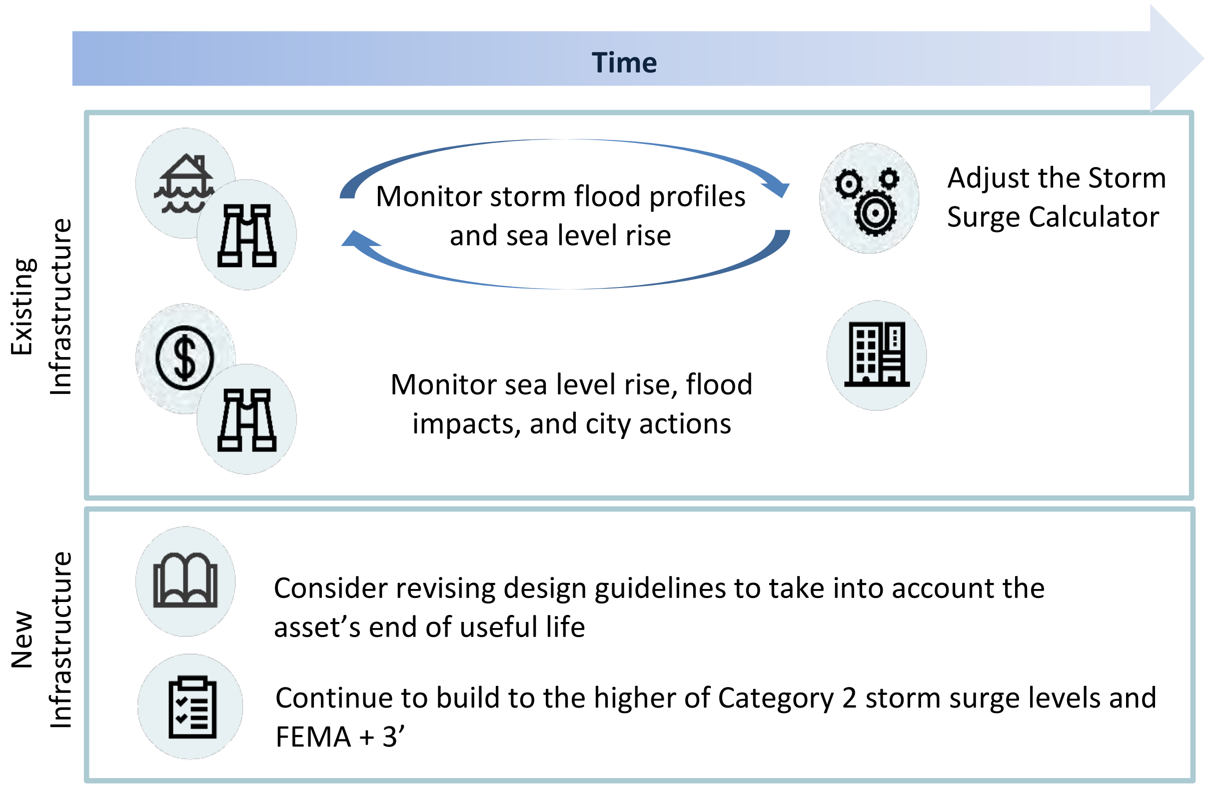
[3] The sea level rise projections in Table 4 use a baseline year of 2000, while the 1 foot of sea level rise in the Con Edison design standard is added to the base water elevation from the 2013 FEMA Flood Insurance Rate Map. For the purposes of this analysis, the two baselines are considered to be equivalent since the sea level rise over the 3 years is minimal.

[4] The FEMA + 5′ RCP 8.5, 83rd percentile scenario corresponds to the upper bound of the likely sea level rise in 2080 (3.08 feet) plus 2 feet of freeboard.

[5] The Storm Surge Calculator is an internal program that determines, for any given storm tide level, the passive (e.g., wall, barrier) or active (e.g., door, sand bags) flood measures that are to be employed for coastal assets.

of smaller flood events can lead to increasing adaptive measures. The design options are suggested to occur in the immediate- to near-term time horizons.

Figure 1 ■ Possible phased implementation of physical and design adaptation measures



Costs and Benefits of Adaptation Options Under a Range of Possible Futures

Con Edison determined in its 2013 Storm Hardening report that planned flood protection measures should meet FEMA + 3′ and not higher due to tradeoffs between the complexity/cost of higher levels and the greater level of protection they afford (Con Edison, 2013a). Current climate modeling performed as part of this study indicates that sea level rise may result in flooding that exceeds the FEMA + 3′ standard between 2030 and 2080 (depending on the emissions scenario and probability of exceedance), which suggests that a monitoring and revise-as-needed approach is the best path forward.

The cost-effectiveness of adaptation options depends, in part, on community planning: Other entities may plan to implement sea level rise adaptation strategies that will afford protection to Con Edison assets, or communities may even retreat from highly vulnerable locations (such that it would be impractical to continue to build there). A range of future possibilities exists, and Con Edison could continue to closely coordinate with the city and other relevant entities (e.g., Westchester) regarding their plans to invest in community-level protection strategies.

Implementation of Adaptation Options Over Time

Given that there remains uncertainty about the rate at which sea levels and flood heights will increase over time, careful monitoring and analysis are required to determine the appropriate points at which to implement adaptation options. The Study team suggests that Con Edison adopt a flexible adaptation pathway approach to contend with this uncertainty. This model relies on consistent monitoring of key external indicators, which can be environmental or societal. There are set thresholds for these indicators: Passing these thresholds triggers the implementation of adaptation measures. The Study team suggests the following as possible indicators for monitoring sea level rise-related concerns and spurring action:

- Updates to design guidelines from New York City
- Sea levels
- Flooding events at existing assets
- Community-scale flood protection strategies

In general, flexible adaptation pathways will consist, as much as possible, of robust adaptation actions that work reasonably well across a wide range of circumstances, both now and in the future. Con Edison has committed to review sea level rise every 5 years, which will help inform these adaptation choices.

3. Con Edison's Response to Superstorm Sandy

In 2012, Superstorm Sandy struck Con Edison's service territory, causing record storm surge levels of 14 feet at the Battery tide gauge in Manhattan (far surpassing the previous record of 10 feet from Hurricane Donna in 1960). In general, storm surge heights experienced during Superstorm Sandy were estimated as a 0.25% annual chance (400-year) event (Lin et al., 2016). The storm severely impacted Con Edison's energy systems, leading to electric service outages to more than 500 customer buildings, steam service outages to around 1 million customers, and gas outages to 4,200 customers (Con Edison, 2015, 2019). The impacts of Superstorm Sandy pointed to unforeseen vulnerabilities in Con Edison's energy system, including underground and overhead electric networks, generating stations, the gas system, and tunnels.

The Storm Hardening and Resiliency Collaborative, brought together to address the impacts of Superstorm Sandy, confirmed that (Con Edison, 2015):

- Underground coastal networks were vulnerable to extreme flood levels from rain and coastal storm surge, particularly in low-lying areas. If extensive flooding occurs, there is the possibility of shock or electrocution, fire, and de-energization.
- Generating stations were vulnerable to extreme flood levels, which can damage the infrastructure and cause shutdowns.
- The gas system was vulnerable to water being introduced into gas distribution equipment, "which can damage pipes, lead to over-pressurization, or result in service interruptions for extended periods" (Con Edison, 2015).
- Tunnels were vulnerable to flooding, in particular, the tunnels containing steam mains, gas mains, and/or high voltage electric feeders that may need to be de-energized for safety.
- In response to these vulnerabilities, Con Edison took immediate hazard mitigation measures in 2013 and developed longer term strategies to implement between 2014 and 2016. These

investments were guided by four principles: (1) protect infrastructure, (2) harden components, (3) mitigate impact, and (4) facilitate restoration.

The company's mitigation measures addressed all system components and included installing submersible equipment to mitigate the impacts of flooding and isolation switches to reduce the impact of disruptions to customers, and building flood protection infrastructure to prevent water from entering the assets.

In 2013, the company also established a flood-resilient design standard for all existing and new infrastructure: the higher of the Category 2 hurricane storm surge elevation or the "FEMA plus three feet" standard. The FEMA + 3′ standard entails the 1% annual flood hazard elevation established by the Federal Emergency Management Agency (FEMA) plus an additional three feet. The additional three feet consists of:

- One foot of sea level rise, which is added to the FEMA 1% annual flood hazard elevation to set a revised base flood elevation (BFE), and
- Two feet of freeboard aligned with the New York City Building Code for critical infrastructure to account for potential uncertainties relating to storm surge elevations.

The components of FEMA's 1% annual flood hazard elevation are graphically illustrated in Figure 2. The components of the Con Edison flood protection design standard are graphically illustrated in Figure 3.

Figure 2 ■ Elements of FEMA's 1% annual flood hazard elevation

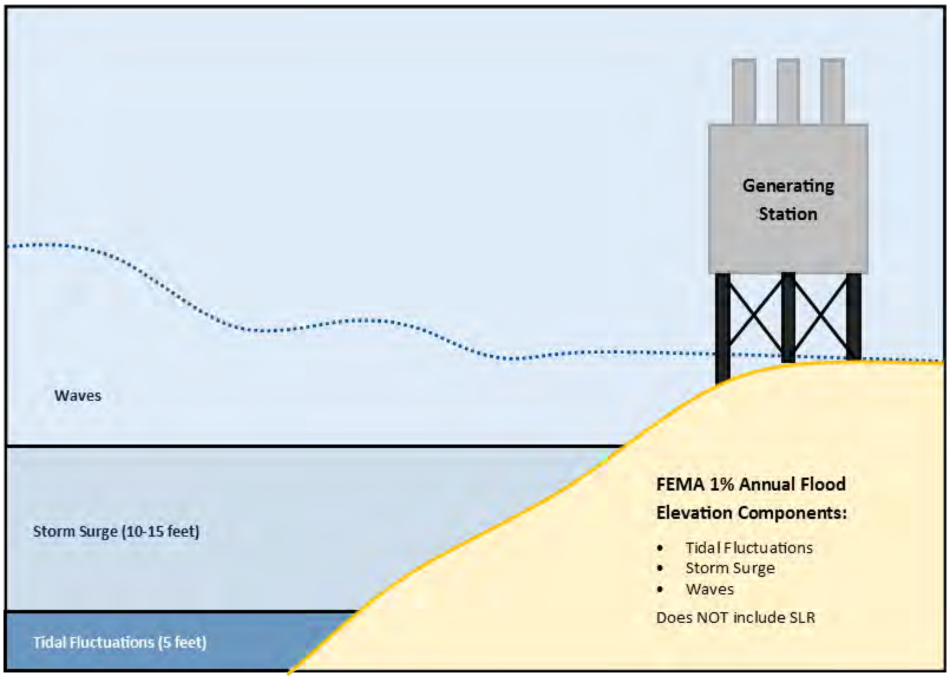
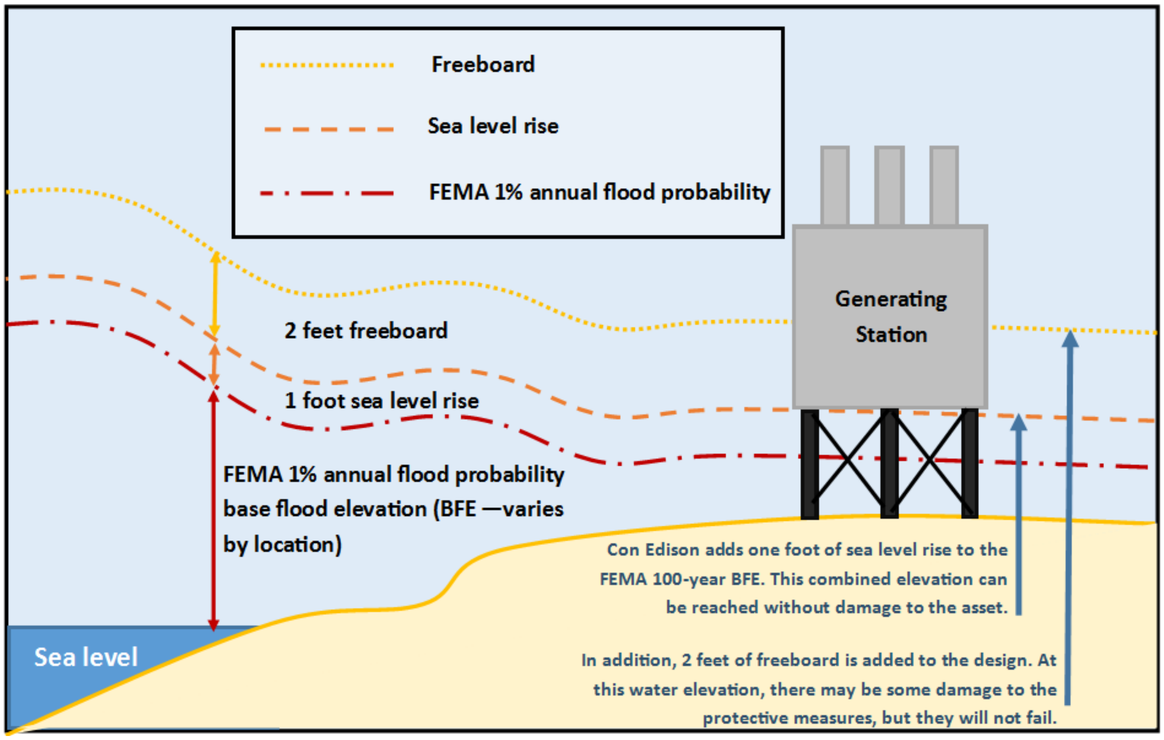


Figure 3 ■ Elements of the Con Edison flood protection design standard



All Con Edison equipment within the FEMA + 3′ flood zone is either designed to be submersible or is protected to that level by a barrier. For example, gas regulators must either have their vent line terminus above the FEMA + 3′ elevation or have a vent line protector installed.[6]

The company designed all storm hardening measures to meet the FEMA + 3′ design standard, except in cases where it determined that it was necessary to exceed this standard (Con Edison, 2015):

- The company is currently relocating the East 13th Street substation control room to a higher floor space, at 3.8 feet above the FEMA + 3′ design level.
- New sheet-pile surge walls around the perimeter of Goethals substation extend beyond the FEMA + 3′ flood control elevation, which protects the station from flooding, as well as groundwater from potential infiltration.

[6] In Westchester, Gas Distribution Engineering is also required to check against the National Weather Service Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model, which models storm surge potential. Areas in Westchester that are not at risk from Category 1 through Category 3 hurricanes are not required to build to the FEMA + 3′ BFE.

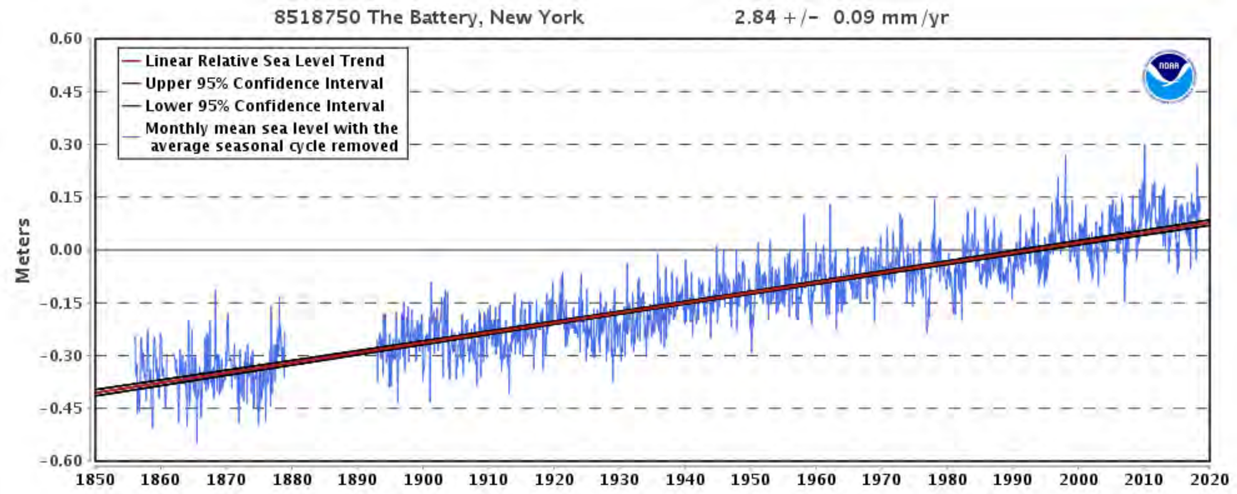
4. Historical and Future Climate Projections

This section presents information on historical and projected climate conditions. Information on system vulnerabilities and adaptation options are presented in sections 5, 6, and 7.

4.1. Historical Changes in Sea Level

Relative sea level in New York City has been increasing over the past century.[7] At the Battery tide gauge in Manhattan, the historical relative sea level rise trend is 2.84 mm/year, with a 95% confidence interval of ± 0.09 mm. This trend is drawn from monthly mean sea level data from 1856 to 2017. The relative sea level trend is equivalent to a change of 0.93 feet (11.2 inches) in 100 years.[8] Figure 4 shows the monthly mean sea level from 1856 to 2017 (except for a gap in available data from 1878 to 1893).[9] The red line shows the long-term linear sea level rise trend.

Figure 4 ■ Relative sea level trend for the Battery tide gauge station in New York City (monthly mean sea level values and the long-term linear trend are shown)[10]



4.2. Sea Level Rise Projections

The Study team drew upon recent peer-reviewed decadal sea level rise projections for New York City. These include the Kopp et al. (2014, 2017) probabilistic projections that account for all contributions[11] to local sea level rise using an underlying methodology established for the New York City Panel on Climate Change (NPCC 2013). The Kopp et al. (2014) projections increasingly appear in city, state, and federal reports; scientific assessments; and guidance documents across the country (e.g., NOAA's report on Global and Regional Sea Level Rise Scenarios for the United

[7] Relative sea level is the height of the sea surface, measured with respect to the height of the underlying land. Relative sea level changes in response to both changes in the height of the sea surface and changes in the height of the underlying land (U.S. GCRP, 2017).

[8] National Oceanic and Atmospheric Administration. Tides & Currents. Relative Sea Level Trend: 8518750 The Battery, New York. Available at: https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8518750

[9] Regular season fluctuations are due to coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents.

[10] NOAA. Tides & Currents. Relative Sea Level Trend: 8518750 The Battery, New York. Available at: https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8518750

[11] Local contributions to sea level rise include the static-equilibrium fingerprint effects of land ice mass changes, land water storage, Global Climate Model projections of atmosphere/ocean dynamics, and tide gauge-based estimates of non-climatic contributors to sea level change, such as glacial isostatic adjustment (Kopp et al., 2014; Kopp et al., 2017).

States,[12] Climate Science Special Report: Fourth National Climate Assessment, Volume I[13]), and align with similar regional studies (Horton et al., 2015). The Kopp et al. (2017) projections supplement Kopp et al. (2014) to account for the potential for significantly higher upper-end projections for Antarctic ice-sheet melt, which increase both global and regional sea level rise above most previously assumed upper limits (DeConto & Pollard, 2016). The Study team employed Kopp et al. (2014) projections and a separate high-end scenario using the upper-end estimates from Kopp et al. (2017) for rapid ice-sheet melt. See Appendix 4.A – Climate Information, for further discussion of this research.

Table 1 provides projections and associated likelihood percentiles for every 21st century decade and for two emissions scenarios (RCPs 4.5 [low emissions scenario] and 8.5 [high emissions scenario]). The earliest likely exceedances of 1 foot are shown in bold.

Table 1 ■ SLR projections for each decade, under RCPs 4.5 and 8.5

RCP	Year	SLR Under Various Percentiles (feet)					High-End Scenario[14]
		5th	17th	50th	83rd	95th	
RCP 4.5	2010	0.10	0.13	0.20	0.30	0.33	0.36
	2020	0.23	0.30	0.43	0.52	0.62	0.69
	2030	0.36	0.49	0.66	0.82	0.95	**1.08**
	2040	0.52	0.69	0.92	**1.15**	**1.31**	1.51
	2050	0.62	0.85	**1.18**	1.48	1.74	2.00
	2060	0.75	**1.05**	1.44	1.87	2.20	2.62
	2070	0.85	1.21	1.74	2.26	2.69	3.31
	2080	0.95	1.38	1.97	2.62	3.12	4.13
	2090	**1.05**	1.51	2.23	2.98	3.58	5.12
	2100	1.15	1.67	2.46	3.31	4.03	6.13
RCP 8.5	2010	0.03	0.10	0.23	0.33	0.39	0.39
	2020	0.07	0.23	0.43	0.66	0.82	0.82
	2030	0.23	0.43	0.69	0.95	**1.15**	**1.18**
	2040	0.43	0.62	0.95	**1.25**	1.51	1.61
	2050	0.62	0.89	**1.25**	1.64	1.94	2.20
	2060	0.79	**1.12**	1.61	2.10	2.46	3.05
	2070	0.95	1.38	1.97	2.56	3.02	4.26
	2080	**1.15**	1.64	2.36	3.08	3.67	5.77
	2090	1.31	1.90	2.76	3.67	4.36	7.54
	2100	1.44	2.13	3.15	4.23	5.05	9.38

Figure 5 and Figure 6 illustrate both historical and projected sea level rise in New York City under RCP 4.5 and RCP 8.5, respectively. Under RCP 4.5, by 2050, sea level rise is likely[15] to be from 0.85 to

[12] NOAA. 2017. Global and Regional Sea Level Rise Scenarios for the United States. NOAA Technical Report NOS CO-OPS 083. Available at: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20180001857.pdf

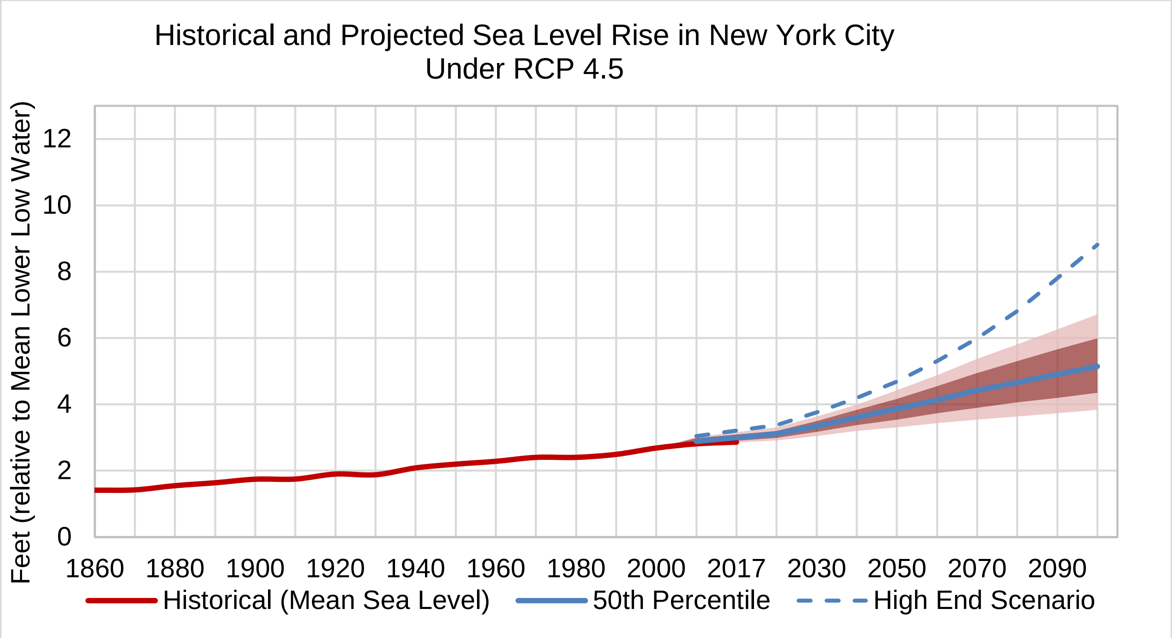
[13] U.S. GCRP. 2017. Climate Science Special Report: Fourth National Climate Assessment, Volume I [D. J. Wuebbles, D. W. Fahey, K. A. Hibbard, D. J. Dokken, B. C. Stewart, & T. K. Maycock (Eds.)]. Washington, DC.

[14] The high-end projection represents a rapid ice-melt scenario.

[15] According to the Intergovernmental Panel on Climate Change, "likely" means that there is statistically a 66% probability of occurrence. The likely range of sea level rise values is drawn from the central part of the model ensemble distribution, or

1.48 feet, and very likely[16] to be from 0.62 to 1.74 feet. Under RCP 8.5, sea level rise is likely to be from 0.89 to 1.64 feet, and very likely to be from 0.62 to 1.94 feet by 2050.

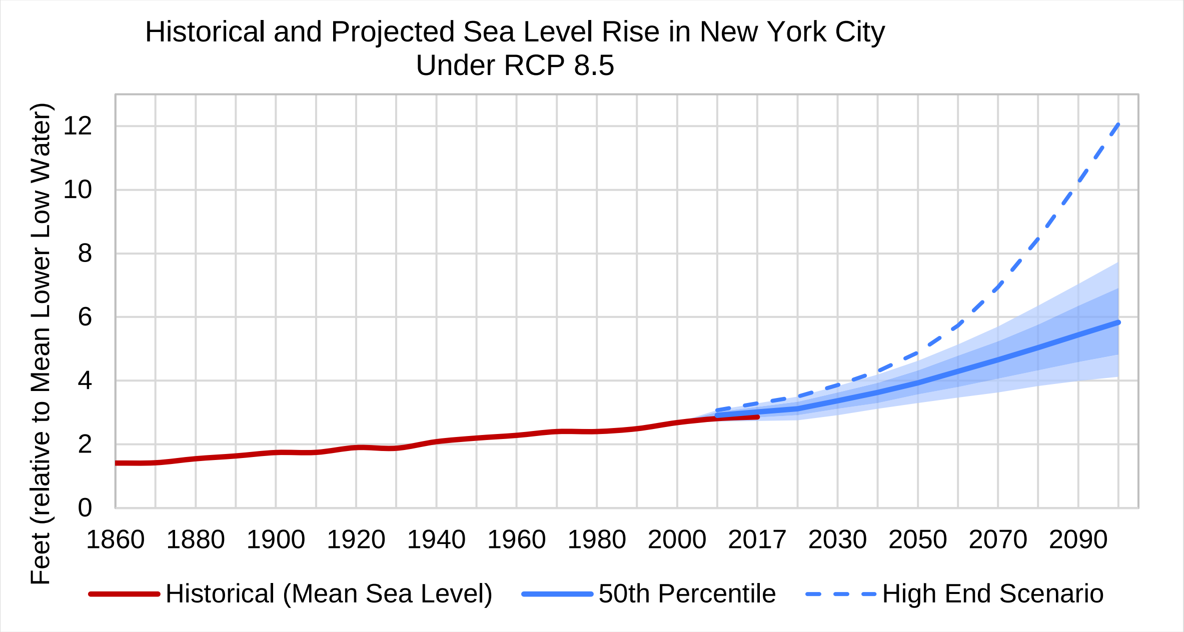
Figure 5 ■ Historical and projected sea level rise in New York City under RCP 4.5. The red line shows historical mean sea level at the Battery tide gauge relative to the Battery Mean Lower Low Water datum. Projected sea level rise beginning in 2010 is added to the historical sea level values (from the 2000 baseline). The solid blue line shows the 50th percentile of projected sea level rise. The darker shaded area shows the likely range (17th to 83rd percentiles), while the lighter shaded area shows the very likely range (5th to 95th percentiles). The blue dashed line depicts a high-end projected scenario (under rapid ice melt).



values between the 17th and the 83rd percentiles. Probability is measured on a scale from 0 to 100. A 66% probability of occurrence means that there is a 34% chance of nonoccurrence.

[16] The very likely range can be described as values between the 5th and 95th percentiles. "Very likely" means that there is a 90% probability of occurrence and a 10% chance of nonoccurrence.

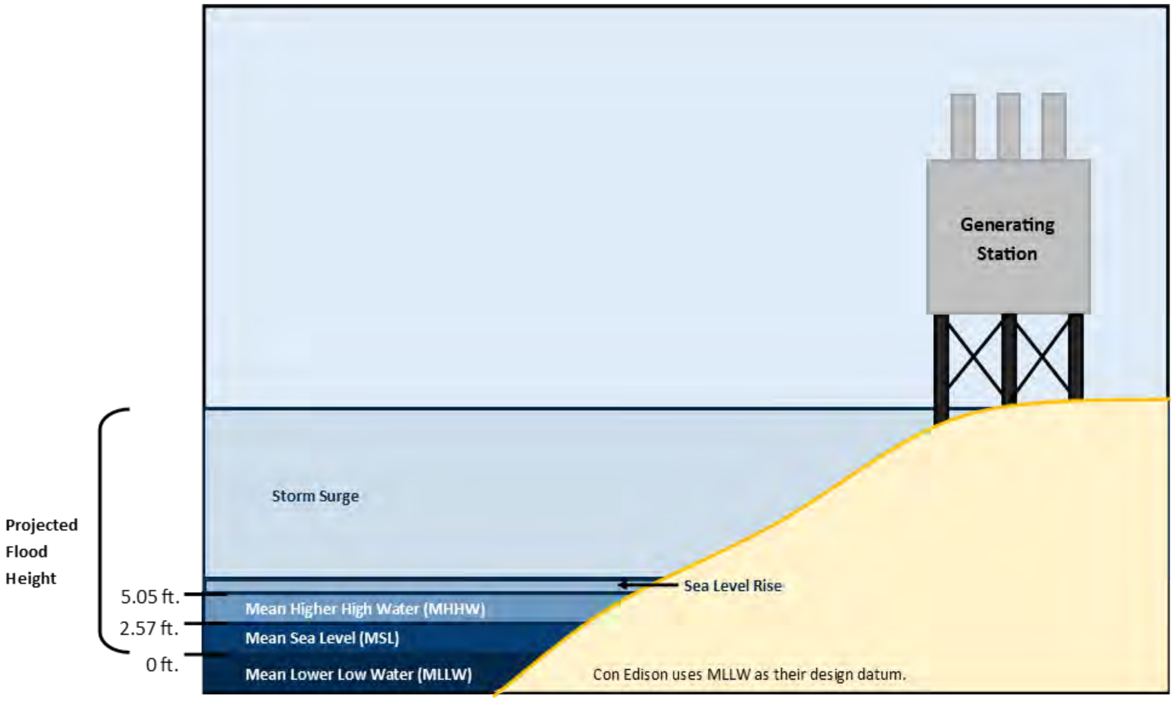
Figure 6 ■ Historical and projected sea level rise in New York City under RCP 8.5. The red line shows the historical mean sea level at the Battery tide gage relative to the Battery Mean Lower Low Water datum. Projected sea level rise beginning in 2010 is added to the historical sea level values (from the 2000 baseline). The solid purple line shows the 50th percentile of projected sea level rise. The darker shaded area shows the likely range (17th to 83rd percentiles), while the lighter shaded area shows the very likely range (5th to 95th percentiles). The purple dashed line depicts a high-end projected scenario (under rapid ice melt).



4.3. Coastal Flood Heights and Frequencies

Rising sea levels increase the frequency of *all types* of flood events, from extreme to nuisance, which may create operational challenges for Con Edison. Understanding not just the increased elevation of water levels, but also the change in their frequency is important for effective adaptation. Coastal flood heights are driven by both local mean sea level and storm tide. Con Edison's future flood height analysis is composed of sea level rise, tide (e.g., mean lower low water, mean higher high water), and storm surge (Figure 7).

Figure 7 ■ Illustration of the components of Con Edison's projected flood height (storm surge, sea level rise, and tides above mean lower low water)



The Study team used a combination of Kopp et al. (2014) distributions of relative sea level change with the observational record of storm tide from the Battery tide gauge[17] in New York City. To describe future coastal flood heights and frequencies, the Study team calculated two flood risk metrics:

1. The changes in height of future flood levels in response to sea level rise (i.e., How does the elevation of a historical 1% annual chance flood event changes in the future as a result of sea level rise?), and
2. The change in frequency of historical return period flood heights (i.e., What is the future return period of the water levels associated with a historical 1% annual chance event?)

Change in Height of Future Flood Levels

Table 2 illustrates projected flood heights of the current monthly, annual, 10% annual chance (10-year), 1% annual chance (100-year), and 0.2% annual chance (500-year) flood events for every 21st century decade and for two emissions scenarios (RCPs 4.5 and 8.5).[18] Flood heights are associated with the *likely range* and a high-end projection of sea level rise that considers a rapid ice melt scenario under each RCP.

As shown in Table 2, the flood height of the 1% annual chance (100-year) flood increases from 10.9 feet to as much as 15.9 feet under RCP 8.5 by 2100 (an increase of ~50%). Figure 8 depicts how the heights of historical flood return intervals are expected to change in the future.

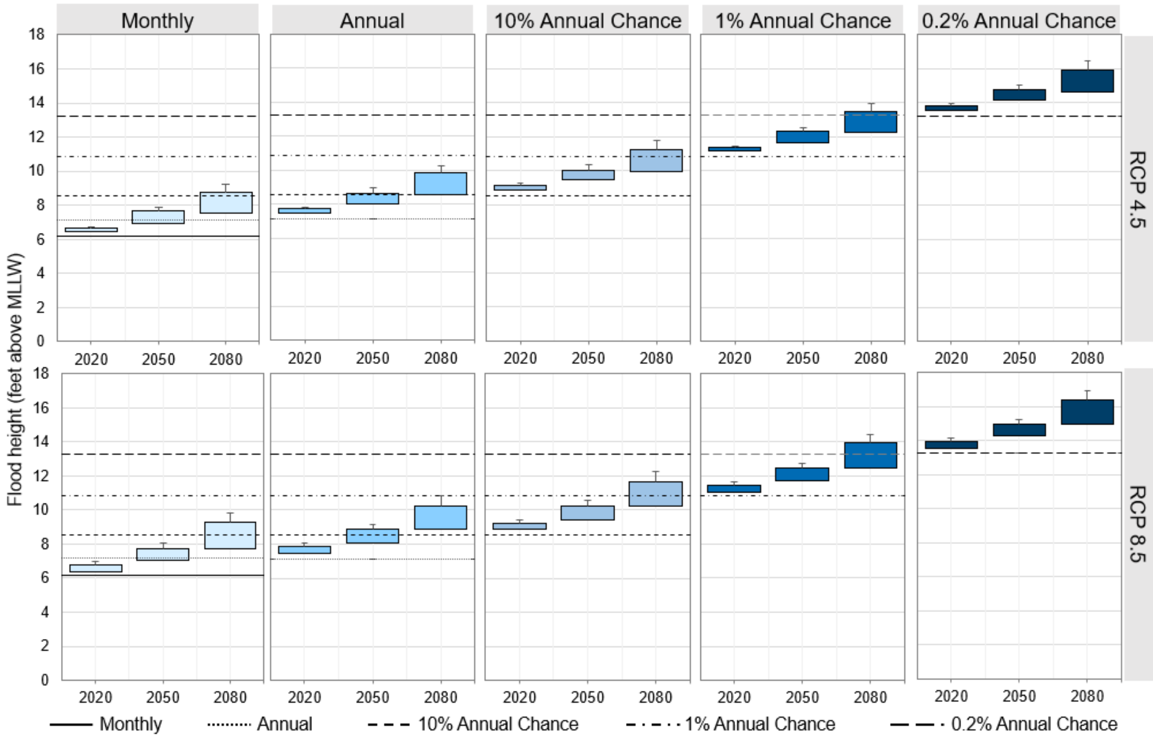
[17] The Battery, NY, Tide Gauge: Station ID 8518750. Available at: https://tidesandcurrents.noaa.gov/stationhome.html?id=8518750
[18] Flood heights do not account for wave crest.

Table 2 ■ Projected flood heights for each decade, under RCPs 4.5 and 8.5[19]

RCP	Year	Flood Heights (feet) Under the Likely Range (17th–83rd percentiles) and High-End Scenario of SLR (shown in parentheses)				
		Monthly	Annual	10% Annual Chance	1% Annual Chance	0.2% Annual Chance
Historical	2000	6.2	7.2	8.6	10.9	13.3
RCP 4.5	2020	6.5–6.7 (6.8)	7.5–7.8 (7.9)	8.9–9.2 (9.3)	11.2–11.4 (11.5)	13.6–13.9 (14.0)
	2030	6.7–7.0 (7.1)	7.7–8.1 (8.2)	9.1–9.5 (9.6)	11.4–11.7 (11.8)	13.8–14.2 (14.3)
	2040	6.9–7.3 (7.5)	7.9–8.4 (8.5)	9.3–9.8 (10.0)	11.6–12.0 (12.2)	14.0–14.5 (14.6)
	2050	7.0–7.7 (7.9)	8.1–8.7 (9.0)	9.5–10.1 (10.4)	11.7–12.4 (12.6)	14.2–14.8 (15.1)
	2060	7.2–8.1 (8.4)	8.3–9.1 (9.4)	9.7–10.5 (10.8)	12.0–12.8 (13.1)	14.4–15.2 (15.6)
	2070	7.4–8.4 (8.9)	8.4–9.5 (9.9)	9.9–10.9 (11.3)	12.1–13.2 (13.6)	14.6–15.6 (16.1)
	2080	7.6–8.8 (9.3)	8.6–9.9 (10.3)	10.0–11.3 (11.8)	12.3–13.5 (14.0)	14.7–16.0 (16.5)
	2090	7.7–9.2 (9.8)	8.7–10.2 (10.8)	10.2–11.6 (12.2)	12.4–13.9 (14.5)	14.8–16.3 (16.9)
	2100	7.9–9.5 (10.2)	8.9–10.5 (11.3)	10.3–12.0 (12.7)	12.6–14.2 (14.9)	15.0–16.7 (17.4)
RCP 8.5	2020	6.4–6.8 (7.0)	7.5–7.9 (8.1)	8.9–9.3 (9.5)	11.1–11.5 (11.7)	13.6–14.0 (14.2)
	2030	6.6–7.1 (7.3)	7.7–8.2 (8.4)	9.1–9.6 (9.8)	11.3–11.9 (12.1)	13.8–14.3 (14.5)
	2040	6.8–7.4 (7.7)	7.9–8.5 (8.7)	9.3–9.9 (10.2)	11.5–12.1 (12.4)	14.0–14.6 (14.8)
	2050	7.1–7.8 (8.1)	8.1–8.9 (9.2)	9.5–10.3 (10.6)	11.8–12.5 (12.8)	14.3–15.0 (15.3)
	2060	7.3–8.3 (8.6)	8.3–9.3 (9.7)	9.8–10.7 (11.1)	12.0–13.0 (13.4)	14.5–15.5 (15.8)
	2070	7.6–8.7 (9.2)	8.6–9.8 (10.3)	10.0–11.2 (11.7)	12.3–13.5 (13.9)	14.7–15.9 (16.4)
	2080	7.8–9.3 (9.9)	8.9–10.3 (10.8)	10.3–11.7 (12.3)	12.5–14.0 (14.5)	15.0–16.4 (17.0)
	2090	8.1–9.9 (10.5)	9.1–10.9 (11.6)	10.5–12.3 (13.0)	12.8–14.5 (15.2)	15.2–17.0 (17.7)
	2100	8.3–10.4 (11.2)	9.4–11.5 (12.3)	10.8–12.9 (13.7)	13.0–15.1 (15.9)	15.5–17.6 (18.4)

[19] Values are above the mean lower low water (MLLW) datum at the Battery tide gauge. MLLW is measured as 2.57 feet below mean sea level. Available at: https://tidesandcurrents.noaa.gov/datums.html?id=8518750

Figure 8 ■ Projected changes in the elevation of flood heights of various return periods



New York City (Battery tide gauge), using the 17th and 83rd percentiles (the likely range) as well as the high end scenario of sea level rise. The black lines show historical flood heights.

Change in Frequency of Historical Return Period Flood Heights

The study team calculated the projected flood frequencies for flood heights of various historical return periods. Table 3 and Figure 10 illustrate projected future frequencies of the historical *monthly, annual, 10% annual chance (10-year), 1% annual chance (100-year), and 0.2% annual chance (500-year) flood event heights for* every 21st century decade and for two emissions scenarios (RCPs 4.5 and 8.5). Flood heights are associated with the *likely range* and a high-end rapid ice-sheet melt scenario under each RCP.

Under the high-end scenario, today's 0.2% annual chance (500-year) flood could look like a 10% annual chance (10-year) flood in 2100, making it 50 times more likely. At the end of the century, today's annual chance flood could occur at every high tide. In the nearer term, today's 10% annual chance flood could occur annually at mid-century, and today's 1% annual chance flood could become a 10% annual chance flood in 2060. Figure 9 depicts these projected changes in flood frequencies (plotted points) and illustrative trajectories of flood frequency and associated flood heights (solid lines).

Figure 9 ■ Projected changes in frequencies of historical flood heights. Plotted points represent projected changes in frequency; solid lines represent illustrative trajectories of flood frequency and associated flood heights.

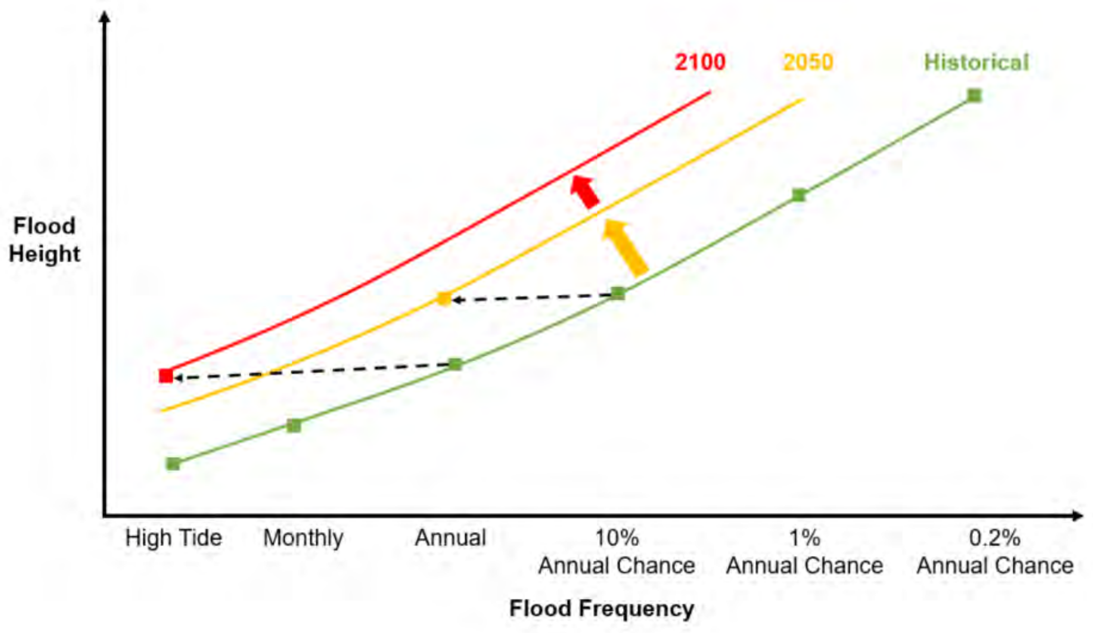
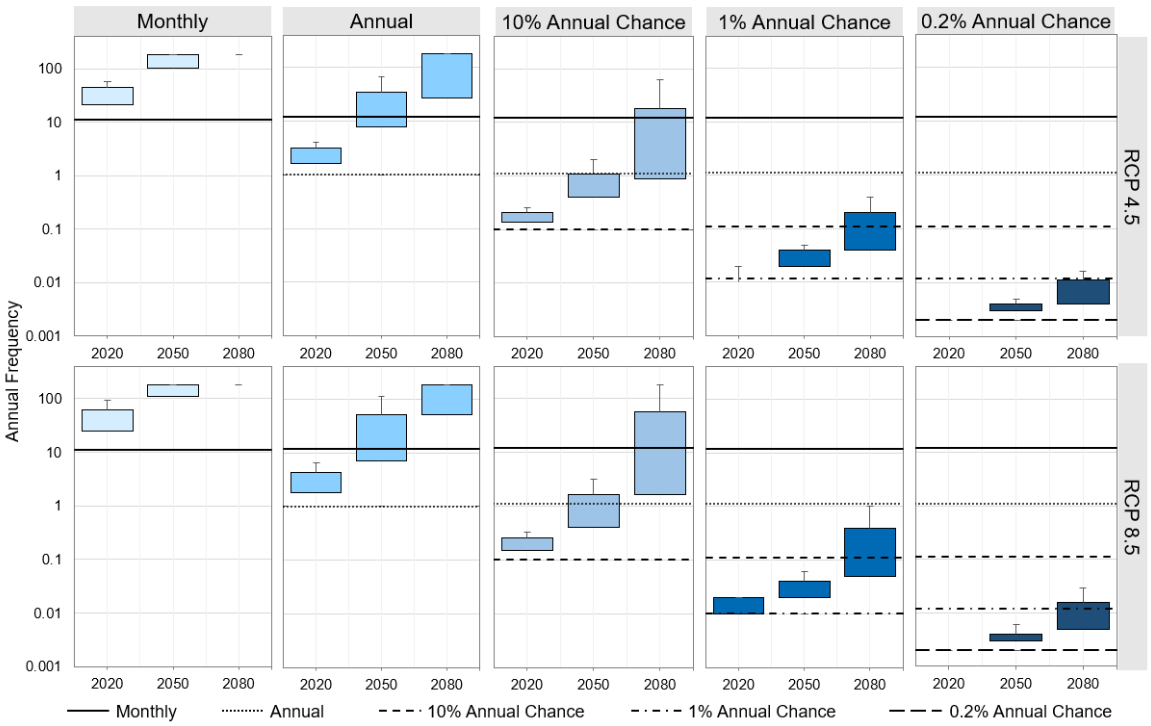


Table 3 ■ Frequencies of historical flood heights for each decade, under RCPs 4.5 and 8.5

RCP	Year	Expected Number of Events per Year Under the Likely Range (17th–83rd percentiles) and High-End Scenario of SLR (shown in parentheses)				
		Monthly	Annual	10% Annual Chance	1% Annual Chance	0.2% Annual Chance
Historical	2000	12	1	0.1	0.01	0.002
RCP 4.5	2020	21–45 (57)	1.6–3.1 (4)	0.14–0.21 (0.25)	0.01–0.01 (0.02)	0.002–0.002 (0.002)
	2030	34.6–94 (131)	2.4–6.6 (9.2)	0.2–0.3 (0.4)	0.01–0.02 (0.02)	0.002–0.002 (0.003)
	2040	57 to *	4–15.1 (22.9)	0.2–0.6 (0.8)	0.02–0.03 (0.03)	0.002–0.004 (0.004)
	2050	102 to *	7.8–34.6 (67.3)	0.4–1.1 (2)	0.02–0.04 (0.05)	0.003–0.004 (0.005)
	2060	168 to *	11.8–93.9 (*)	0.5–2.6 (6)	0.02–0.06 (0.09)	0.003–0.006 (0.007)
	2070	*	17.8 to *	0.7–7 (21)	0.03–0.1 (0.2)	0.003–0.007 (0.01)
	2080	*	27 to *	0.9–18 (62)	0.04–0.2 (0.4)	0.004–0.011 (0.016)
	2090	*	37.6 to *	1.2–44.4 (*)	0.04–0.3 (0.9)	0.004–0.015 (0.026)
	2100	*	57 to *	1.7–102 (*)	< 7	< 0.04
RCP 8.5	2020	25–62 (94)	1.8–4.3 (6.6)	0.15–0.26 (0.33)	0.01–0.02 (0.02)	0.002–0.002 (0.002)
	2030	41–131 (*)	2.9–9.2 (15.1)	0.2–0.4 (0.6)	0.01–0.02 (0.03)	0.002–0.003 (0.003)
	2040	67 to *	4.7–19.3 (37.6)	0.3–0.7 (1.2)	0.02–0.03 (0.04)	0.002–0.004 (0.004)
	2050	110 to *	7.1–52.5 (110.9)	0.4–1.6 (3.1)	0.02–0.04 (0.06)	0.003–0.004 (0.006)
	2060	*	13.9–168.1 (*)	0.6–4.7 (11.8)	0.03–0.08 (0.13)	0.003–0.006 (0.009)
	2070	*	26.7 to *	0.9–15.1 (48)	0.03–0.2 (0.3)	0.003–0.009 (0.014)
	2080	*	52.5 to *	1.6–57 (*)	0.05–0.4 (1)	0.005–0.016 (0.029)
	2090	*	102 to *	2.9 to *	0.06–1 (5)	0.006–0.029 (0.066)
	2100	*	*	5.1 to *	< 18	< 0.16

* Indicates that a flood event may occur every other day, or more than 182.5 times per year.

Figure 10 ■ Projected change in frequency of historical flood heights under RCPs 4.5 and 8.5



New York City (Battery tide gauge), using the 17th and 83rd percentiles (the likely range) as well as the high end scenario of sea level rise. The black lines show historical frequencies.

5. Priority Vulnerabilities and Adaptation Options

This section provides an in-depth review of the vulnerability of Con Edison's assets and operations/planning practices to sea level rise and related variables. The assessment of vulnerabilities is broken down into the following sections:

- **Design Standards for New Infrastructure:** Assessment of the general robustness of Con Edison's current flood-related design standards to projected future sea level rise.
- **Physical Vulnerabilities of Existing Infrastructure:** Assessment of the specific vulnerabilities of Con Edison's existing assets to future sea level rise impacts.

After discussing the vulnerabilities of these design standards and assets to sea level rise-related variables, the Study team proposed adaptation strategies to address these various concerns.

5.1. Design Standards and Adaptation Options

As discussed in Section 3, Con Edison's current design standard for flood protections includes 1 foot of sea level rise. The Study Team used available sea level rise information to project when this sea level rise risk tolerance may be exceeded. Under both RCP 4.5 and RCP 8.5, sea level rise may exceed 1 foot as early as 2030 (high-end scenario) and as late as 2080 (RCP 8.5, 5th percentile) to 2090 (RCP 4.5, 5th percentile).[20] The 50th percentile projections indicate that sea level rise may

[20] The sea level rise projections in Table 4 use a baseline year of 2000, while the 1-foot of sea level rise in the Con Edison design standard is added to the base water elevation from the 2013 FEMA Flood Insurance Rate Map. For the purposes of this analysis, the two baselines are considered to be equivalent since the sea level rise over the 3 years is minimal.

exceed 1 foot by 2050 under both RCPs 4.5 and 8.5. Table 4 provides projected sea level rise values above 1 foot, with bolded values indicating the first exceedance under each percentile.

Table 4 ■ Projected sea level rise values exceeding Con Edison's established risk tolerance of 1 foot of sea level rise. Bolded values indicate the first occurrence of 1 foot or more of sea level rise under each percentile.

RCP	Year	SLR Under Various Percentiles (feet)					High-End Scenario[21]
		5th	17th	50th	83rd	95th	
RCP 4.5	2030						**1.08**
	2040				**1.15**	**1.31**	1.51
	2050			**1.18**	1.48	1.74	2.00
	2060		**1.05**	1.44	1.87	2.20	2.62
	2070		1.21	1.74	2.26	2.69	3.31
	2080		1.38	1.97	2.62	3.12	4.13
	2090	**1.05**	1.51	2.23	2.98	3.58	5.12
	2100	1.15	1.67	2.46	3.31	4.03	6.13
RCP 8.5	2030				**0.95**	**1.15**	**1.18**
	2040				1.25	1.51	1.61
	2050			**1.25**	1.64	1.94	2.20
	2060		**1.12**	1.61	2.10	2.46	3.05
	2070	**0.95**	1.38	1.97	2.56	3.02	4.26
	2080	1.15	1.64	2.36	3.08	3.67	5.77
	2090	1.31	1.90	2.76	3.67	4.36	7.54
	2100	1.44	2.13	3.15	4.23	5.05	9.38

Figure 11 and Figure 12 depict the range of sea level rise projections through the end of the century at the Battery for RCP 4.5 and RCP 8.5. The dashed black line represents the 1-foot threshold within the design standard to account for sea level rise. The graphs show that the 1-foot sea level rise threshold may be exceeded as early as 2030 or as late as 2080.

[21] The high-end projection represents a rapid ice melt scenario.

Figure 11 ■ Projected sea level rise (RCP 4.5) relative to 2000 under various percentiles. The black dashed line depicts the 1-foot sea level rise threshold from the current design standard.

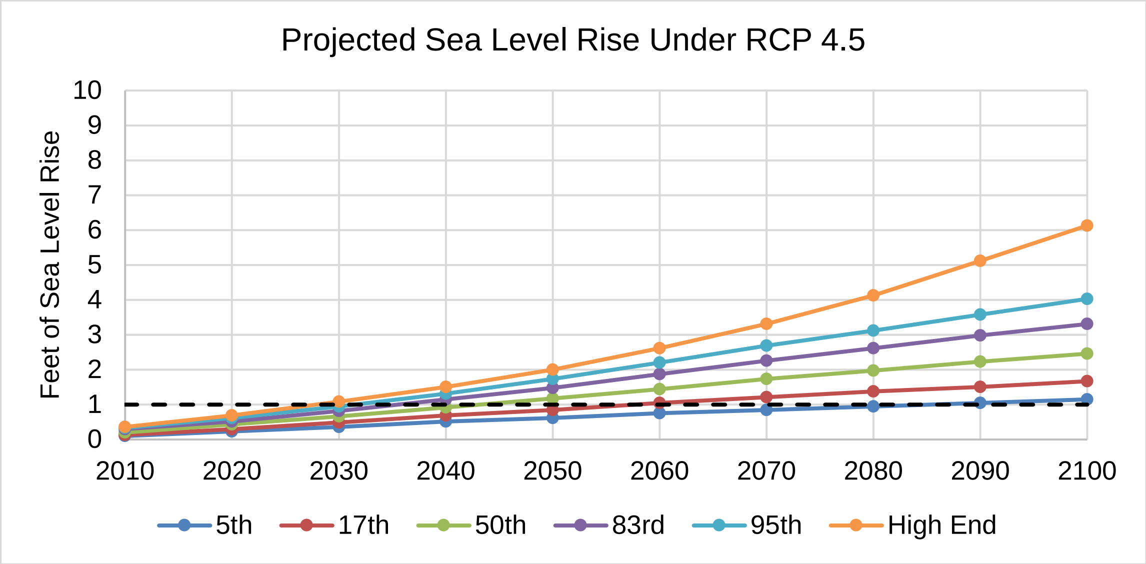


Figure 12 ■ Projected sea level rise (RCP 8.5) relative to 2000 under various percentiles. The black dashed line depicts the 1-foot sea level rise threshold from the current design standard.

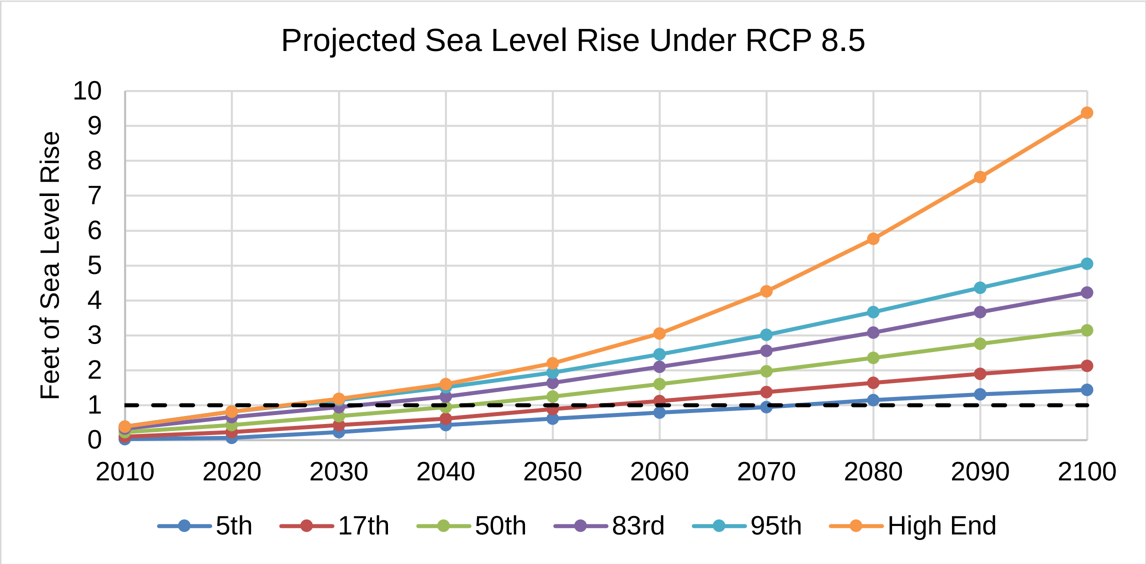
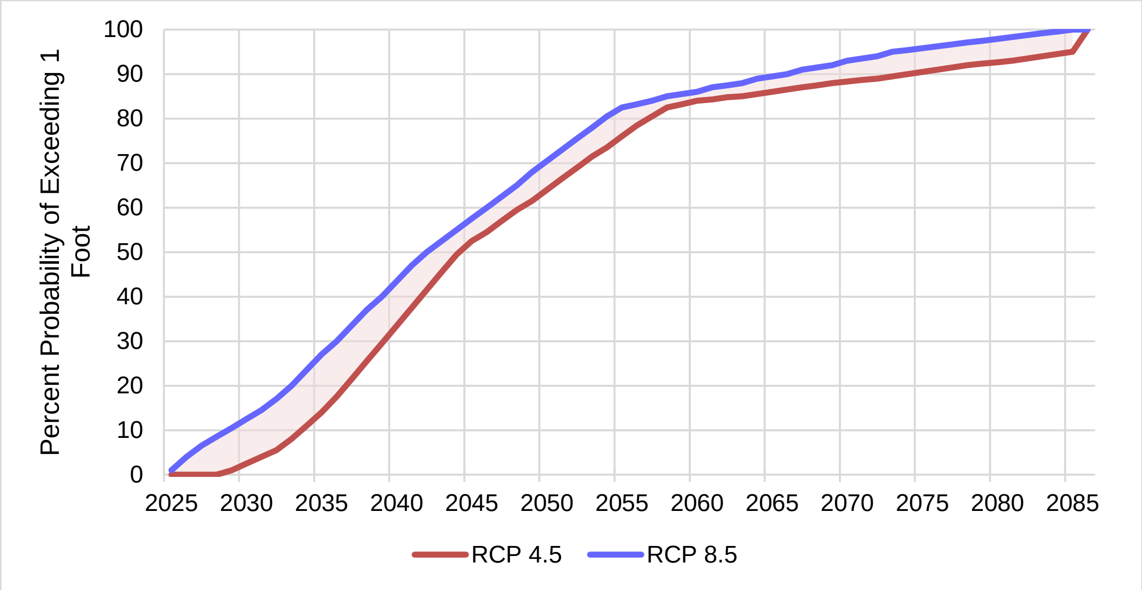


Figure 13 depicts the percent probability of exceeding 1 foot of sea level rise[22] through time under RCP 4.5 and RCP 8.5. The graph shows that 1 foot of sea level rise will be exceeded as early as the 2020s (< 10% probability) or as late as the 2080s (100% probability). In 2050, there is a ~65% (RCP 4.5) to 70% (RCP 8.5) probability that 1 foot of sea level rise will be exceeded.

[22] The baseline sea level rise projections begin in 2000. Sea levels at the Battery have increased approximately 2 inches since that time.

Figure 13 ■ Percent probability of exceeding 1 foot of sea level rise



Adaptation Strategies

Revise design guidelines to consider sea level rise projections and facility useful life. Given that Con Edison's existing sea level rise risk tolerance will be exceeded sometime between 2030 and 2080, updating design standards to increase the resilience of newly built infrastructure could help avoid adverse impacts associated with sea level rise. Beyond Con Edison, New York City is also considering options for increasing the resilience of built infrastructure. In April 2018, the New York City Mayor's Office of Resiliency published a set of Climate Resiliency Design Guidelines, which provide specific guidance on flood protection standards for critical infrastructure (New York City Mayor's Office of Resiliency, 2018). Con Edison's standards pre-date New York City's Design Guidelines.

Under these new guidelines, a facility's recommended flood elevation is a product of the facility's useful life and projected sea levels associated with that timeframe. This approach is similar to Con Edison's current FEMA +3' approach in that it begins with the FEMA annual 1% flood hazard elevation, but adds either 2 feet of freeboard for critical facilities or 1 foot for non-critical facilities and then an adjustment for future sea level rise. This is in contrast to Con Edison's current approach of adding 1 foot of sea level rise and 2 feet of freeboard across the board. In addition, the city's guidelines recommend that the standard depicted in Table 5 be based on the asset's anticipated useful life. Therefore, according to the city's guidelines, the lowest sea level rise adjustment is at 6 inches; this is for assets with an end of useful life through 2039. Con Edison's current sea level rise adjustments begin at 12 inches, which is higher than that of the city's design guidelines because Con Edison's adjustment was based on a timeframe closer to mid-century.

For assets with useful lives beyond 2040, the city's guidelines recommend a greater than FEMA + 3' elevation, going all the way up to FEMA + 5' for assets expected to last beyond 2100. These levels are based on the median sea level rise values from projections selected by the New York City Panel on Climate Change (NPCC).[23] The scaling of design flood elevation (DFE) based on useful life has

[23] Appendix 4.A provides information on the differences between Con Edison's sea level rise projections and those prepared by NPCC.

the advantage of providing a higher standard of protection for assets more likely to need it, without imposing unnecessary costs on shorter lived assets. These NYC Climate Resiliency Design Guidelines are consistent with Con Edison's existing sea level rise risk tolerance, which might be exceeded sometime between 2030 and 2080.

For assets with useful lives through 2039, the city's guidelines recommend a design flood elevation less than FEMA + 3′, meaning that such assets are already protected under Con Edison's current standard. Thus, the Study team suggests that Con Edison consider revising the design guidelines to include a range of seal level rise adjustments based on an asset's projected end of useful life.

Table 5 Recommended Design Flood Elevation (DFE) Calculation Table from the NYC Climate Resiliency Design Guidelines

Critical Facilities				
End of Useful Life	**Base Flood Elevation**	**+ Freeboard**	**+ Sea Level Rise Adjustment**	**= Design Flood Elevation**
Through 2039	FEMA 1%	24"	6"	FEMA 1% + 30"
2040–2069	**FEMA 1%**	**24"**	**16"**	**FEMA 1% + 40"**
2070–2099	FEMA 1%	24"	28"	FEMA 1% + 52"
2100+	FEMA 1%	24"	36"	FEMA 1% + 60"
Non-Critical Facilities				
End of Useful Life	**Base Flood Elevation**	**+ Freeboard**	**+ Sea Level Rise Adjustment**	**= Design Flood Elevation**
Through 2039	FEMA 1%	12"	6"	FEMA 1% + 18"
2040–2069	FEMA 1%	12"	16"	FEMA 1% + 28"
2070–2099	**FEMA 1%**	**12"**	**28"**	**FEMA 1% + 40"**
2100+	FEMA 1%	12"	36"	FEMA 1% + 48"

The recommendation to incorporate sea level rise projections and facility useful life into design standards is limited to new projects and significant rehabilitation/retrofit projects. As discussed in detail in Section 6, Con Edison previously performed an analysis to determine that implementing higher flood protection design standards across the board for existing assets is not financially feasible at this time, especially given the uncertainty in the rate of sea level rise. Section 6 contains a discussion of potential adaptation options for existing at-risk assets.

Continue to build to the higher of the FEMA + 3′ level and the Category 2 storm surge levels at new-build sites, as is current practice. Add sea level rise to the Category 2 maps to account for future changes and a greater flood height/frequency. When developing new sites, Con Edison typically compares the elevation and the costs of building to the FEMA + 3′ standard with the elevation and costs of building to a DFE that is based on Category 2 hurricane flood modeling from the National Hurricane Center (Con Edison, no date).[24] In most cases, the Category 2 standard represents a higher level of protection than the FEMA + 3′ standard and, based on past experience, it can frequently be accomplished at a relatively small incremental cost for new infrastructure developments. Con Edison could continue to build to the higher standard, where practical. The risks from hurricane flooding, compounded by sea level rise, is discussed in further detail in Appendix 5 – Extreme Events.

[24] National Hurricane Center. National Storm Hazard Maps – Version 2. Available at: https://www.nhc.noaa.gov/nationalsurge/

5.2. Existing Infrastructure Physical Vulnerabilities and Adaptation Options

Vulnerabilities

Electric

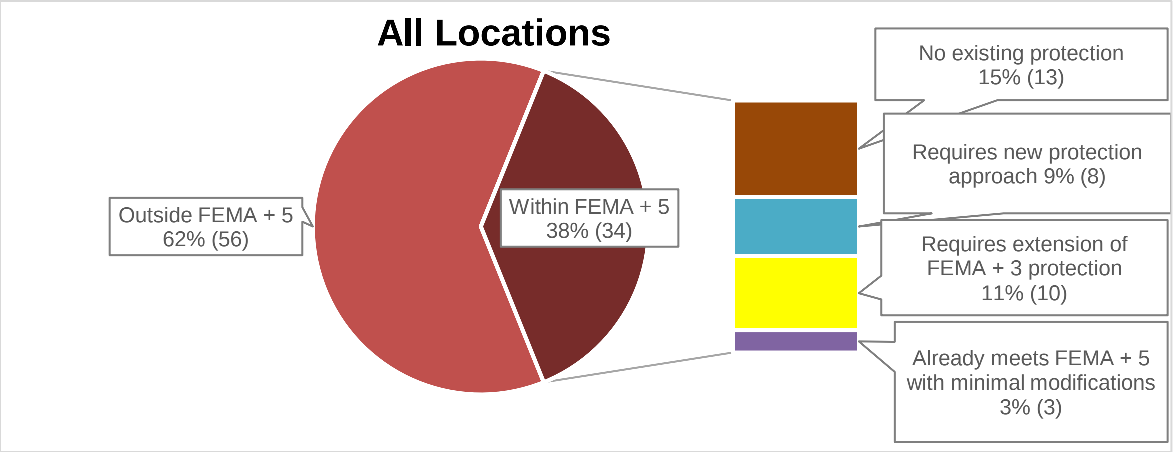
As previously discussed, the FEMA + 3′ protections installed by Con Edison after Superstorm Sandy will be effective at protecting existing electric infrastructure until sea levels exceed 1 foot, which is projected to occur between 2030 and 2080. According to the Study team's analysis, hardening of assets to a FEMA + 5′ standard would provide a level of protection consistent with sea level rise in 2080 under a high-end emissions scenario (RCP 8.5, 83rd percentile). The Study team selected 5 feet because it is the summation of the existing FEMA flood elevations, plus the Con Edison design requirements of 2 feet of freeboard, plus the 2080 RCP 8.5, 83rd percentile SLR projection (3.08 feet). In 2050, under that same emissions scenario, the Study team's analysis indicates that the relevant flood protection level is FEMA + 4.62′. Mapping showed a minimal difference in assets affected between 2050 and 2080 projections. This would suggest that setting an incremental design standard of FEMA + 4′ would not be practical. As a result, the Study team developed a map of the inland extent of the current FEMA 100-year floodplain plus 5 feet of additional elevation to understand the scope of the assets that could potentially need to be retrofitted with additional protections between 2030 and 2080 (Figure 20).

FEMA Base Flood Elevation (BFE) + 2′ freeboard + 3′ SLR (2080 RCP 8.5, 83rd percentile) = FEMA + 5′

A list of assets that may require additional protection was developed by intersecting the locations of Con Edison's assets with the FEMA + 5′ area.

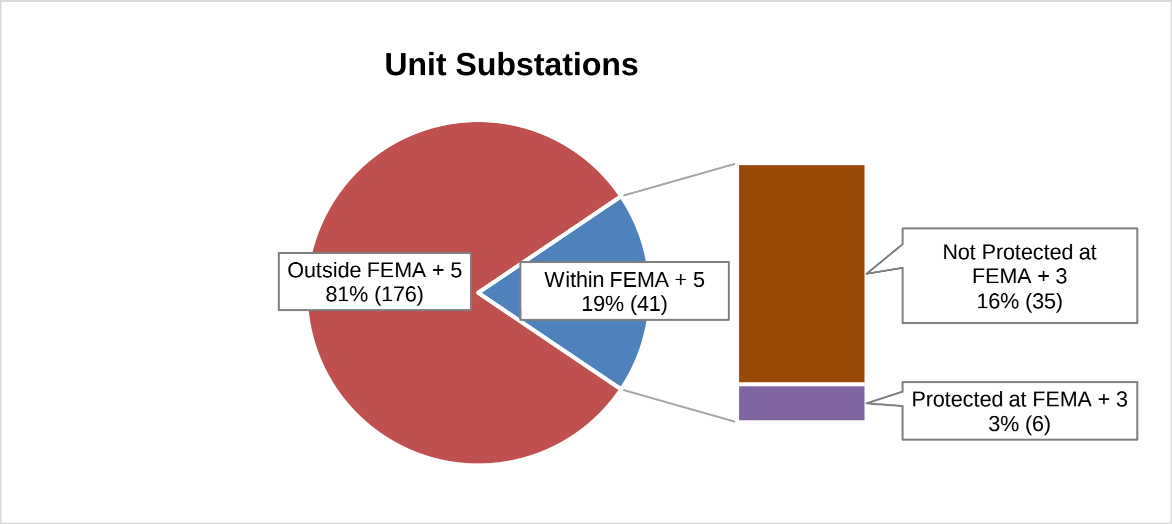
Using this list of potentially exposed assets, the Study team conducted a preliminary assessment of Con Edison's substation locations (encompassing generating stations, area substations, transmission stations, and Public Utility Regulating Stations), and determined that 9% of the locations within the FEMA + 5′ zone (3 out of 34) are currently protected at the FEMA + 5′ level (Figure 14). Of the 34 locations within the FEMA + 5′ zone, 15% (13 locations) are not presently protected, 11% (10 locations) require extension of FEMA + 3′ protections, and 9% (8 locations) require a new protection approach.

Figure 14 ■ Current protection level of Con Edison substation assets relative to FEMA + 3' and FEMA + 5' design standards, and the potential for extending existing protections



The Study team determined that 19% of unit substations are within FEMA + 5′. Of those 41 unit substations, six unit substations are protected at FEMA + 3′ (using water-filled barriers called "tiger dams"), and 35 unit substations are not protected at FEMA + 3′ (see Figure 15).

Figure 15 ■ Current protection level of Con Edison unit substation assets relative to FEMA + 3'



Gas

The Con Edison gas system has established specifications that set criteria for any new equipment installations that address FEMA + 3′, and could be updated to set FEMA + 5′ as a new standard at the appropriate time. For example, after Superstorm Sandy, only two regulator stations had to be upgraded for FEMA + 3′, including one City Gate for the gas system. Under a FEMA + 5′ worst case scenario, 31 (9%) more regulator stations would have to be upgraded. This would entail sealing all penetrations, extending vent lines and vent posts, and raising equipment such as communication panels, uninterrupted power supply (UPS), and other electronics. All gas regulators are underground.

Steam

The Con Edison steam system has implemented storm hardening measures in response to recent significant storms. These measures include hardening of steam production stations, development of location-specific storm response preparation plans and drills, waterproofing and/or relocation of critical equipment, installation of a new steam main that ensures continued service to the Lower East Side hospital corridor, and introduction of strategically located isolation valves that reduce the number of customers that would be impacted by future storm flooding. The isolation of steam lines is necessary for significant flooding conditions. Accordingly, Con Edison is mindful of the various flooding sources, such as water main breaks, rainfall deluges, and storm tides, and has established appropriate risk mitigation strategies, both physical and operational, which are periodically reviewed and updated.

Adaptation Strategies

These adaptation strategies serve to manage the vulnerabilities of existing infrastructure, from implementing increased monitoring and planning efforts to leveraging new innovations in physical flood protections:

Perform coastal monitoring of sea level rise to determine when to act to increase adaptive measures for existing locations. Given the broad range of outcomes in sea level projections and the complexity among the methods, space limitations, and costs to further modify existing infrastructure, Con Edison could monitor sea level rise to better determine when, where, and how to act on adaptive measures. Implementing monitoring programs will help Con Edison determine when to update protections at existing assets or pursue alternative energy delivery methods to manage risks from rising sea levels. Con Edison could consider leveraging existing coastal land holdings for siting monitoring equipment and infrastructure.

Leverage and adjust the existing Con Edison Storm Surge Calculator. Con Edison's current Storm Surge Calculator is a tool used for risk assessment of their facilities when facing an impending tropical storm. It indicates whether their facilities will be flooded when the permanent passive protections are in place. Active protections would be deployed when the Storm Surge Calculator indicates that the facilities are being flooded. Con Edison could leverage this calculator to plan for impacts from sea level rise and storm events into the future. Making adjustments to the Storm Surge Calculator will allow Con Edison to extend the usefulness of their existing tool to capture greater risks from flooding. For example:

- *Input high-end forecasted surge*. As is, the calculator uses the NOAA projection of storm surge at the Battery tide gauge applied uniformly across the critical assets. The Storm Surge Calculator could be enhanced to account for variable storm surge at select locations, such as the nearest harmonic stations, to increase fidelity.
- *Perform coastal monitoring to develop an enhanced calculator*. In collaboration with the city, NOAA, or the U.S. Geological Survey, could perform greater monitoring of the impact of actual storm events along the coast. The Storm Surge Calculator could be enhanced to account for variable storm surge at a few locations at the nearest harmonic stations to Con Edison facilities. This type of monitoring could feed improvements of the Storm Surge Calculator regarding the behavior of storm surge in various locations and improve the accuracy of the Storm Surge Calculator.
- *Adjust the Storm Surge Calculator's storm surge elevation*. Adjusting the Storm Surge Calculator to include wave heights will ensure that there is a buffer of operational risk tolerance. Con Edison could consider adding either wave elevations from the FEMA 100-year floodplain maps

(which would be varied throughout the service territory) or adding 2 feet to surge projections uniformly to account for uncertainty (e.g., waves). This would help ensure that Con Edison is adequately deploying resources to account for the full range of possible storm impacts, as the Storm Surge Calculator is a tool for guiding action in response to storm events as they approach—a tool that is currently more conservative in determining where to deploy active measures.

- *Regularly revisit the definition of critical equipment*. Currently, Con Edison's central engineering department has a definition and design standards for critical equipment and routinely updates these (Standard CE-SS-2014, Rev. 02). Ensuring that these updates to critical equipment and elevations are included in routine updates to the Storm Surge Calculator can help Con Edison ensure that flood protection planning and design consider the most relevant and comprehensive information.

Consider how changes in the frequency of smaller flooding events could impact Con Edison's assets. Increased frequency of moderate flooding events might affect the functionality or life span of certain assets through accelerated deterioration or increased operations and maintenance costs. For example, some Con Edison substations are equipped with large, deployable flood barriers to handle future Superstorm Sandy-like storm events. While these barriers provide substantial protection, they may be too costly and disruptive to deploy on a regular basis if moderate floods become more frequent. The frequency with which these strategies are deployed and the costs to deploy them could be tracked over time to determine when it becomes more cost-effective to invest in a dual-protection strategy—one for moderate flood events that are becoming more common, while maintaining the current strategy for large storm events. Figure 18 and Figure 19 in Appendix 4.A – Climate Information depict how the frequency of smaller flooding events may increase in the future.

Leverage new innovations and advancements in flood protections. As discussed in Section 3, after Superstorm Sandy, Con Edison implemented hazard mitigation measures such as installing submersible equipment, adding isolation switches, and building flood protection infrastructure. As Con Edison continues to implement hazard mitigation measures to address system vulnerabilities, it will be important to leverage new innovations and advancements. For example, enhancing smart grid and microgrid capabilities, such as advanced metering infrastructure, can provide increased resilience to critical facilities (U.S. DOE, 2016; National Academies of Sciences, Engineering, and Medicine, 2017).

6. Costs and Benefits of Adaptation Options Under a Range of Possible Futures

6.1. Increasing Protection of Existing Assets

As part of the post-Superstorm Sandy storm hardening initiative, Con Edison was asked in the Storm Hardening Collaborative to examine how a flood protection design standard based on the June 2013 FEMA 1% flood map elevations plus 5 feet (i.e., 3 feet for sea level rise and 2 feet for freeboard) would affect the cost of selected storm hardening projects. Con Edison determined in its 2013 Storm Hardening report that planned flood protection measures should meet, but generally not exceed, FEMA + 3′, because FEMA + 5′ would require additional complexity and cost. In some cases, raising protection levels for interior equipment requires substantial changes to existing infrastructure and operations that represent tipping points for project affordability and suitability. For example, at the East River Generating Station, raising mechanical equipment would require significant and costly alterations to the hydraulics of the steam system. Similarly, at East 13th Street, flood waters associated with the FEMA + 5′ level would reach the tertiary bushings on some 345-kilovolt transformers, resulting in arcing and critical failure of the unit. These impacts would require transformers to be raised to meet the higher design standard, necessitating the raising of the overhead bus, other adjacent transformers, and other connected equipment throughout the station. Based on the analysis, it was determined that introducing the higher flood protection design standard (FEMA + 5′) was not financially feasible at the time.

The Study team has revisited this approach and approximated the costs of hardening Con Edison's substation assets to the FEMA + 5′ standard. Three different approaches were used to develop the cost estimates based on the existing protection at the asset site. Note that these costs do not include three assets that are already protected to the FEMA + 5′ level: the Academy and Hellgate transmission substations, and the Bruckner area substation. It also does not include the costs to retrofit submersible equipment since such equipment is protected against any amount of flooding and needs no further hardening.

Locations previously hardened to FEMA + 3′, where the existing protection approaches could be extended to FEMA + 5′. For locations that had been hardened to FEMA + 3′, the cost to harden to FEMA + 5′ was based on that asset's actual post-Superstorm Sandy hardening cost times a multiplier. The multiplier was determined by an analysis that the company performed in 2013 to determine the difference in cost for protection at the FEMA + 5′ level versus the FEMA + 3′ level for four stations. The analysis found that increasing the protection levels from FEMA + 3′ to FEMA + 5′ would increase the storm hardening cost by 10% to 36%.

In order to be conservative when extrapolating the 2013 study to current cost increases to meet a FEMA + 5′ level of protection, Con Edison used a multiplier of 0.4 for facilities that were already protected to FEMA + 3′ and could be extended. This multiplier is just above the high end of the range found in 2013, and was deemed appropriate because the 2013 costs assume efficiencies that come from constructing FEMA + 5′ protection all at once rather than an incremental process of constructing to FEMA + 3′ and then adding on to meet FEMA + 5′. Table 6 provides an example of the calculation to harden the Sherman Creek transmission station.

Table 6 ■ Example of hardening costs for the Sherman Creek transmission station

Cost to Harden Sherman Creek to FEMA + 3′	*x*	*Multiplier to Extend to FEMA + 5′*	*=*	*Cost to Extend to FEMA + 5′*
$8,880,000	x	0.4	=	$3,552,000

Locations previously hardened to FEMA + 3′, where the existing protection approaches cannot be extended to FEMA + 5′. For locations that had been hardened to FEMA + 3′ but that could not be extended to FEMA + 5′, the cost to harden to FEMA + 5′ was based on that location's actual post-Superstorm Sandy hardening cost times a multiplier. Con Edison used a multiplier of 1.3 times the initial costs to harden the location to FEMA + 3′. The 1.3 multiplier was selected based on the following assumptions:

- The costs to tear down the existing protection systems and rebuild to a higher standard will be greater than the initial costs to harden to FEMA + 3′.
- Some components of the existing protection systems (e.g., pumps) will remain operational and therefore do not need to be replaced.

Table 7 provides an example of the calculation to harden the 13th Street transmission station.

Table 7 ■ Example of hardening costs for the 13th Street transmission station

Cost to Harden 13th Street to FEMA + 3′	*x*	*Multiplier to Extend to FEMA + 5′*	*=*	*Cost to Extend to FEMA + 5′*
$164,260,000	x	1.3	=	$213,538,000

Locations not previously protected to the FEMA + 3′ standard. For locations that were not previously protected to the FEMA + 3′ standard (e.g., they were not within the impacted area and therefore not part of the 2013–2016 hardening efforts), the cost to harden was based on the average cost of post-Superstorm Sandy hardening for that asset class and design type. The asset classes included generating station, transmission substation, area substation, Public Utility Regulating Station (PURS), and unit substation. The design types included open-air, enclosed, or both (open-air and enclosed).

For example, it is assumed that the Astoria West open-air transmission stations will cost approximately $30,620,000 since that was the average cost to harden open-air transmission stations after Superstorm Sandy.

Figure 16 and Table 8 show the overall breakdown of costs to harden assets to FEMA + 5′ in 2018 dollars. Table 9 summarizes the number of facilities and costs based on the type of work that would be required to protect to FEMA + 5′. Thirty-six percent of the cost is associated with brand new protection and 58% of the cost is associated with demolishing and rebuilding protection originally constructed to harden to FEMA + 3′.

Figure 16 Distribution of hardening costs among asset types (in 2018 dollars)

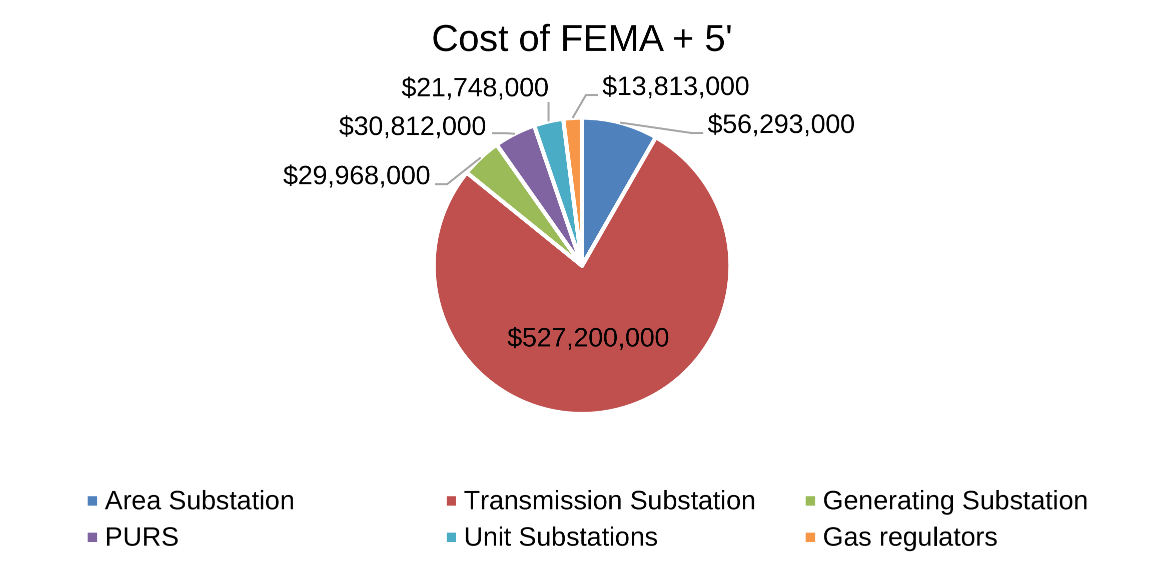


Table 8 Distribution of hardening costs among asset types (in 2018 dollars)

Asset Type	Cost to Harden (in 2018 dollars)	Number of Locations
Area Substation	$56,293,000	10
Transmission Substation	$527,200,000	13
Generating Substation	$29,968,000	5
PURS	$30,812,000	3
Unit Substations	$21,748,000	41
Gas regulators	$13,813,000	30
Total	**$679,834,000**	**102**

Table 9 Breakdown of costs to harden assets to FEMA + 5’ (in 2018 dollars)

Protection Type	Number of Locations	Cost to Harden (in 2018 dollars)
Brand new protection	84	$ 244,167,000
Demolish and rebuild	8	$ 395,656,000
Extend protection	10	$ 40,010,000
Grand Total	**102**	**$ 679,833,000**

6.2. Community Planning

In some cases, appropriate sea level rise adaptation measures for Con Edison, and the costs of those measures, will be linked to the degree, distribution, and timeframe of neighborhood-scale adaptation. For example, a substation located in a neighborhood that may be exposed to future flooding may end up being protected by a future flood barrier designed to protect the entire neighborhood. In this case, additional protection of the substation may be redundant and unnecessary. As a converse example, if it is determined that relocation of a given neighborhood by 2100 is more practical than building to 2100 flood levels in that particular location, it may be impractical to design a substation in that neighborhood to withstand projected 2100 flood levels. Con Edison could continue to closely coordinate with the city to determine where there are plans to invest in community-level protection strategies.

7. Implementation of Adaptation Options Over Time

Sections 5 and 6 describe adaptation options for rising sea levels, increasing flood heights, and increasing frequencies of historical return period flood heights. Given that there remains uncertainty about the rate at which sea levels and flood heights will increase over time, careful monitoring and analysis are required to determine the appropriate points at which to implement these adaptation options. For example, the 1-foot sea level rise threshold may be exceeded as early as the 2030s (high-end scenario) and as late as the 2080s (5th percentile).

Community planners in many areas around the world are relying increasingly on a model known as a "flexible adaptation pathway" to manage resilience investments amid uncertainty. This model relies on consistent monitoring of key external indicators, which can be environmental or societal, and which trigger the implementation of adaptation measures when the conditions of the indicators surpass certain thresholds. This approach allows asset managers to develop a fully formed adaptation plan in advance, but to delay or reconfigure adaptation measures based on the actual conditions that emerge, reducing the costs of managing uncertainty (Haasnoot et al., 2013). The New York City Panel on Climate Change (NPCC) is in the process of developing an adaptation pathways framework, and New York City's 2018 Climate Resiliency Design Guidelines promote the approach (New York City Mayor's Office of Resiliency, 2018).

San Diego Gas & Electric is developing a flexible adaptation pathways approach, following the recommendation of a 2018 report published as part of California's Fourth Climate Change Assessment (Bruzgul, et al., 2018). The flexible adaptation pathways approach is also a core recommendation of a recent report from the State of California's Climate-Safe Infrastructure Working Group (California Climate-Safe Infrastructure Working Group, 2018).

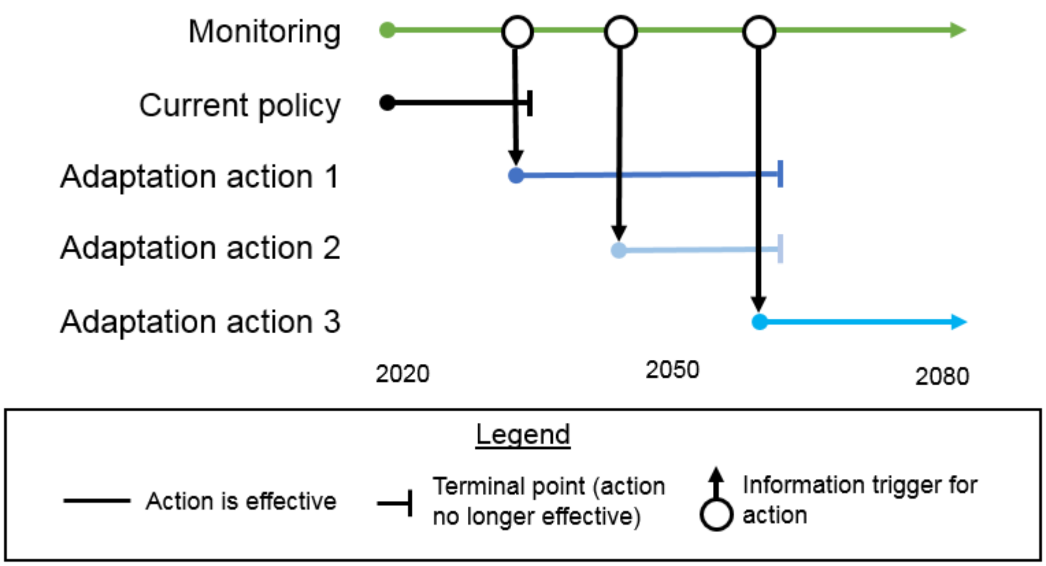
Examples of potential indicators for monitoring as part of a flexible adaptation pathways approach could include:

- **Updates to design guidelines from New York City.** If New York City or other regulatory entities update design guidelines to increase freeboard or sea level rise requirements, Con Edison might consider adopting the same design standards for new infrastructure. Updated design guidelines from peer organizations or regulatory entities may trigger an update of internal design standards to ensure consistency with established criteria.
- **Sea levels.** Monitoring of actual sea levels (by Con Edison or outside entities) can provide a sense of how quickly sea levels are approaching thresholds from current design standards. Keeping abreast with the latest information on actual sea levels can indicate when adaptations might be required. For example, the decision to relocate a substation might be triggered by water levels at a nearby tide gauge surpassing a set threshold. This threshold would be selected so that asset managers have sufficient time to elevate equipment prior to the point at which it faces inundation risk from additional sea level rise, but also no earlier than necessary to avoid premature costs. If asset managers determine that relocating a substation takes 5 years, the decision to relocate would be triggered by water levels rising to a height at which flood threat to the substation is plausibly 5 or more years away.

- **Flooding events at existing assets.** While updating design guidelines affects the development of new infrastructure, existing infrastructure may require modifications or added protections to ensure that they are resilient to increasing sea levels. Monitoring the highest risk assets for impacts or near-impacts from flooding events can provide information about when adaptation options may be required.
- **Community-scale flood protection strategies.** Monitoring the planning and construction of community-scale flood protection strategies can inform where Con Edison may not need to invest in stand-alone flood protection strategies.

Figure 17 provides a theoretical illustration of a flexible adaptation pathway. Monitoring of one or more external indicators, illustrated by the green line, triggers adaptation actions when the indicator value surpasses certain thresholds. In the model below, adaptation actions 1 and 2 are complementary (e.g., elevated equipment and submersible equipment), whereas action 3 is triggered at the point at which actions 1 and 2 will soon be insufficient (e.g., relocating the substation).

Figure 17 ■ Sample flexible adaptation pathway diagram



In general, flexible adaptation pathways will consist as much as possible of robust adaptation actions that work reasonably well across a wide range of circumstances, both now and in the future (as opposed to those that are optimized for present-day conditions or a single future outcome that ignores uncertainty).

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Appendix 4.A – Climate Information

Sea Level Rise Projections

The Study team drew upon the best available sea level rise projections for New York City. These include the Kopp et al. (2014, 2017) probabilistic projections, which account for all contributions to local sea level rise. The Kopp et al. (2014) projections increasingly appear in city, state, and federal reports; scientific assessments; and sea level rise guidance documents across the country. The Kopp et al. (2014) projections were constructed by combining Global Climate Model (GCM) projections of thermal expansion, glacier surface mass balance model projections, semi-empirical projections of land water storage changes, and ice-sheet projections based on a combination of the expert assessment of the Intergovernmental Panel on Climate Change's Fifth Assessment Report (IPCC AR5) and the expert elicitation study of Bamber and Aspinall (2013). These global projections were localized by accounting for the static-equilibrium fingerprint effects of land ice mass changes, GCM projections of atmosphere/ocean dynamics, and tide gauge-based estimates of non-climatic contributors to sea level change, such as glacial isostatic adjustment. The Kopp et al. (2017) projections update the Kopp et al. (2014) projections to account for the potential for significantly higher upper-end projections for Antarctic ice-sheet melt, which increase both global and regional sea level rise above most previously assumed upper limits (DeConto & Pollard, 2016).

Sea level rise projections from Kopp et al. (2014) and NPCC (Horton et al., 2015) work in tandem and employ a shared methodology using a component analysis to estimate sea level rise over the 21st century. There is broad agreement between the two studies, with Kopp et al. (2014) having the benefit of projecting sea level rise at a higher temporal resolution (decades) and reporting estimates for the entire probabilistic distribution for two RCP scenarios.

Nevertheless, differences between the two studies exist, particularly for projections during the latter half of the 21st century, which reflect differences in their scientific approach. First, Kopp et al. (2014) use a hybrid of expert sources to constrain future ice-sheet contributions to sea level rise, including estimates from both Bamber and Aspinall (2013) and IPCC AR5 (2013). In contrast, Horton et al. (2015) principally use only estimates from Bamber and Aspinall (2013), which were higher than those in IPCC AR5. Thus, the NPCC report includes higher estimates of ice-sheet mass loss and late-century sea level rise. As previously noted, the Study team additionally incorporates projections from Kopp et al. (2017) to account for potential high-end ice-sheet contributions to sea level rise (DeConto & Pollard, 2016). Second, Horton et al. (2015) made the decision to sum sea level rise components at each percentile to calculate total sea level rise, which produces higher projections than in Kopp et al. (2014).

Coastal Flood Heights and Frequencies

Coastal flood heights are driven by both local mean sea level and storm tide. Storm tide is composed of astronomical tides and storm surge. The Study team used a combination of Kopp et al. (2014) distributions of relative sea level change with the observational record of storm tide from the Battery tide gauge in New York City.

The Study team combined 10,000 Monte Carlo samples from the Kopp et al. (2014) distributions of relative sea level change with the observational record of storm tide from the Battery tide gauge in New York City. Using these data, the Study team calculated two flood risk metrics: (1) the change in height of future flood return levels in response to sea level rise, and (2) the change in frequency of flood return periods. Rising sea levels increase the frequency of flooding at *all levels*, from extreme to nuisance. Understanding not just the increased elevation of water levels, but also the change in their frequency is important for effective adaptation.

The Study team's approach has drawn upon methods from the scientific literature that have been applied to cities and organizations, such as in Boston and San Francisco. This approach provides a broader range of flood levels than the NYC Flood Hazard Mapper, which uses the FEMA 2015 100-year and 500-year flood levels. The NYC Flood Hazard Mapper also uses the New York Panel on Climate Change's sea level rise projections from 2015, which combine inputs from RCPs 4.5 and 8.5 in a non-probabilistic manner.

These flood heights and frequencies should be used as indicators rather than precise estimates. These values are for the Battery tide gauge, which may not perfectly represent water levels throughout the New York City coastline within the Con Edison service territory. The Study team's framework accounts for mean wave height, which is often, but not always, a good approximation (Lin et al., 2012; Georgas et al., 2014). The team assumed a historic distribution of storms, which imperfectly samples the true probability distribution, which may change in a warming climate (Christensen et al., 2013). The projection of changes in storminess involves deeper layers of uncertainty and is a nascent area of research for individual ocean basins.

The Study team developed maps showing coastal inundation in order to visualize the impact of coastal flood heights on the Con Edison service territory. Figure 18 and Figure 19 depict monthly inundation and flood depth under a range of likely sea level rise scenarios (RCP 4.5, 17th percentile and RCP 8.5, 83rd percentile) by 2050 and 2080. Coastal inundation maps use the 10-meter horizontal resolution National Elevation Dataset from the U.S. Geological Survey and reveal both citywide and localized flooding.

In addition, the Study team mapped the extent of the current FEMA 100-year floodplain plus 5 feet of additional elevation (FEMA + 5') to show the scope of additional protections possibly required by 2080 (Figure 20). The Study team used the 2013 FEMA 100-year flood map to determine a base flood elevation and added 5 feet to establish a FEMA + 5' flood elevation. The team then overlaid this information on photogrammetry derived street map elevations in order to determine and spatially cross reference the FEMA + 5' flood boundary on system maps. Next, the Study team identified assets that were within or in contact with the boundary of the FEMA + 5' flood elevation, regardless of flood height at the asset. This extent exceeds that associated with the current FEMA 100-year floodplain plus the 75th percentile NPCC sea level rise projection (NPCC, 2013).

Figure 18 ■ Citywide monthly coastal inundation and flood depth under both low-end (RCP 4.5, 17th percentile) and high-end (RCP 8.5, 83rd percentile) sea level rise for 2050 and 2080

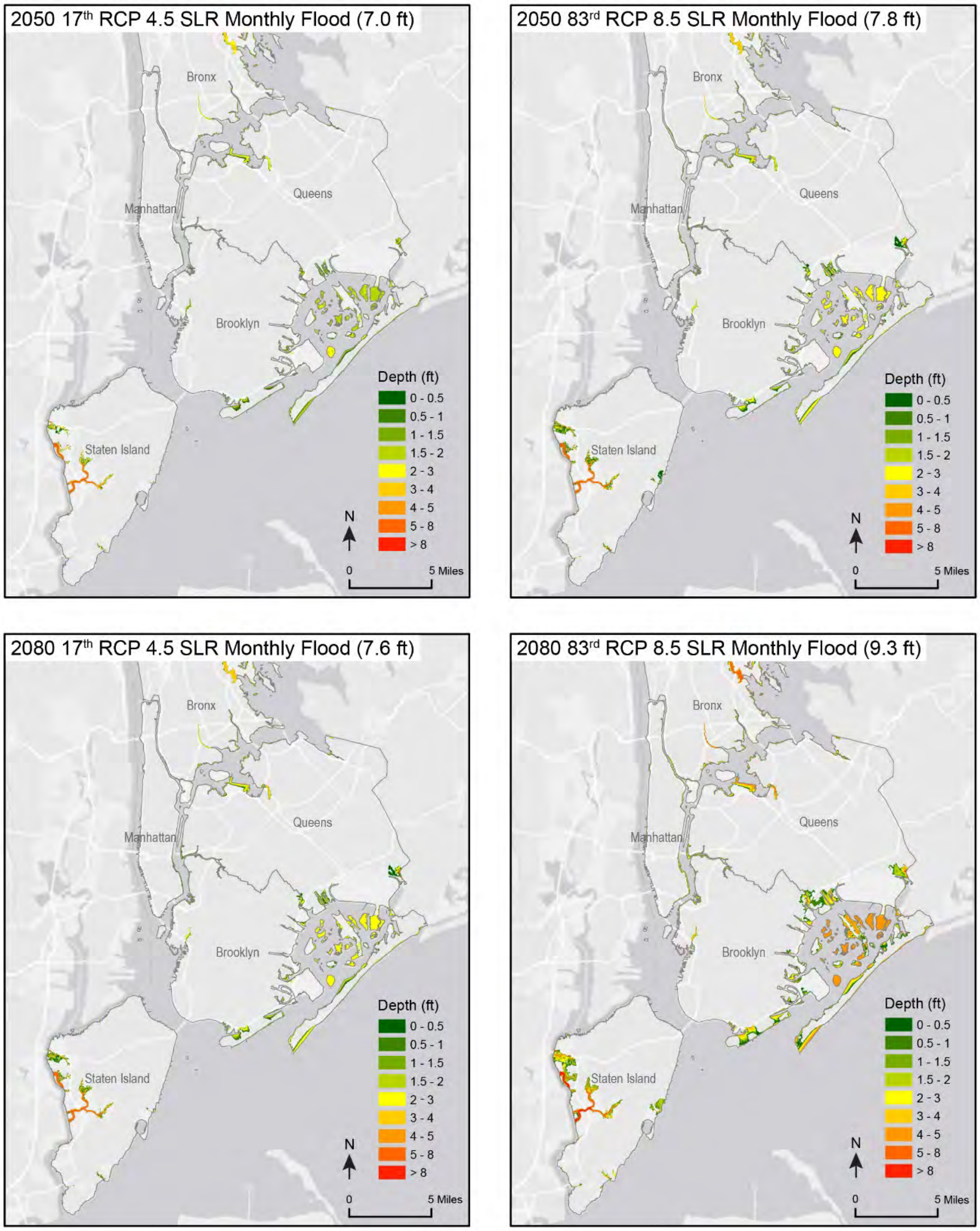


Figure 19 ■ Lower East Side of Manhattan monthly coastal inundation and flood depth under both low-end (RCP 4.5, 17th percentile) and high-end (RCP 8.5, 83rd percentile) sea level rise for 2050 and 2080

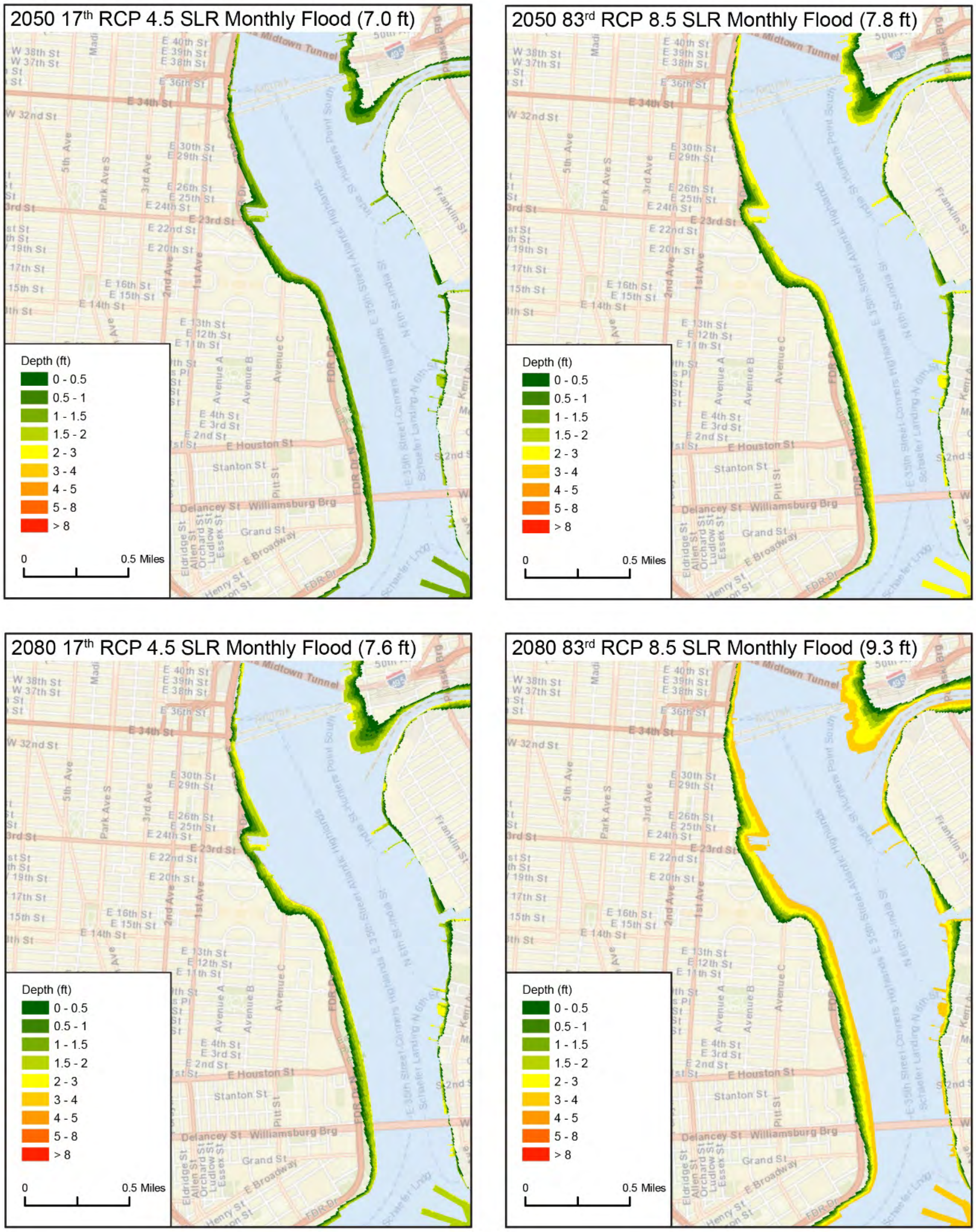
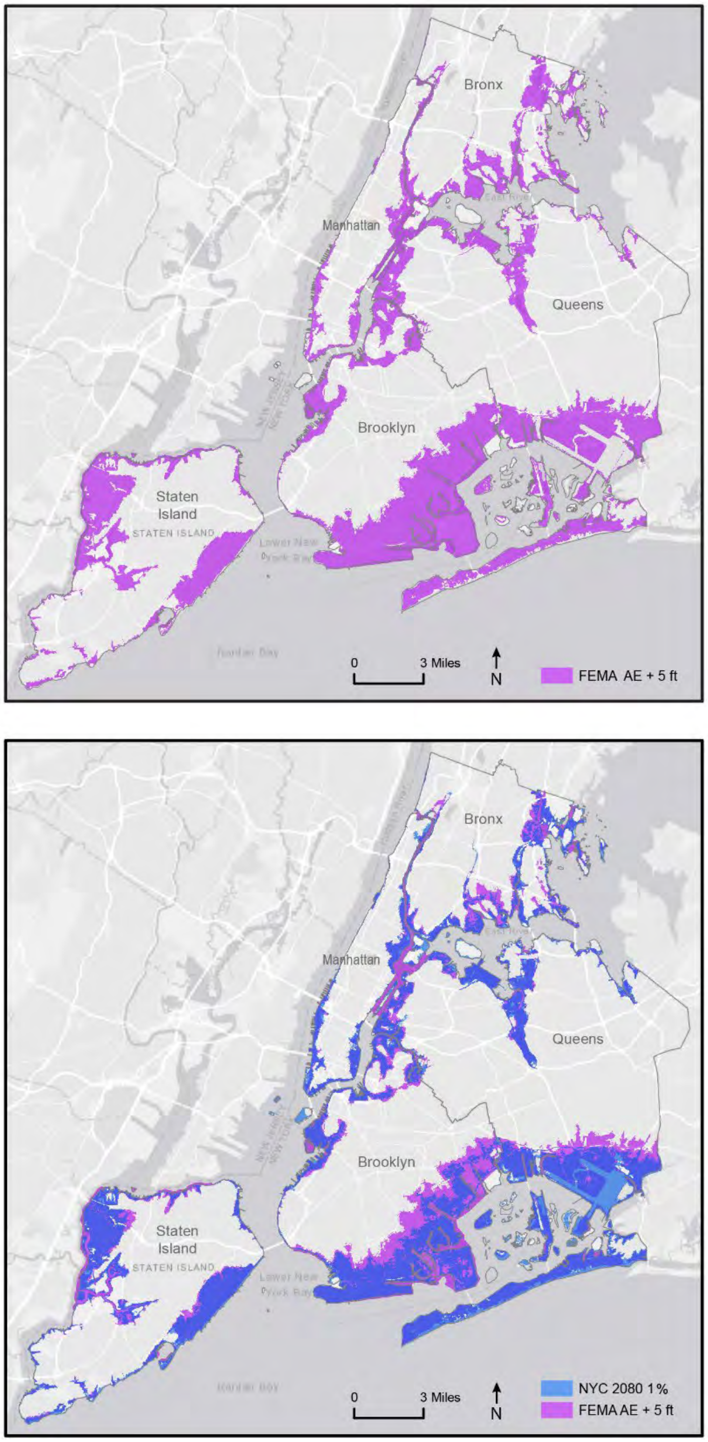


Figure 20 ■ Top figure shows the coastal flooding extent associated with the current FEMA 100-year floodplain (zone AE) plus an additional 5 feet of elevation (FEMA + 5'). The bottom figure compares flooding extents associated with FEMA + 5' and the current FEMA 100-year floodplain plus the 75th percentile NPCC sea level rise projection (NPCC, 2013).



Appendix 4.B – Glossary

100-year flood/base flood: Flood height of 1% annual probability. Con Edison defines this elevation using data from the Battery (Manhattan) from FEMA's most recent Flood Insurance Rate Map data (2013).

Base flood elevation (BFE): Con Edison uses the FEMA definition of base flood elevation ("elevation of flooding, including the greater of wave crest elevation and wave runup, having a 1% chance of being equaled or exceeded in any given year") plus one additional foot to account for sea level rise.

Design flood elevation (DFE): Con Edison's current design standard for flood elevation is base flood elevation plus 2 feet (3 feet over FEMA BFE). The additional 2 feet provides freeboard for critical infrastructure, as required under New York City Building Code.

Median lower low water (MLLW): "The average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch" (NOAA 2018). Con Edison uses the MLLW mark at the Battery tide gauge as their datum for design and for flood height calculations.

Projected flood height: This analysis defines the projected flood height as tides and sea level rise (collectively referred to as "still water") plus storm surge. FEMA's existing 100-year flood height data include wave crest elevation, but not sea level rise.

Relative sea level: The height of the sea surface, measured with respect to the height of the underlying land. Relative sea level changes in response to both changes in the height of the sea surface and changes in the height of the underlying land (U.S. GCRP, 2017).

Stillwater: Sea level elevation relative to a set datum (in this case, mean lower low water) with no waves.

Storm surge: Water height increase at shoreline over mean lower low water level or predicted astronomical tide due to storm pressure and wind.

Wave crest elevation: Peak wave height (not including wave runup or setup).

Wave runup: Maximum height that the water reaches when it hits shoreline due to wave momentum (higher than crest elevation).

Wave setup: Defined by FEMA as **"**The increase in the water level caused by the onshore mass transport of water that happens due to waves breaking during a storm. Wave setup is affected by the wave height, the speed at which waves approach the shore, and the slope of the shore" (FEMA 2018). In other words, the increase in wave height caused by the decrease in water depth associated with water moving over land.

The following diagrams can help to visualize some of these definitions.

Figure 21 ■ FEMA's 100-year flood/base flood

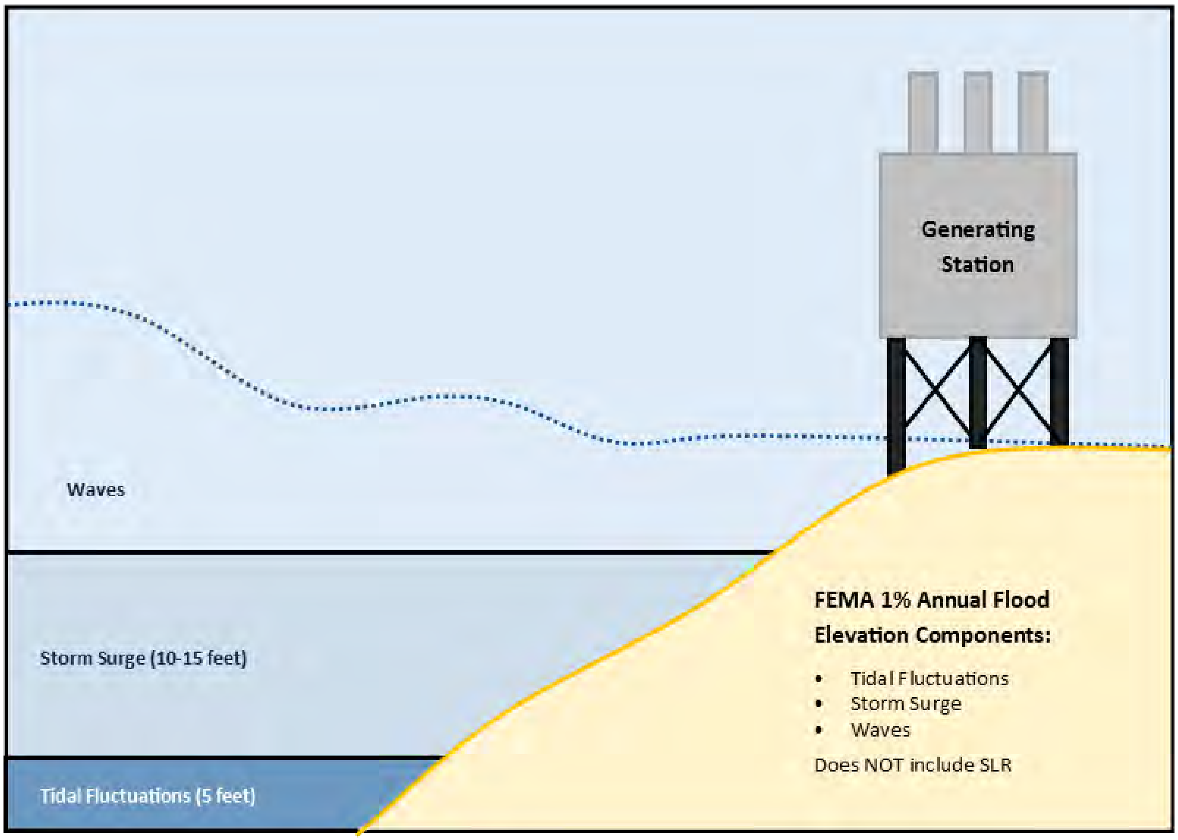
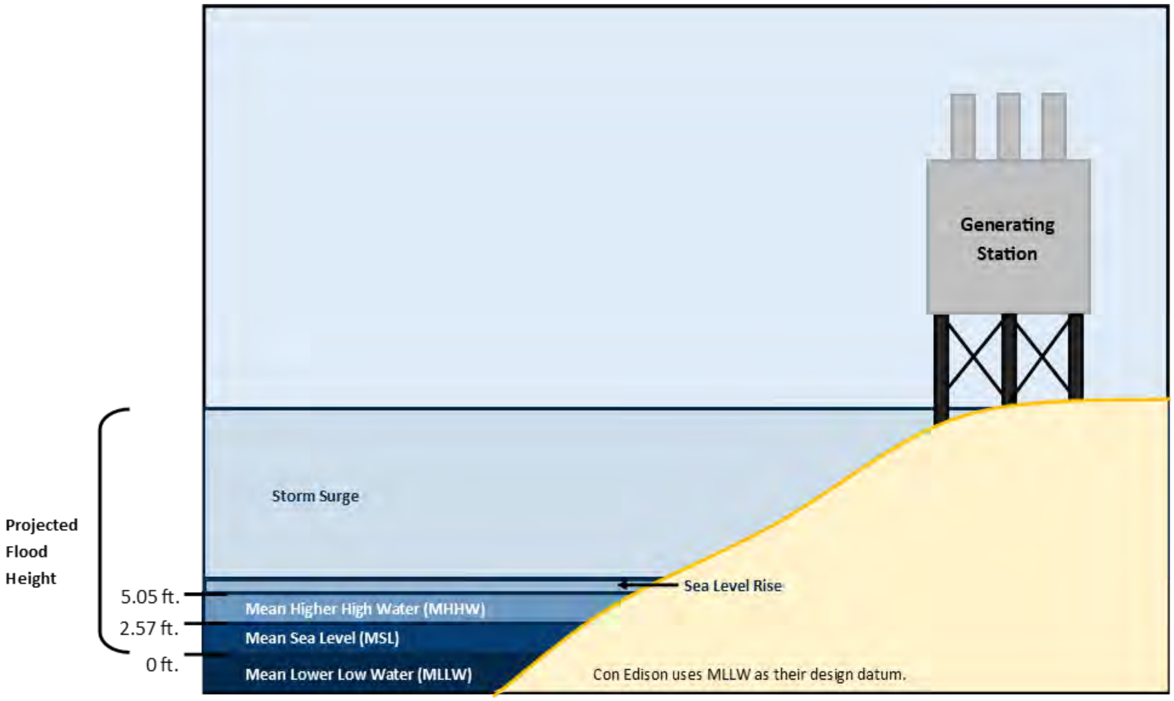


Figure 22 ■ Con Edison's projected flood height



APPENDIX 5

Extreme Events

1. Introduction

This appendix describes how extreme weather events, including concurrent or consecutive extreme events, may become more frequent and severe due to climate change. It considers the extreme weather's potential impact on operations, planning, and infrastructure across the electric, gas, and steam segments of Con Edison's business over the coming century. Extreme events present unique challenges associated with changes in the frequency and intensity of historically low-probability, high-impact storms, heat waves, heavy precipitation, and winds. Such events commonly represent tipping points in public perception of climate change and in how institutions such as Con Edison are expected to address challenges posed by climate change. This appendix addresses these rare extreme weather event impacts and Con Edison's preparation and experience with extreme weather to evaluate exposure and risk mitigation strategies to promote systemwide resilience to such events.

As described in the report introduction, the analysis for this appendix involves a decision-first and risk-based approach, blending the best available climate science for rare, difficult-to-model extreme events on the one hand to decision-maker-defined high impacts on the other. The union of these two perspectives is critical to developing flexible and adaptive solutions to some of the most vexing climate vulnerability assessment challenges.

The analyses and recommendations in this appendix are tailored to address unique challenges posed by extreme events, in contrast to previous appendices focusing on chronic climate hazards such as long-term increases in temperature, precipitation, and sea level. To build resilience to rare extreme events, the Study team proposes an overarching resilience management framework designed to minimize impacts of extreme events throughout asset life cycles. The timing, frequency, and intensity of extreme events can be highly uncertain, making it difficult or cost-prohibitive to build resilience effectively through hardening measures alone. To address this, the Study team looked across Con Edison's broader integrated system, from upstream supply chains to downstream customers. Through this lens, the team considered how the system can withstand, absorb, recover, and adapt to risks posed by extreme events.

This approach complements recent studies emphasized by the City of New York that, in part, use climate projections to inform resilience strategies for critical infrastructure (e.g., New York City Panel on Climate Change [NPCC], 2019). This appendix supports these efforts and adds granularity by taking a deeper dive into Con Edison's system, the company's customers, and related interdependencies.

2. Highlights

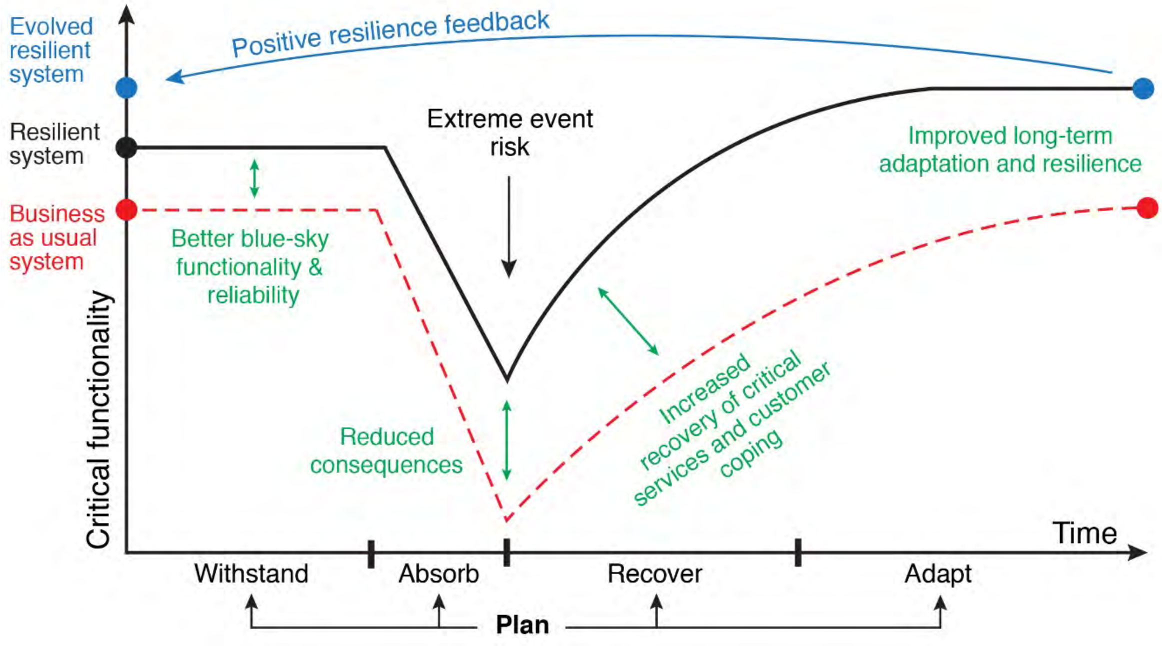
In developing this appendix, the Study team focused on Con Edison's vulnerability to rare, extreme events and identified adaptation measures to address potential impacts and increase system resilience. This section provides an overview of key findings and recommendations.

Rare extreme events are low-probability, high-impact climatic phenomena, such as major hurricanes, long-duration heat waves, and powerful extratropical cyclones (e.g., nor'easters). Although these climatic extremes are generally projected to increase in both frequency and intensity as a result of climate change (Intergovernmental Panel on Climate Change [IPCC], 2013), the spatial and temporal extent of this increase remains uncertain. This is in part because extremes are controlled by local, transient weather conditions that are difficult to model.

In the face of these unknowns—and because extreme events present acute risks to a Con Edison system positioned at the center of increasingly interconnected societal, technological, and financial systems—different adaptive approaches to extreme events are required than those used to address risks from chronic climate change. To address this need, the Study team identified an overarching resilience management framework that could help Con Ed mitigate risks associated with extreme weather events most relevant to its service territory.

Resilient systems are composed of more than hardening measures alone. They instead consider measures that increase resilience throughout the lifecycle of an extreme event. These measures include the system's capacity to "withstand," "absorb," "recover from," and "adapt to" extreme event risks (see Figure 1). In turn, resilient systems offer critical co-benefits, such as improved system reliability and blue-sky functionality, reduced consequences from non-climatic risks, and more resilient customers. A resilience management framework also facilitates long-term adaptation, which enhances the critical functionality of the system through time and creates a positive resilience feedback (Figure 1). To succeed, each measure of a resilient system requires proactive planning and investments.

Figure 1 ■ Conceptual figure representing a resilience management framework designed to withstand, absorb, and recover and adapt to extreme event risks. Investing in a more resilient system (black line) provides benefits (green arrows and annotations) relative to a less resilient, or business-as-usual, system (red-dashed line) before, during, and after an extreme event. Resilient systems also adapt so that the functionality of the system improves through time (blue line). Each component of a resilient system requires proactive planning and investments.



Withstand

Con Edison can continue to make investments to better withstand extreme weather events. Such investments work to mitigate service disruptions through hardening infrastructure and adding redundancy, diversity, and flexibility in power delivery. Energy systems that invest in efforts to withstand extreme events such as worst-case climate and weather scenarios also build increased capability into their systems. In turn, those capability increases provide important co-benefits, such as better blue-sky functionality and reliability.

Con Edison bases its infrastructure design on many factors, including experience with prior extreme events and industry standards. Different elements of the system (e.g., electrical distribution versus gas distribution) require different treatment, necessitating a flexible approach to formulating and adopting resilience measures. The Study team met with Con Edison subject matter experts (SMEs) to identify extreme event-specific vulnerabilities across the electric, steam, and gas systems and to develop adaptation measures to address them.

Examples of "withstand" adaptation strategies are:

- Routinely review and update asset ratings in light of historical observed climatology and future projections.
- Continue to engage with regional partners and standard-setting bodies, such as the Institute of Electrical and Electronics Engineers (IEEE) to better integrate extreme weather events into design and standard criteria.
- Strategically diversify and add redundancy to systems.
- Engage forward-looking technologies to further reduce the impact of extreme events on all systems.
- Implement targeted infrastructure retrofits or reinforcements to allow assets to withstand the impacts of severe storms.
- Develop a load relief plan that integrates future climate projections.
- Partake in continual exploration and expansion of operational measures to increase system resiliency.
- Update the Con Edison meteorological model used to predict work crews required to service weather-driven outages and customers impacted, and increase model capability to simulate impacts from extreme events.
- Extend existing protection or construct new protection in locations that have been flagged as vulnerable.

Absorb

Con Edison cannot and should not try to withstand every potential extreme weather event. However, actions that reduce demand for Con Edison services can be used to protect exposed systems and reduce damage during events. By reducing demand, Con Edison's ability to deliver sufficient capacity to serve critical loads during extreme weather events is improved. Con Edison currently implements several such actions, including:

- Demand Response Programs: In preparation for high load and/or limited capacity days, Con Edison asks customers enrolled in the demand response program to limit their electricity or gas use during peak hours or during critical events.

- Enhanced Energy Efficiency Programs: These programs improve the efficiency of appliances and buildings in order to permanently reduce load (not just during extreme weather events) and increase the reserve capacity on the system.
- Selective Load Shedding: Con Edison is currently deploying advanced metering infrastructure (AMI), which demonstrates strong potential for absorbing the impacts of extreme weather events.

Examples of "absorb" adaptation strategies are:

- Adopt best practices to ensure continued participation in demand response programs, even with increasing frequency and duration of events (Demand Response Programs).
- During load relief planning, consider if extreme events could reduce the effectiveness of demand response programs (Demand Response Programs).
- Continue support for energy efficiency programs and further expand the energy-efficiency program portfolio to include additional incentives for energy-efficient building envelope upgrades (Enhanced Energy Efficiency Programs).
- Use AMI to rapidly shed load to help ensure demand does not exceed supply, thus reducing potential damages and the likelihood of network-wide outages (Selective Load Shedding).

Recover

Although resilience investments may lessen the impacts and recovery times of extreme events, Con Edison customers are likely to still experience outages during or after these events. The City of New York assumes primary responsibility for coordinating resident emergency response efforts; however, Con Edison can still play a role in supporting resilient customers. Resilient customers are prepared for outages by having access to power (either at home or in locations in their community), the ability to shelter in place without power, and/or prioritized service restoration.

Examples of "recover" adaptation strategies to improve customer coping are:

- Work with the city to identify and support the development of resilience hubs, including deploying additional distributed generation and storage systems at critical community locations.
- Use AMI to create a "virtual resilience hub" by prioritizing customers for continuous power, such as pharmacies, gas stations, community centers, shelters, grocery stores, health care facilities, banks, cell towers, and key city services such as police and fire.
- Continue to invest in energy storage strategies, including on-site generation at substations or mobile storage on demand/Transportable Energy Storage System (TESS) units and compressed natural gas (CNG) tank stations.
- Continue to support customer-installed distributed generation.

The other part of recovery includes pre-planning for emergency situations. Con Edison's emergency response to extreme weather hazards is currently composed of a diverse and robust set of strategies, all of which are specified in the company's hazard-specific Emergency Response Plans for electric, steam, and gas systems, and in Coastal Storm Plans (CSPs). Despite having an effective response framework, Con Edison may face future extreme events that present risk levels exceeding its response capacity. In case of such events, Con Edison should begin to consider a range of additional adaptation strategies to increase the scope and effectiveness of its recovery operations.

Examples of “recover” adaptation strategies to increase emergency preparedness and system recovery are:

- Expand the Enterprise Risk Management framework to include lower probability extreme weather events and long-term issues (e.g., 20-plus years).
- Conduct additional extreme weather tabletop exercises informed by the future narratives outlined in this appendix with external partners including NYC Emergency Management.
- Incorporate supply shortages into emergency planning exercises.
- Increase recovery efficiency by expanding options for the workforce to get to job sites and obtain information on the state of the system.
- Review the Learning Center courses to ensure they are developing the skills required for emergency response.
- Standardize parts where possible, both within Con Edison and with neighboring utilities.
- Develop a resilience checklist for resilient sourcing, including requiring vendors to report on their internal extreme event preparedness.
- Ensure backup communication systems are in place and regularly tested, especially as technology becomes a greater part of the response efforts.
- Install fiber-optic communication and control systems to additional pieces of equipment to enhance resilience to flooding.
- Engage in continued coordination with telecommunication providers.
- Engage in continued coordination with New York City regarding resilience enhancements to the stormwater system and other services Con Edison is dependent upon. These could be codified through MOUs or similar mechanisms.

Adapt

Adapting infrastructure, planning, and operations in light of future risks will allow Con Edison to achieve a higher resting state of resiliency. For the company to restore service to a better adapted state following an extreme event (i.e., building back better), Con Edison should engage in pre-planning for post-event construction. This approach can turn a damaging situation into an opportunity for resilience.

Examples of “adapt” adaptation strategies are:

- Develop a plan in advance of extreme weather events for the selection and procurement of repair or replacement assets designed to be more resilient in the future.
- Build on existing Con Edison approaches to post-event reporting to help identify opportunities to better prepare for, respond to, and rebuild from disasters in fundamentally more resilient ways.

3. Rare Extreme Events and Climate Change: Managing Risks in an Uncertain Future

This appendix focuses on rare extreme events that are low-probability and high-impact climatic phenomena, such as major hurricanes, long-duration heat waves, and powerful extratropical cyclones. While the frequency and intensity of many types of climatic extremes will likely increase due to climate change (IPCC, 2013), there remains greater uncertainty associated with the rarest and most intense versions of extreme events like heat waves, as well as certain other types of extreme events like hurricanes and nor'easters across their entire strength distribution. While earlier appendices have outlined how climate models and other sources of information can be used to develop quasi-probabilistic projections of long-term mean variables (e.g., monthly temperature) and extreme events (e.g., number of days over 90°F), it is more challenging to project the rarest events, like the 1-in-100-year heat wave, as well as complex and multifaceted events, like hurricanes, with important spatial scales much smaller than climate models. Obstacles to modeling rare and complex extreme events include the shortness of the historical record relative to the rarity of the event, and challenges involved in modeling the most intense extremes, which can have important features at very local scales (e.g., urban heat islands).

Extreme events can present outsized risks compared to chronic events, risks that in some instances also extend to larger geographic areas. For example, impacts from hurricanes can overwhelm multiple facets of Con Edison's system and surrounding communities. Con Edison is positioned at the center of increasingly interconnected societal, technological, and financial systems, making it difficult and inefficient to evaluate risks on a component-by-component basis (Linkov et al., 2014). Together, these factors necessitate different approaches to considering adaptation compared with climate changes for which probabilities are more easily assigned. In addition, rare extreme events play an outsized role in shaping the public's perception of climate change and how institutions should address their unique challenges. While small, incremental changes in temperature often go unnoticed, a single extreme storm event impacting New York City—whether its frequency or intensity has been modified by climate change or not—can lead to paradigm shifts in our thinking around climate and climate change impacts and, in turn, the responsibility Con Edison shares in promoting citywide resilience.

In response to these concerns, this appendix introduces an overarching resilience management framework to address acute climate risks, such as rare extreme weather events that have large uncertainties and may not have clear thresholds to build into hardening measures alone. The resilience framework uses specific adaptation strategies designed to allow Con Edison's system to withstand, absorb, recover, and ultimately adapt to extreme events. The framework aims to preserve not only the critical functionality of Con Edison's system, but also to mitigate risks to customers and adjacent, interdependent systems before, during, and after an extreme event. In this way, this appendix highlights how Con Edison can promote citywide resilience within an increasingly interconnected system perturbed by climate-driven extreme events.

Figure 2 ■ This conceptual figure represents a resilience management framework designed to withstand, absorb, and recover from extreme event risks. Investing in a more resilient system (black line) provides benefits (green arrows and annotations) relative to a less resilient, or business-as-usual, system (red dashed line) before, during, and after an extreme event. Resilient systems also adapt so that the functionality of the system improves through time (blue line). Each component of a resilient system requires proactive planning and investments.

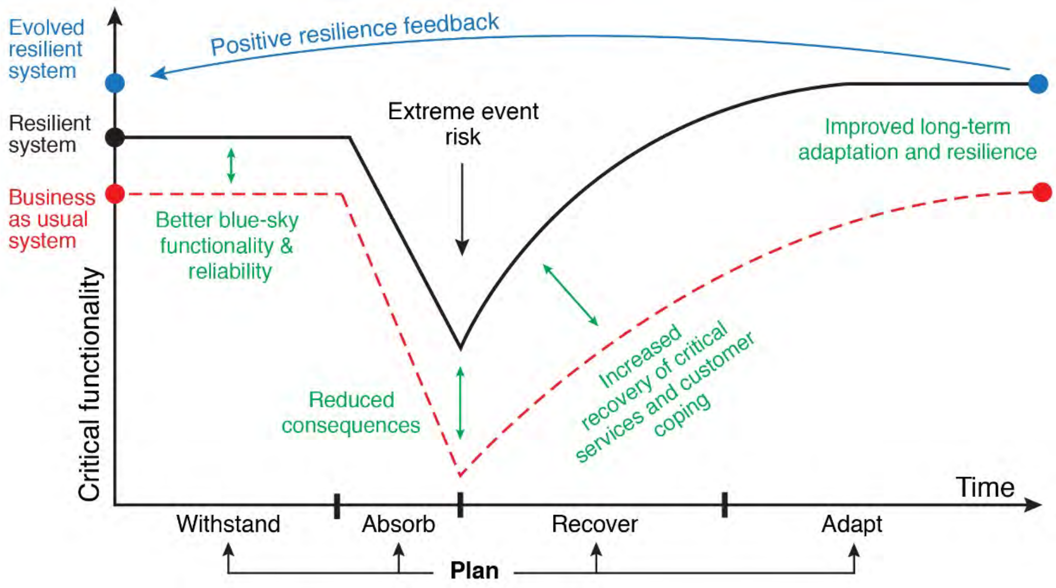


Figure 2 presents a conceptual model showing how a resilient management framework addresses risk associated with an extreme event through time. Under this framework, a resilient Con Edison system (e.g., black line in Figure 2) better withstands and plans for, absorbs, recovers from, and adapts to extreme events compared with a less resilient, or business-as-usual, energy system (red dashed line in Figure 2).

The resilience of a system is related to the height of the withstand line, slope of the absorb curve, and shape of the recovery curve (Figure 2), indicating how highly resilient energy systems offer benefits over business-as-usual systems, before, during, and after an extreme event (green arrows in Figure 2). Resilient systems not only reduce consequences during extreme events and increase the rate of recovery afterward, but also offer important co-benefits beforehand, such as increased blue-sky functionality and reliability, and resilience against other non-climate related events that pose significant risks to Con Edison's system.

In addition, highly resilient systems adapt through time so that their functionality improves with respect to their initial condition (blue line in Figure 2). This positive resilience feedback diminishes extreme event risk over subsequent events, further increasing and maintaining the level of critical functionality through time and ultimately achieving a higher resting state. For example, the company's storm hardening investments after Superstorm Sandy enabled Con Edison to avoid 60,000 customer outages when the Riley and Quinn storms hit the region in 2018. Up to that date, over 300,000 customer outages had been avoided during smaller events due to storm hardening.

Each component of a resilient system, including its ability to withstand, absorb, recover and adapt to extreme events, requires smart planning and proactive investments. Planning recommendations are woven into the appendix to facilitate an efficient approach to implementing a resilient system through time. Ultimately, this appendix aims to help facilitate a robust resilience management framework by considering proactive investments and smart planning across components of Con

Edison's broader integrated system, including Con Edison, its customers, the city, and critical infrastructure operators.

4. Screen for Priority Extreme Events

On March 12, 2019, Con Edison held an internal workshop with 25 subject matter experts (SMEs) to explain how extreme weather events may change in the region and to gather preliminary feedback on extreme events of greatest concern. This screening exercise helped to narrow the range of extreme events under consideration and helped set the stage for future discussions with the SMEs.

Based on prior experience with major events, current preparedness planning efforts, and the potential for stronger or more frequent events in the futures, SMEs were asked to rate individual extreme weather events on a scale of 1 to 5, with 1 corresponding to no impact, 3 corresponding to serious impact, and 5 corresponding to extreme impact. The average scores from the participants are presented in Table 1, with hurricanes being the greatest concern for the participants. Higher scores were generally assigned to events that affect a broader set of the utility infrastructure. For example, hurricanes and nor'easters affect electric, gas, and steam, while extreme heat primarily affects the electric sector.

Table 1 ■ Priority individual extreme events

Extreme Event	Average Potential Impact Rating (Out of 5)	Key Concerns
Hurricane or Tropical Cyclone	4.1	• Damage to overhead distribution infrastructure from wind, rainfall, and lightning. Significant downed trees. • Widespread area of mutual aid needs • Flooding of steam mains, which could lead to ruptures. Flooding primarily occurs when the city's stormwater system is overwhelmed • Water infiltration into gas lines. • Quantity of repairs required would be significant.
Nor'easter, Blizzard, or Ice Storm	3.4	• Many impacts, similar to hurricanes. • Heavy ice loading and winds can cause significant damage on the overhead system. • Freezing conditions and snow limit ability of repair workers to access jobs. • Salting to melt snow impacts the underground system.
Thunderstorms and Lightning	3.2	• Lightning can lead to significant damage, as during the 1977 blackout. • Flooding of steam mains can lead to ruptures. • Flash flooding can occur throughout the service territory. • Potential for water intrusion in the gas system.
Tornadoes or Heavy Winds	2.8	• Heavy winds can significantly damage the overhead system. • Winds can also affect transmission into the NYC area.
Extreme Heat	2.7	• Lower capacity ratings paired with higher load due to high temperatures can stress the system. • Component failures are more likely at higher loads, resulting in greater risk of outages. • Longer heat waves could limit the ability to repair damaged equipment before other failures occur. • Drop in outdoor worker productivity can occur due to safety concerns.
Downpours	2.5	• Flooding of steam mains, which could lead to ruptures. Flooding primarily occurs when the city's stormwater system is overwhelmed. • Water infiltration in gas lines. • Potential flooding of manholes.

Extreme Event	Average Potential Impact Rating (Out of 5)	Key Concerns
Extreme Cold	2.4	• Steam production impacted if there is high demand and a shortage of gas supply. While #6 fuel can usually be used as a backup, extreme cold could also affect fuel barge delivery. • Increased incidence of water main breaks can lead to flooding. • Lack of gas availability limits electric generation capacity. • Chemicals stored at steam plants may freeze. • Gas system could be highly strained, especially if transmission is interrupted. • Increased salt use can seep into the underground electric system and lead to corrosion and manhole events.
Drought	1.9	• May impact upstream generation (e.g., wildfires). • City water curtailments could impact steam production.

Ultimately, feedback from SMEs helped to prioritize and formulate a set of future extreme event narratives that illustrate low probability, high impacts to Con Edison's energy infrastructure. The next section describes the extreme event narratives in more detail. The narratives then motivate a range of adaptation options and recommendations to increase systemwide resilience to mitigate risks from extreme events.

5. Historical and Future Extreme Events

Rare and difficult-to-model extreme events are low-probability and high-impact phenomena that present outsized risks to infrastructure, operations, and services across the Con Edison territory. Some classes of extreme events, such as severe thunderstorms and tornadoes, occur over small areas and short time periods, which makes them difficult to simulate in coarse-resolution global climate models and develop comprehensive (and quantitative) projections of their future changes. For these and other reasons, predictions of rare and difficult-to-model extreme events and their spatial and temporal evolution remain challenging and at the forefront of scientific research. For the remainder of the appendix and for brevity's sake, we refer to rare and difficult-to-model extreme events simply as "extreme events."

Despite the unknowns, more research exists to suggest that many extreme events will likely increase in frequency and intensity as a result of long-term climate warming. There are many climate processes linking warmer temperatures and extreme phenomena. For example, long-term atmospheric warming will directly drive more frequent and intense (i.e., hot) heat waves, as described in Appendix 1. Other linkages are less direct and remain the focus of advanced climate research. For example, a warmer atmosphere is able to hold more water vapor and can provide additional convective energy, which drives more intense downpours and more frequent thunderstorms, respectively. In this way, observed changes in average conditions, appropriately interpreted, can provide a proxy for expectations of low probability, high impact event occurrence in the future (Haasnoot et al., 2018). Ultimately, pronounced temperature increases are expected to drive a range of climatic processes that increase the likelihood of extreme weather in Con Edison's service territory.

These linkages highlight the interconnectedness of the global climate system and suggest that changes in one part of the climate system can affect climatology and weather in the Con Edison service territory. For example, accelerated warming in the Arctic, though far away from New York City, can potentially alter mid-latitude atmospheric circulation patterns (Delworth et al., 2016), potentially increasing the probability of local extreme event-driven atmospheric blockages, including heat waves, cold snaps, and stalled hurricanes (Taylor et al., 2017).

To characterize future changes in extreme events and their potential impacts in the service territory, the Study team drew from key climate information including (1) recent historical analogs (e.g., weather station and satellite observations of historical extreme events in the region), (2) the state-of-the-art climate research, and (3) where appropriate, climate model projections. Historical analogs provide a baseline view of extreme event impacts, while climate research and projections help characterize the magnitude and direction of change in the future.

To illustrate expected changes and impacts in extreme events in the Con Edison service territory, the Study team focused on three extreme event "narratives," including (1) hurricanes, (2) an extreme heat wave, and (3) nor'easters. In contrast to prior appendices, the narratives are meant to represent plausible future (mid-to-late 21st century) *worst-case scenarios* and, in turn, one possible permutation of extreme weather to identify specific potential vulnerabilities and to allow contemplation of commensurate adaptation and resilience strategies across Con Edison's integrated system. The narratives were prioritized by Con Edison SMEs because they include important weather "sub-drivers" that drive consequences and impacts to the service territory. For example, hurricanes include the potential for extreme wind, downpours, tornadoes, and storm surge, while nor'easters include the potential for snow, ice, wind, and cold temperatures. Thus, the narratives are indicative of a wide range of potential extreme events that could impact the service territory. While the narratives should not be considered forecasts or projections with probabilistic uncertainties, they represent plausible low-probability, high-impact events that underscore the extent that future extremes may worsen in a warming climate.

5.1. Hurricanes and Tropical Cyclones

Tropical cyclones are rapidly rotating low-pressure systems that produce extreme precipitation, high winds, and coastal storm surge. These storms are classified according to their intensity and wind speed, with Category 1 and Category 5 hurricanes featuring 74 mph and 157 mph sustained winds, respectively. Many factors influence hurricane trajectory and intensity, such as atmospheric conditions and sea surface temperatures, and the combination of these factors at any given time determines how a particular storm will manifest. Unfortunately, general climate model projections are unable to adequately resolve many of these factors to simulate how specific storms will change in the future.

Historical Information

Prevailing westerly winds generally steer hurricanes away from the coast as storms approach the northeastern United States. Although a direct strike is rare, the tri-state region has experienced several strong hurricanes over the last century (Table 2). An analysis of historical datasets reveals that the strength and impact of these storms depends, in part, on hurricane trajectory as they approach the service territory. Historically, the most damaging storms with respect to the *combined* impacts of rain and wind track over Long Island. These storms, such as Gloria (1985) and Donna (1960), have featured sustained winds of 60 mph, gusts over 100 mph, and rainfall totals between 3 and 5 inches. In contrast, storms tracking farther west generally produce more rainfall, including Irene (2011), which produced 8 to 12 inches of rain locally and nearly 7 inches in Central Park. Finally, storms tracking east of Long Island generally produce higher wind speeds but lower rainfall amounts. For example, Esther (1961) produced 98 mph gusts in Central Park, but only 1 to 3 inches of rain.

Storm surge driven by hurricanes varies depending on storm trajectory, intensity, and timing relative to high tide. While not a particularly intense storm at landfall, Superstorm Sandy experienced a larger-than-average radius of maximum winds, allowing the surge to build up days in advance of the storm. In addition, Sandy was blocked by a high-pressure system, which prevented the storm from steering away from the coast. These factors combined with landfall to the south of New York City during an astronomically high tide created a catastrophic storm surge (e.g., greater than 14 feet at the Battery tide gauge relative to the Mean Lower Low Water [MLLW] measure). How would the consequences from Superstorm Sandy have worsened if the storm system was stronger and stalled as it approached the service territory?

Table 2 ■ Recent historical hurricane analogs on the Atlantic Coast

Name	Date	Rainfall	Winds	Battery Water Level (MLLW)	Maximum Measured Water Level for Storm (MLLW)	Impacts
Hurricane Sandy	October 29, 2012	~0.5 to 1 inch of rain	30 to 55 mph, gusts to 75 mph	14.06 feet[1]	14.58 feet at Bergen Point Beach, NJ	Major coastal flooding and power outages in the service territory; Record maximum water level at the Battery
Hurricane Irene	August 28, 2011	~5 to 6 inches of rain	30 to 45 mph, gusts to 65 mph	9.42 feet	12.34 feet at Kings Point, NY	Center of storm passed directly over New York City. Significant inland flooding (upwards of 12 inches of rain northwest of the service territory)
Hurricane Floyd	September 19, 1999	~ 5 inches of rain	25 to 40 mph, gusts to 45 mph	—[2]	Reported[3] 15-foot storm tide at Long Beach, NC	Major inland flooding (10–12 inches of rain) in areas just to the west of the service territory
Hurricane Bob	August 19, 1991	~2.5 to 3 inches of rain	Gusts to 50 mph	5.8 feet	Reported[3] 12–15 feet at Buzzards Bay, MA	Strongest impacts just to the east of the service territory. Winds approached approximately 100 mph over eastern Long Island
Hurricane Gloria	September 27, 1985	~2.75 to 4 inches of rain	Gusts to 50 mph	8.03 feet	11.46 feet at Kings Point, NY	Storm hit at low tide, still causing flooding. 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	~1 to 2 inches of rain	Gusts to 55 mph	6.38 feet	7.18 feet at Charleston, SC	Slow-moving storm that caused significant rainfall flooding just to the west of the service territory. Locations in Pennsylvania saw approximately 10 inches of rain

[1] Sandy's storm surge was amplified, in part, because the storm coincided with high tide during a full moon.
[2] No storm surge identified at the Battery in the tide gauge
[3] Characterized using National Weather Service storm reports

Name	Date	Rainfall	Winds	Battery Water Level (MLLW)	Maximum Measured Water Level for Storm (MLLW)	Impacts
Hurricane Esther	September 18, 1961	~1 to 3 inches of rain	Gusts to 100 mph	N/A[4]	6 feet at Wilmington, NC	Coastal flooding and winds of nearly 100 mph. Significant power outages on Long Island
Hurricane Donna	September 12, 1960	~1 to 3 inches of rain	Gusts to 75 mph	10.01 feet	Reported 12.5 feet near Naples, FL	Significant coastal flooding in lower Manhattan. Strongest wind gusts of ~100 mph over New Jersey

Notes: Precipitation data are the range of observations from the three main reporting stations in the service territory. Data are from NOAA.

Wind data are the range of observations from the three main reporting stations in the service territory. Data are from NOAA.

Water level is the height measured at the Battery tide gauge in New York City, as well as the maximum water depths produced by the storm to provide relevant historical storm surge magnitudes. Data are from NOAA and the National Weather Service.

Future Projections

Dynamically downscaled global climate model projections show 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 (Knutson et al., 2013; IPCC, 2013). Increasing storm intensities indicate stronger hurricane winds and, in turn, coastal storm surge. As a result, the frequency of the strongest storms, including Category 4 and 5 hurricanes, will likely increase in the North Atlantic (Knutson et al., 2015; Knutson et al., 2013). Projections and historical data also both show a persistent northward migration of the location of hurricane maximum intensity, increasing the likelihood that a hurricane exceeding Category 2 status could make a direct hit in the New York metro region in the future (Kossin et al., 2014; Bandini et al., 2016). 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 (Knutson et al., 2013), 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 (Emanuel, 2013). 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. It can therefore be argued that climate change could make it more likely for one of these storms to impact the New York metro region, although the most dominant factor will remain unpredictable climate and weather variability (Horton and Jipeng, 2014).

Hurricane intensification has already been attributed to climate change and warming temperatures. Recent hurricanes Harvey and Florence approached the coast over sea surface waters that were significantly warmer than average, which contributed to their rapid intensification. These storms also produced catastrophic rainfall amounts, which led to widespread and record-breaking flooding. Both Harvey and Florence were complicated by their slow movement, effectively stalling near the coast as a result of weak prevailing winds aloft that were linked to abnormally large high-pressure systems situated across the inland United States. Long-lasting storms increase the likelihood that their storm surge will coincide with multiple high-tide cycles and increase the potential for destructive rainfall and winds. Recent work linked these atmospheric phenomena to climate change (Mann et al., 2017), increasing the possibility that the underlying factors driving

[4] Data not available from NOAA Battery tide gauge record.

stronger and more impactful storms could progressively become the new normal throughout the 21st century. As these slower-moving and more intense storms become more likely, a similar event occurring in the New York area would result in more significant regional impacts.

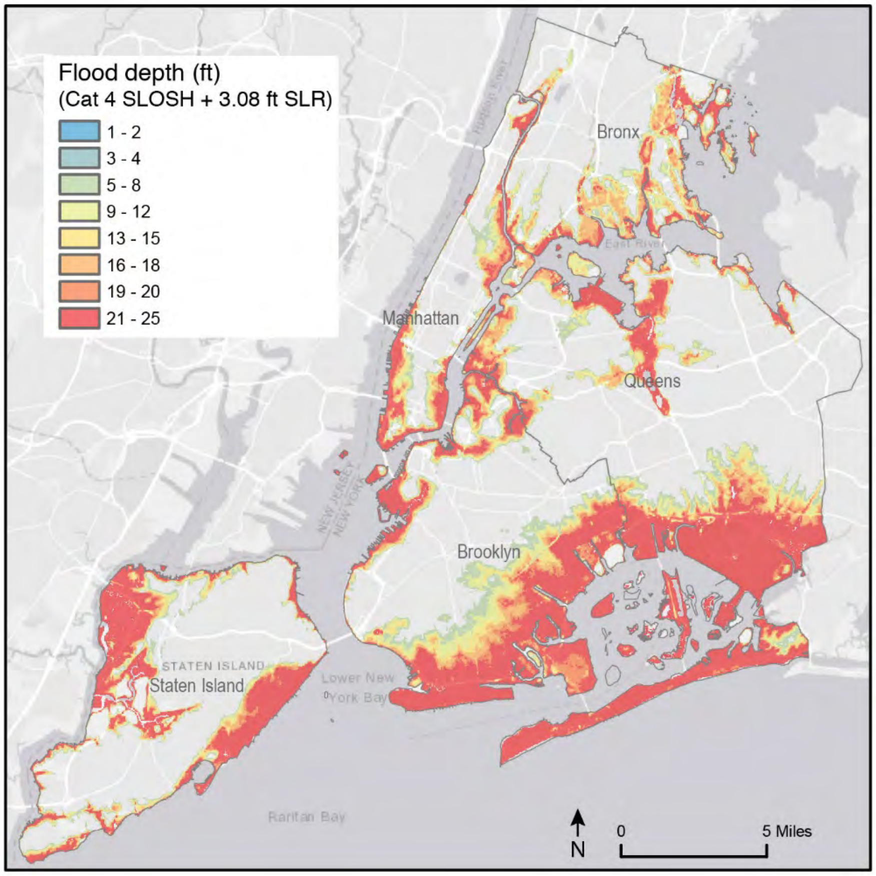
Future Narrative

A plausible extreme event worst-case scenario for mid-to-late century is for a Category 4 hurricane to track toward Long Island and stall or migrate west, immediately south of New York City, due to a significant blocking high pressure system. In this scenario, the hurricane would directly impact the Con Edison service territory for more than 24 hours. A storm of this magnitude could present the following representative risks and upper limit exposure to the service territory:

- Initial sustained winds could be as high as 130 to 155 mph at the storm center (e.g., only within the hurricane eyewall). These winds would likely quickly dissipate as the storm approaches the service territory when it interacts with land, undergoes shear, or weakens due to cold ocean water upwelling.
- Wind gusts could reach 100 mph across the service territory and remain highest near the coast. Inland locations toward Westchester County could experience lower wind gusts (~80 mph).
- Flooding depths due to storm surge could exceed 20 feet at the coast relative to MLLW (based on Category 4 NOAA SLOSH modeling)[5] for large segments of the service territory, including lower/mid-Manhattan, Harlem, and southeast-facing coastal sections of Staten Island, Brooklyn, Queens, the Bronx, and Westchester County (Figure 3).
- Projected sea level rise could exacerbate flooding extent and depth along the coast.
- Storm surge could extend through multiple tidal cycles due to the slow-moving storm. As a result, storm surge could amplify water depths at high tide (as reflected in NOAA SLOSH model simulations) and low tides could remain higher than normal due to ocean water buildup.
- Total rainfall amounts could exceed 10 inches across wide swaths of the service territory over the duration of the storm. Flooding could be exasperated at the convergence of runoff and storm surge, particularly due to base-level increases within the Hudson River backwater.

[5] Storm surge depths represent the maximum simulated storm surge at high tide relative to NAVD88 ground level and do not model potential increases in future sea levels. (https://noaa.maps.arcgis.com/apps/MapSeries/index.html?appid=d9ed7904dbec441a9c4dd7b277935fad&entry=1)

Figure 3 ■ Coastal flood extent associated with a Category 4 hurricane storm surge, modeled using NOAA SLOSH output and assuming maximum storm surge during high tide. Storm surge depths (measured as water depth above-ground relative to the NAVD88 vertical datum) are evaluated by linearly adding 3.08 feet of sea level rise. (corresponding to 83rd percentile sea level rise in 2080 assuming RCP 8.5)[6] to the SLOSH model output in order to represent estimated flood depths were a Category 4 hurricane to threaten the service territory in the late 21st century.



5.2. Extreme Heat

As described in appendices 1 and 2, extreme heat can manifest as heat waves that increase demand for air conditioning and, in turn, demand on electrical systems; derate Con Edison's infrastructure capacity; and limit the capability of efficiency reductions. The National Weather Service defines heat waves as an interval of 3 or more consecutive days with maximum temperatures of at least 90°F, whereas Con Edison defined heat waves for Appendix 2 of this study as 3 or more consecutive days where average daily temperatures exceed 86°F. In addition, heat waves often coincide with abnormally warm nighttime temperatures.

Unlike hurricanes or other extreme storms, heat wave intensity and frequency are tightly linked to long-term changes in atmospheric temperature and are thus comparatively well-simulated in climate model projections. This appendix looks at the totality of projections, independent of definition, in order to determine plausible extreme heat events in the future. Additionally, higher temperatures associated with urbanization, a phenomenon referred to as the "Urban Heat Island" (UHI) (Oke, 1982), such as from lower surface reflectivity of built surfaces and waste heat from

[6] Sea level rise projections are detailed in Appendix 4 and follow projections and methods in Kopp et al., 2014.

buildings, can exacerbate the impacts of extreme heat events. Specialized models that account for finer-scale thermal processes and feedbacks are used to understand the characteristics of the UHI effect and potential impacts it can impose on the energy sector (Ortiz et al., 2018).

Historical Information

The Con Edison service territory is already familiar with extreme heat events. Between 1971 and 2000, New York City experienced an average of two heat waves per year of 4 days in duration (NPCC, 2015). The city averaged 18 days per year above 90°F during this time period (NPCC, 2015). Recent historical heat waves analogs in New York City include the July 2019, July 1999, July 1993, and August 1953 events, which featured 4, 10, 11, and 12 consecutive days with maximum daily temperatures at or above 90°F.

Future Projections

Model projections reveal significant increases in the frequency, duration, and intensity of extreme heat days by the later 21st century in the service territory (e.g., NPCC, 2019). As discussed in Appendix 2, New York could experience up to 15 heat waves per year by late-century with average daily temperatures exceeding 86°F for 3 or more consecutive days assuming RCP 8.5 90th percentile projections, and relative to historical values of 0.2 heat waves per year. Smaller increases are projected in Westchester County.

The number of 3-day heat waves with maximum daily temperatures exceeding 90°F per year is projected to increase to 6 days by 2050 and 7 days by 2080 in New York City,[7] compared to 1.1 days per year historically.[8] Similarly, the mean heat wave duration is expected to increase to 13 days by 2050 and 27 days by 2080 (NPCC, 2019). Overall, the number of days per year experiencing temperatures above 90°F is projected to increase to 56 by 2050 and 75 days by 2080, compared to 9.6 days historically (NPCC, 2019).

Extreme heat projections should be considered within the context of synoptic scale climate and meteorological changes over the coming century. For example, the occurrence of heat waves could be exacerbated if weaker prevailing winds and static weather patterns become more common, ultimately increasing the likelihood of long-duration heat waves in the service territory. The ability of climate models to simulate the full range of possible changes in the frequency of static weather patterns is unknown.

Future Narrative

A plausible worst-case extreme event scenario for mid-to-late century is a 27-day heat wave with daily maximum temperatures exceeding 90°F each day. An event of this magnitude could present the following representative risks and upper limit exposure to the service territory:

- Maximum daily temperatures could exceed 95°F for significant stretches within the prolonged heat wave (e.g., more than 5 consecutive days).
- Temperatures could exceed 100°F within the prolonged heat wave.

[7] NPCC projections are drawn from a 52-member bias-corrected downscaled global climate model ensemble (26 models, RCP 4.5 and 8.5). Projections noted here are for the 90th percentile of the full RCP 4.5 and 8.5 model ensemble to represent plausible upper-end, or extreme, changes.

[8] Baseline refers to 1971–2000 average climate characteristics at Central Park, LaGuardia, and JFK.

- Nighttime temperatures could experience commensurate increases, meaning that daily mean temperatures could remain above 86°F for significant portions of the heat wave (e.g., for at least 20 days during the heat wave).
- The effects of UHI could lead to heterogeneous heat exposure across the service territory, with hot spots having, on average, daily maximum temperatures about 5°F warmer than surrounding areas.

5.3. Nor'easters

Extratropical cyclones, regionally and commonly referred to as nor'easters, are low-pressure systems driven by the convergence of cold polar air from Canada and warm air over the Atlantic Ocean. As a result, nor'easters occur most frequently during the cold season between November and April, when the temperature contrast between these air masses is greatest. Nor'easters track along the East Coast of the United States and typically achieve their strongest intensity as they approach New England and Atlantic Canada.

Nor'easters present a range of risks to the Con Edison service territory, including extremely heavy precipitation, hurricane-force winds, and coastal flooding. Depending on atmospheric conditions and temperatures, nor'easters can be accompanied by rainfall or frozen precipitation, including snowfall, sleet, and freezing rain. Some of the strongest nor'easters with frozen precipitation achieve blizzard conditions when winds persistently gust more than 35 mph or visibility is reduced to one-quarter mile due to heavy or blowing snow. In addition, nor'easters are often followed by intensely cold northwest winds as storm systems exit the region to the northeast.

Historical Information

Historically, nor'easters are responsible for some of the heaviest snowfall on record in the New York metropolitan region, as well as extreme winds, coastal storm surge, and ice. Table 3 highlights recent historical analogs for high-impact nor'easters. Of note are the January 23, 2016, and February 9, 2013, storms that produced up to 24 inches of snow and blizzard conditions (e.g., 40–45 mph wind gusts) in the service territory. Recent icing events include storms on February 12, 2017, and February 2, 2015, when up to 0.15 to 0.20 inches of ice accumulated locally. Finally, the December 12, 1992, nor'easter produced a storm surge of nearly 7 feet at the Battery and severe flooding along FDR Drive due to winds exceeding 75 mph in the city.

Table 3 ■ Recent historical nor'easter analogs in the New York metro region

Date	Precipitation	Winds	Water level (MLLW)	Impacts
March 2, 2018	~1.75 inches of rain	40 to 50 mph winds, gusts up to 65 mph	7.91 feet	Multiple tide cycles with coastal flooding. Strong winds caused tree and wire damage.
January 23–24, 2016	18 to 24 inches of snow	30 to 40 mph winds, gusts up to 45 mph	—[9]	Largest snowstorm on record in New York City (Central Park). Blizzard conditions observed across the service territory.
December 26–27, 2010	20 to 24 inches of snow	25 to 40 mph gusts up to 60 mph	—	Heaviest snowfall from the New York City metro area into the lower Hudson Valley. Blizzard conditions observed across the service territory.
March 13, 2010	~0.50 to 3 inches of rain	40 to 60 mph winds**	8.83 feet	Significant wind and coastal flooding event. Heaviest rainfall from New York City, south and east.
February 25–26, 2010	12 to 20 inches of snow	20 to 35 mph winds**	—	Temperatures near freezing caused a heavy, wet snowfall, with greatest amounts in the lower Hudson Valley. Tree and power line damage reported across the service territory.
February 11–12, 2006	~24 inches of snow	25 to 45 mph winds**	—	Storm fell short of blizzard conditions in some areas; however, strong winds still caused power outages.
February 16–17, 2003	15 to 20 inches of snow	25 to 50 mph winds**	—	Cold temperatures (in the teens) combined with very heavy snowfall and strong wind gusts.
January 7–8, 1996	20 to 24 inches of snow	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	10 to 14 inches of snow	Gusts of 60 to 70 mph	8.35 feet	Snow changed to rain, then back to snow. Extreme wind gusts caused significant power outages. Coastal flooding also reported.
December 11, 1992	~2.5 inches of rain	Gusts of 65 to 75 mph	9.69 feet	Significant flooding in the New York City region. Power outages impacted transportation systems. Snow fell the next day (~6 inches).

Notes: Precipitation data are the range of observations from the three main reporting stations in the service territory. Data are from NOAA.

Wind data are the range of observations from the three main reporting stations in the service territory. **Indicates that these are the peak wind speeds. Data are from NOAA.

Water level is the height measured at the Battery tide gauge in New York City. Data are from NOAA.

Future Projections

As with hurricanes, it remains difficult to adequately resolve individual nor'easters in global climate model projections. However, focused studies using regional downscaled climate models can help approximate their direction and magnitude of future change (Colle et al., 2013; Colle et al., 2015). Some studies project an increase in storm track density and frequency of the most intense storms along the East Coast toward mid-to-late century, due to amplified temperature gradients between merging polar continental air and the warm Atlantic Ocean. In particular, studies reveal a 10% to 20% increase in cyclone track density over the East Coast, as well as a 10% to 40% increase in the frequency of very intense (e.g., 980 mb)[10] storm systems (Colle et al., 2013) by late century

[9] No significant storm surge identified at the Battery tide gauge.

[10] Millibars (mb) are a metric measurement of air pressure, usually adjusted to sea level so that different areas can be compared. The average air pressure at sea level is 1,013 mb. Strong storms have low air pressures. While typical low-

simulating both RCP 4.5 and 8.5 scenarios respectively. In addition, models suggest a 20% to 40% increase in storm strengthening (i.e., producing the types of storms with destructive winds) immediately inland of the coast, suggesting stronger storms may more frequently impact the densely populated Interstate 95 corridor, including the New York City metro region, with heavy precipitation, wind, and storm surge (Colle et al., 2013).

Similar to projected changes in extreme precipitation associated with hurricanes, extratropical cyclones along the East Coast could become 5% to 25% wetter in the future relative to present-day (Zhang and Colle, 2017). Precipitation type (i.e., rainfall versus frozen precipitation) associated with nor'easters is determined by air temperatures. Models project that snowstorms are expected to decrease in frequency over the coming century in a warming climate (Zarzycki, 2018). However, 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 Con Edison service territory (Zarzycki, 2018). This means that while the likelihood of a given nor'easter producing snow instead of rain will decrease in the future, storms will produce more snow (or ice) than in the present day if atmospheric conditions are cold enough to support frozen precipitation (Zarzycki, 2018).

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. Nor'easters 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, large uncertainty associated with future changes in extratropical cyclones, including nor'easters, remains.

Future Narrative

A plausible extreme event worst-case scenario for mid-to-late century is for the Con Edison service territory to be inundated by a historically unprecedented nor'easter tracking immediately east of New York City, with regional impacts persisting for 24 hours. An event of this magnitude could present the following representative risks and upper limit exposure to the service territory:

- Storm track allows all precipitation to remain frozen, resulting in 30 inches of snow accumulation in New York City (Central Park) and higher amounts (up to 40 inches) in Westchester County.
- Incursion of warm air aloft could cause widespread ice accumulation of up to 0.5 inches before the snow event.
- Wind gusts could reach between 50 mph and 80 mph across the territory.
- Storm surge could exceed 10 feet at the Battery relative to MLLW, based on historical precedent (e.g., the nor'easter of December 1992 detailed in Table 3).
- Storm surge could extend through multiple high tides and be amplified due to the long-lasting nature of the slow-moving storm.
- Bitterly cold, subzero temperatures could last several days following the storm, as northwest winds draw cold polar air into the region from Canada.
- Cold snap could be broken by several days of temperatures well above freezing, causing rapid snowmelt and salt runoff into the underground system.

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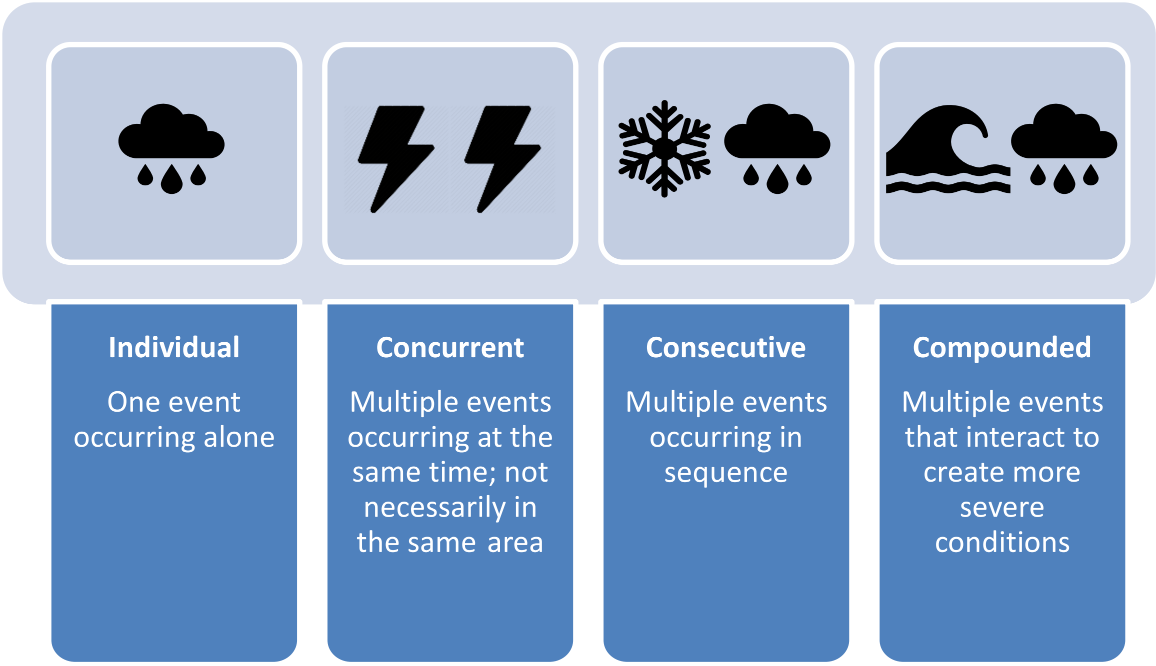
pressure systems have air pressures near 1,000 mb, very intense mid-latitude cyclones, such as nor'easters, have air pressures closer to 980 mb. For comparison, Category 4 hurricanes often have air pressures below 950 mb.

5.4. Multiple Extreme Weather Events

While preceding appendices assess the likelihood and consequences of climate hazards individually, Con Edison recognizes that multiple extreme events can occur concurrently or consecutively, which can combine to create compounded conditions and impacts within the service territory (see Figure 4).

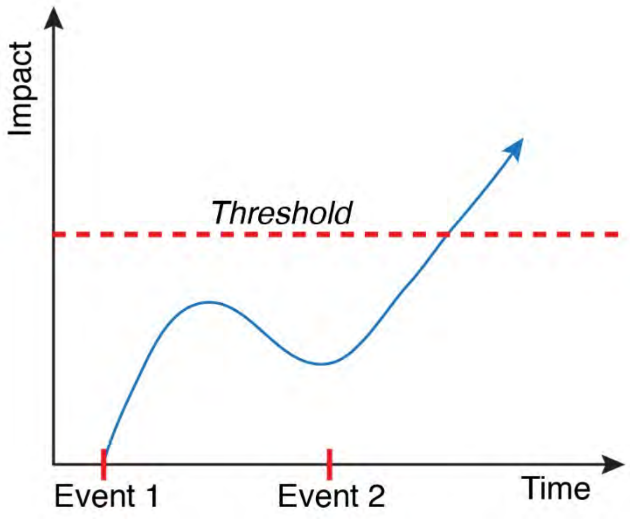
Figure 4 ■ Temporally determined relationships between multiple extreme weather events



Compounded events often form a cascade whereby individual events increase the likelihood of one another. For example, changing precipitation and storm patterns due to climate change, in the presence of sea level rise, can cause more frequent extreme rainfall and storm surge that, in turn, increase the likelihood of flooding. Consideration of the interconnected nature between climate hazards and their associated impacts across time and space can provide a more complete assessment of risks than considering only one hazard at a time. This approach could prove critical in addressing mounting challenges associated with increasingly complex hazards in a changing climate.

Multiple extreme events cause two categories of impacts. First, each event causes independent consequences as if occurring separately. Second, multiple events may have compounding impacts that are made more severe because the extreme events occurred simultaneously or consecutively. One way that multiple events create compounding impacts is if the sum of their independent consequences exceeds a resilience threshold, beyond which Con Edison's physical assets and system-oriented assets or communities are unable to cope (Figure 5).

Figure 5 ■ This conceptual model shows increasing impacts from multiple extreme events exceeding a resilience threshold.



Multiple extreme events can exceed resilience thresholds on a range of spatial and temporal scales. At the local scale, consecutive nor'easters in March 2018 impacted the service territory in sequence, which resulted in more than 7,000 repair jobs affecting nearly 210,000 Con Edison customers (Con Edison, 2018c). In this case, multiple events hampered Con Edison's emergency response by stretching workforce capacity, limiting work time, and restricting access to nearby mutual assistance resources. At a regional scale, concurrent extreme events occurring across different areas may similarly degrade Con Edison's system and lead to compounding consequences. For example, a hurricane impacting the Gulf Coast can stress supply chains and the bulk power system in ways that limit Con Edison's capacity to address local events.

While extreme events are strongly controlled by natural weather conditions at a range of spatiotemporal scales, it's 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 Con Edison service territory will experience extreme heat waves through 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 occur concurrently, consecutively, or in a compounded nature.

At the March 12, 2019, internal workshop, 25 Con Edison SMEs were asked to provide insight into the combinations of events that may be particularly disruptive to the service territory. They identified the relevant consequences associated with each combination of events and categorized these concerns by affected asset group. Table 4 presents their responses, organized by extreme event category.

Table 4 ■ Multiple extreme event combinations, including primary extreme events (e.g., hurricanes) and sub-drivers (e.g., downpours and heavy winds)

First Event	Second Event	Key Concerns
Hurricanes		
Downpour	Cold Snap	**Gas:** Cracked mains; low pressure
	Heavy Winds	**Overhead:** Damage to overhead distribution lines and utility poles from undermined trees
Storm Surge	Heat Event	**Substations:** Equipment failure during a period of high loads
	Cold Snap	**Steam Distribution:** Isolated customers; delayed restoration; increased system demand
	Downpour	**Steam Distribution:** Isolated customers; delayed restoration; increased system demand **Steam Mains:** Flooding of mains; customer outages; delayed customer restoration; accelerated deterioration of equipment **General:** Overwhelmed water handling equipment from flooding; forced shutdowns
Heavy Winds	Downpour	**Switchgear, Insulators:** Water intrusion, causing flashover
Hurricane	Nor'easter	**Health and Safety:** Major system disruption; access for recovery efforts limited
Heat Waves		
Heat Event	Heat Event	**Electrical Underground:** Multiple locations without multiple contingencies
Drought	Heat Event	**Electrical Underground:** Reduced cooling for transmission feeders **Steam:** Impacted cooling capacities from increase in river or municipal water temperature; crippled steam production from restricted municipal water usage
Nor'easters		
Ice Storm	Cold Snap	**Electrical Underground**: Salt flow into manholes
Snowfall	Cold Snap	**Manholes:** Salt flow into manholes; manhole explosions **Above Ground:** Electric shocks; cable failures
	Downpour	**Electrical Underground:** Salt impacts
	Snowfall	**Electrical Underground:** Salt impacts
	Ice Storm	**Switchgear, Insulators:** Contaminated insulators from de-icing salts; flashovers
	Heavy Winds	**Overhead:** Damage from heavy, wet snow
	Thunderstorm	**Manholes:** Flooding
	Nor'easter	**Overhead:** Electric failures, damaged equipment, high demand
Cold Snap	Nor'easter	**Steam Station:** Ability of backup fuel (#6 oil) to enter New York harbor
Nor'easter	Heavy Winds	**Overhead Electric:** Damaged overhead equipment from heavy, wet snow

Combining information from SMEs and climate projections highlight multiple extreme event scenarios that could present outsized risks to Con Edison's service territory. 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. For example, the region could experience an increased risk of major hurricanes followed by extended extreme heat events (Matthews et al., 2019), which would compound impacts to Con Edison's system and customers if restoration times are slow and power outages caused by the storm persist through the heat wave. This combination of events may lead to high customer demand while critical system components are not functioning. As a result, large portions of Con Edison's customer base may lose cooling capabilities, 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.

This sequence of events does not necessarily require a major hurricane. Potential increases in severe summertime thunderstorm activity and lightning strikes due to increased atmospheric convective potential in a warmer climate could cause more frequent outages that, occurring in sequence with an extreme heat wave, could create similarly adverse conditions over a shorter duration and more localized scale. Other combinations of extreme events have similarly context-dependent impacts.

For cold snaps, the primary concern is if low temperatures delay the response effort for other extreme weather events. Additionally, a cold snap can crack gas mains, allowing subsequent rainfall or water from melting snow to seep into the system.

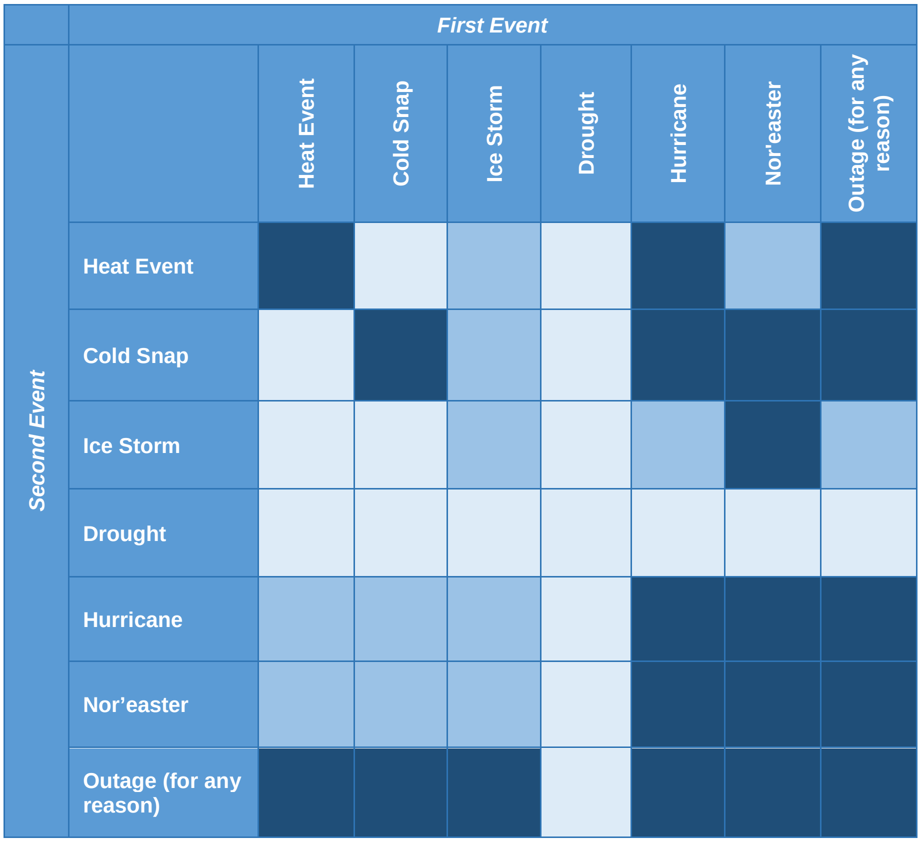
Ice storms followed by warm weather (i.e., temperatures below freezing followed by several days with temperatures above 60°F) would most prominently pose risks to Con Edison's underground system. This event would more likely cause fast ice melt, which would drive an influx of salty water into manholes, ultimately causing equipment damage and increased risk of manhole fires, or even explosions.

The combination of heavy rain and storm surge, in tandem or back-to-back, can result in increased flooding issues and delayed service restoration. If existing water handling equipment is overwhelmed, it may force equipment shutdowns for steam and electric. The undermining of trees from heavy rainfall followed by wind events could lead to more overhead system disruptions.

If any of the individual events listed in Table 4 are preceded or followed by an outage, the consequences of the event are amplified. For example, when a heat event is preceded by an outage, the system can experience more pervasive and longstanding outages and may not be able to meet the high-load demand of its customers. The consequent lack of air conditioning in some areas may compromise customer health and safety, and heat wave conditions may hinder or harm repair crews. Similarly, when a cold snap is preceded by an outage, large bases of customers may lose power and experience dangerously low temperatures

Table 5 shows the relative impact of compounding events as gauged by Con Edison SMEs. Some combinations of events are more likely than others, though this was not factored into the impact intensity rating. Darker boxes represent higher relative impacts, while lighter boxes represent lower relative impacts.

Table 5 ■ Relative impact to Con Edison from multiple, compounded events. Darkest squares represent comparatively larger potential impacts. Impact scoring is informed in part by input from Con Edison SMEs



The driving events detailed in Table 5 manifest impacts through specific sub-drivers. For example, hurricanes involve storm surge, high winds, and heavy rains. While storm surge and heavy rains may contribute to flooding and asset inundation, high winds may cause pole blow-overs or power line damage from falling trees. When followed by another event, these sub-drivers have unique compounding consequences. For example, consecutive nor'easters could initially present storm surge and wind followed by snowfall, which may limit repair efforts for fallen poles and power lines. At the same time, consecutive nor'easters may cause inundated assets to freeze, further impairing these components of Con Edison's system. Unique compounding sub-driver impacts occur throughout all event combinations and motivate specific restoration and resilience strategies.

6. Historical Analogs and Con Edison's Preparedness

Con Edison is periodically faced with events that stress its system beyond previous resilience capabilities. Such events often result in infrastructure damage and can cause widespread customer outages. Table 6 outlines the 10 storms of highest customer impact to date.

Table 6 ■ Historical Con Edison storm impacts (Con Edison, 2018c)

Date	Storm Name & Type	Number of Customers with Disrupted Electric Service
10/29/2012	Superstorm Sandy	1,115,000
3/1 & 3/7/2018	Nor'easters Riley and Quinn	209,437
8/28/2011	Hurricane Irene	203,821
3/13/2010	Nor'easter	174,800
10/29/2011	Nor'easter	135,913
9/9/1985	Hurricane Gloria	110,515
9/2/2006	Tropical Storm Ernesto	78,300
2/5/2010	Snow	65,200
1/18/2006	Wind/Rain	61,486
3/31/1997	Nor'easter	45,180

Superstorm Sandy and the consecutive Westchester nor'easters (Riley/Quinn), which had the two highest customer impacts in Con Edison's history, illustrate consequences associated with extreme stress levels and highlight Con Edison's commitment to mitigating future impacts of similar events.

Superstorm Sandy hit the region in October 2012, bringing unprecedented flooding and sustained high winds. The ensuing damage to the system left over a million customers without electricity, and thousands more without steam and gas. Years later in March 2018, back-to-back nor'easters, Riley and Quinn, struck Westchester County, blanketing the region in snow and limiting access to rescue materials and personnel. The consecutive storms left nearly 210,000 customers without power for 3 days (Con Edison, 2018c).

Sandy and the Riley/Quinn storms devastated large portions of Con Edison's energy infrastructure and customer base, revealing key system vulnerabilities and successful system adaptations. Con Edison has made significant investments to increase resiliency, many of which are outlined in the company's Post Sandy Enhancement Plan (Con Edison, 2013) and Winter Storms Riley and Quinn report (Con Edison, 2018c). For example, approximately 60,000 customer outages were avoided during Riley/Quinn as a result of storm hardening efforts completed after Superstorm Sandy. The response documents provide a framework for the implementation of the following series of hardening measures.

Fortified Steam, Gas, and Electric Systems

- Adopting the Dutch approach of "defense-in-depth" to all critical and vulnerable system components
  - Upgrading and increasing the number of flood barriers and other protective structures
  - Reinforcing tunnels
  - Replacing equipment with submersible equivalents in flood zones
- Installing isolation devices to de-energize individual sections of the system when necessary
- Incorporating redundant supply sources
- Integrating stronger poles into the distribution network
- Reducing the number of customers served by each circuit
- Developing a more diligent inspection system

- Installing advanced smart meters throughout the service territory
- Selectively undergrounding portions of the overhead structure
- Proactively trimming nearby vegetation and monitoring parts of the system that are regularly disrupted by vegetation

Improved Restoration Timing and Process

- Working with the City of New York to improve access to distributed generation
- Working with municipal partners in New York City and Westchester to increase the resilience of critical infrastructure in their communities
- Improving contractor and material base for post-storm repair crews and equipment
- Updating emergency preparedness plans and running comprehensive storm drills
- Facilitating equipment-sharing programs across New York state
- Utilizing AMI to better target and inform response efforts

Strengthened Information-Sharing With Customers and Other Stakeholders

- Enhancing communications systems among customer networks
- Generating a more efficient and higher quality flow of information to stakeholders

Con Edison's extensive plan of system hardening measures demonstrates a commitment to improved future resilience. As extreme weather events intensify and occur more frequently, the implementation and expansion of these measures will become increasingly vital to the company's prosperity and customers' safety.

7. Priority Vulnerabilities and Adaptation Options

In general, Con Edison is more vulnerable to extreme events, including consecutive or concurrent extreme events, relative to chronic long-term climate changes such as increases in average temperature or heavy precipitation, because extreme events present comparatively larger impacts. While high-impact, extreme events are also low-probability, predicting their occurrence is often obscured by climate projection uncertainty and natural variability.

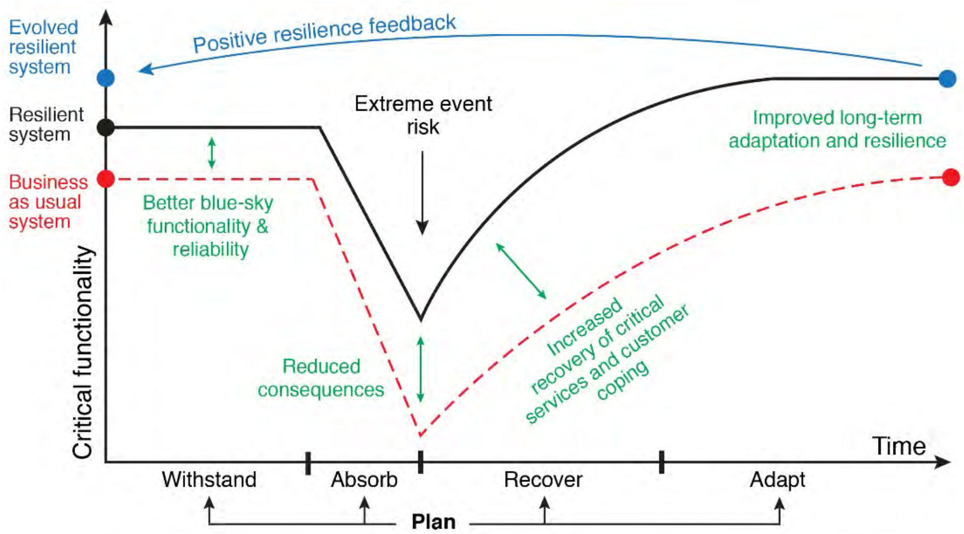
This is a critical distinction, which implies that the extreme event narratives discussed in this appendix are most appropriately viewed through the lens of stress-testing Con Edison's system to understand systemwide vulnerabilities and construct corresponding resilience measures, rather than to craft definitive hardening initiatives and design standards in the short term. In many cases, Con Edison cannot harden its energy systems to try to withstand every possible future extreme weather event. In this way, the present analysis complements previous appendices. For example, whereas flooding from sea level rise is expected to incrementally encroach the coast over the next century, making it easier to monitor and harden for storm surge from a Category 4 hurricane represents an extremely low probability event that may not be best mitigated and planned for through hardening measures alone.

In this section, the Study team reviews the vulnerability of Con Edison's system to future extreme events based on the extreme event narratives outlined in Section 5. The analysis evaluates potential critical functionality and performance losses from extreme events and major disruptions to the service territory. To address these losses, the Study team identifies ways that Con Edison could increase resilience to extreme events by using the resilience management framework described in

Section 3. In this way, Con Edison could work to maintain the critical functionality of its system and minimize impacts to customers and interdependent systems during and after extreme events.

Figure 6 details the critical concepts of a resilient management framework to address risks associated with extreme events through time. Under this framework, a resilient Con Edison system better withstands, absorbs, recovers from, and adapts to extreme events compared to less resilient, or business-as-usual, systems (see Figure 6). Section 7 addresses specific adaptation strategies to promote resilience within each facet of this framework. Ultimately, adapting to extreme events creates a positive resilience feedback, whereby systems achieve a higher resting critical functionality after integrating what was learned during extreme events into the system.

Figure 6 ■ This conceptual figure represents a resilience management framework designed to withstand, absorb, and recover from extreme event risks. Investing in a more resilient system (black line) provides benefits (arrows and annotations) relative to a less resilient, or business-as-usual, system (dashed line) before, during, and after an extreme event. Resilient systems also adapt so that the functionality of the system improves through time (blue line). Each component of a resilient system requires proactive planning and investments.



A robust resilience management framework requires proactive investments and smart planning across different components of Con Edison's broader integrated system, including the company, its customers, the city, and critical infrastructure operators and partners. While Con Edison's system can harden against extreme events to a point, other important levers are available within the resilience management framework in both the company and adjacent systems to minimize risks. To address this, the next sections focus on each component of the resilience management framework—including "withstand," "absorb," "recover" and "adapt"— that together comprise a resilient system.

Extreme events present low probability and often uniquely high stress levels to Con Edison's infrastructure and the service territory. Differences in the relationship between climate design assumptions across Con Edison infrastructure and the magnitude of extreme events require a flexible approach to choose and adopt adaptation measures to increase resiliency across the energy system. Table 7 provides a generalized framework to guide adaptation prioritizations based on the relationship between extreme event stress levels and climate design assumptions. Adaptation options draw from all of the factors highlighted in the resilient management framework

(Figure 6), including measures to withstand, absorb, recover, and adapt to extreme events, depending on the degree to which extreme event stress levels exceed design standards.

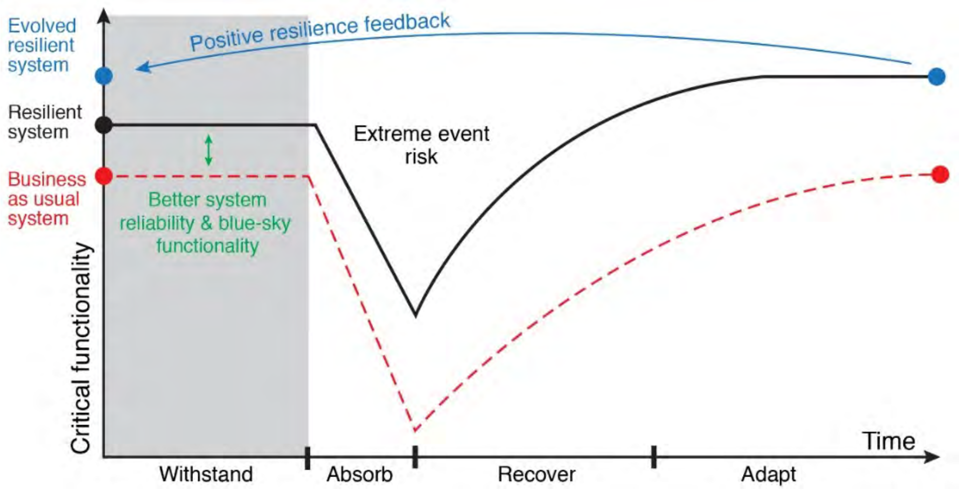
Table 7 ■ Relationship between climate stressors, design standards, impacts, and adaption options to promote a resilient management framework

Stress level relative to climate design assumptions	Impact	Adaptations
Well above	Significant impact to service level	Prioritize adaptations to increase ability to absorb, recover, and adapt
Marginally above	Increasing impact to service level	Prioritize adaptations to marginally increase ability to withstand, absorb, recover, and adapt
Within standard	Little to no impact to service level	Design standard adaptations consistent with appropriate climate change pathway

The strategies in this appendix address single, discrete extreme events, as well as those that occur concurrently or consecutively, in which an initial event compromises the system and increases the likelihood that the system experiences compounded or worsened consequences during a second event.

7.1. Withstand

Figure 7 ■ The "withstand" portion of a resilient energy system increases the reliability of the system before and during an extreme event.



Con Edison can continue its planning and investments to withstand extreme weather events to promote a more resilient energy system. Energy systems that invest in efforts to withstand against extreme climate and weather scenarios also build into their systems increased capacity, which offers important co-benefits such as better blue-sky functionality and reliability, as well as resiliency to a range of non-climate-related risks. The next sections address potential asset sensitivities and vulnerabilities within Con Edison's system related to the extreme event narratives highlighted in this appendix and provide potential adaption options to withstand them.

A critical aspect of increasing capacity to withstand extreme events across Con Edison's electric, gas, and steam systems is maintaining strong asset ratings and design standards that account for potential climate change and more frequent and severe extreme events. Some asset ratings may already be outdated and do not account for recent climate changes. For example, overhead transmission lines are rated based on the 1995 New York Power Pool Final Report on Tie-Line Ratings, which relies on weather data from 1983 through 1992. This historical dataset does not account for the future range of natural variability or for increases in temperature over the last 26 years. To ensure Con Edison uses up-to-date ratings and standards, the company could:

- **Routinely review asset ratings in light of historical observed climatology and future projections.** Across assets, there are varied approaches to reviewing and updating ratings. Climate information used for the ratings should be included in routine reviews to ensure they are in line with recent historical observations. For each equipment type, the process for conducting this review and the frequency with which it takes place should be specified and agreed upon.
- **Engage with regional partners and standard-setting bodies such as the IEEE** to assess and build consensus on how to uniformly amend utility design standards to best reflect potential and projected changes in extreme weather events.

Electric

Asset Sensitivity and Vulnerability

Con Edison's electric system includes 62 area substations and over 37,000 miles of overhead distribution lines (Con Edison, 2019a). Con Edison's underground network electric distribution system includes 65 second-contingency networks and 19 first-contingency networks spread across all boroughs of New York City and Westchester County.[11] Together, these networks serve approximately 2.6 million customers and include over 97,000 miles of underground cable and over 42,000 underground transformers. Con Edison also has non-network systems that serve parts of Brooklyn, Queens, Staten Island, the Bronx, and Westchester, known as Con Edison's radial grid (on approximately 34,000 miles of overhead wire and accounting for about 14% of Con Edison's distribution load).

The Study team collected feedback from Con Edison SMEs to characterize a more nuanced understanding of specific vulnerabilities to the electric system related to the extreme events highlighted in this appendix, including hurricanes, heat waves, and winter nor'easters. In general, hurricanes and nor'easters present physical risks associated with heavy winds, precipitation, and flooding, which can lead to widespread system outages and, at worst, physical destruction. Alternatively, heat waves present a range of effects that can contribute to failures, including lower ampacity rating while increasing load demand, causing cables and splices to overheat, transformers to overheat, and transmission and distribution line sag. Table 8 highlights these vulnerabilities, their relevant thresholds relative to plausible future extreme conditions, customer impacts, and associated adaption options to construct a more resilient system.

[11] A first-contingency or second-contingency network can continue operating with its equipment within rating limits despite the loss of one or two supply feeders, respectively.

Table 8 Electrical system asset sensitivity to extreme events and corresponding adaptation options

Extreme Event	System	Climate Design Assumptions[12]	Failure Mechanism	Degraded State	Customer Impact	Adaptation Options (withstand)
Heat wave 27-day heat wave with daily maximum temperatures above 90°F and 20 days with mean daily temperatures above 86°F[13]	Underground network distribution	10 years historical summer weather as input to the NRI reliability model.[14] Temperature variable of 86 (1 in 3) as input to load forecast model.	High temperatures result in high loads. Higher component failure rates during high load periods result in feeder failures, exceeding the NRI design standard.	> N-1 or N-2 feeders out of service in a network, or multiple networks in distress	Potential loss of service to some or all customers served by network	• High reliability components • Splitting networks • Feeder loops • Distributed energy resources (DER) • Distribution substations[15] • Technology to reduce feeder processing time (e.g., automated splicing) • Demand response
Heat wave 27-day heat wave with daily maximum temperatures above 90°F and more than 5 consecutive days with maximum ambient air temperatures above 95°F	Overhead non-network distribution	10 years historical summer weather as input to NNRI reliability model.[16] Temperature variable of 86 as input to load forecast model. Ambient temperature of 95°F (overhead wire standard).	High temperatures result in high loads. Higher component failure rates during high load periods result in feeder failures exceeding the N-1 design standard. Overhead transformer trips due to overload.	>N-1 or N-2 feeders out of service in a non-network load area	Potential loss of service to some or all customer served by distribution load area	• High reliability components • Splitting networks • Feeder loops • DER • Distribution substations • Technology to reduce feeder processing time (e.g., automated splicing)
Heat wave 27-day heat wave with daily maximum temperatures above 90°F, and 20 days with mean temperatures above 86°F	Overhead transmission system	10 years historical weather as input to TPRA reliability model.[17] Temperature variable of 86 as input to load forecast model. Ambient temperature of 95°F (overhead wire).[18]	Greater line sag during high load; high ambient temperature results in flashovers and line trips	> N-1 or N-2 transmission feeders out of service	Potential for customer impact due to loss of transmission supply to substations	• Uprate transmission lines • Higher temperature conductor • Increase tree trimming and terrain contouring

[12] Design assumptions reference assumed weather conditions.
[13] Details, assumptions, and justification for extreme event climatology are provided in Section 5.
[14] Network Reliability Index is a measure of the relative reliability of an underground network.
[15] A distribution substation comprises a bus (or buses) located in a network at a midpoint between the substation from which the network is supplied (termed an "area substation") and the distant reaches of the network.
[16] Non-Network Reliability Index is a measure of the relative reliability of a non-network load area.
[17] Transmission Probabilistic Reliability Assessment model evaluates the reliability of the transmission system.
[18] From Table 1 in the New York Power Pool Tie-Line report.

Extreme Event	System	Climate Design Assumptions[12]	Failure Mechanism	Degraded State	Customer Impact	Adaptation Options (withstand)
Heat wave 27-day heat wave, daily maximum temperatures above 90°F; More than 5 consecutive days with maximum ambient air temperatures above 95°F	Area and transmission substation transformers	Daily average temperature of 92.1°F	Nominal sensitivity to failure at higher loads	One or more substations in N-1 or N-2 state	Potential loss of service to some or all customer served by network or load area	• Load relief to reduce load on substation • Additional transformer cooling • Transformer health monitoring and trending • Demand response
Hurricane Category 4 hurricane: wind gusts up to and locally exceeding 100 mph	Overhead transmission	NESC loading district = "Heavy" 100 and 110 mph wind, 3-second gust,[19] 0.75-inch radial ice and 50 mph wind concurrently	Tower and/or line failure due to wind stress and windblown debris	> N-1 or N-2 transmission feeders out of service	Potential for customer impact due to loss of transmission supply to substations	• Address weak points in lines (e.g., compression fittings) • Reinforce transmission structures
Hurricane Category 4 hurricane: wind gusts up to and locally exceeding 100 mph	Overhead distribution	NESC loading district = "Heavy" NESC construction grade "B" (0.5-inch ice and 40 mph wind); Overhead distribution system wind design ~100 mph[20]	Damaged trees and wind-blown debris cause damage to overhead infrastructure	Multiple primary feeders out of service. Significant amounts of secondary lines out of service	Very likely more than 600,000 non-network customers and more than 1.6 million network customers[21]	• Retrofit open-wire design with aerial cable • Stronger poles (e.g., ductile iron poles) • Sectionalizing switches to reduce circuit segment size • Undergrounding • Alternate power supplies to autoloops • Increase tree trimming • Increase spares (e.g., poles) to replace critical lines • Increase staff ahead of extreme event to increase recovery time
Hurricane Up to 10 inches of rain in 24 hours	Substations	6 inches of rain in 24 hours	Substation flooding	Overflow of oil-contaminated water from transformer spill moats	No direct impacts	• Raise height of transformer moats • Install additional oil-water separator capacity • Increase pumping capacity

[19] In Staten Island, the design wind speed is 110 mph. In most of Westchester County, the design wind speed is 100 mph on the west side and 110 mph to the east side.
[20] Based on modeling that uses O-Calc Pro, applies NESC rule 250C, and assumes nominal 3-second wind gusts and standard overhead line pole construction (three-phase open-wire crossarm, secondary services, one aerial cable, and three-telecom bundle, but no transformer or other primary equipment).
[21] Values reflect territory-wide overhead outage counts caused by Superstorm Sandy, which represent the maximum weather-induced outage count on record at Con Edison. These outages interrupted approximately 70% of non-network customers. Network customer count reflects substations that could be inundated during a Category 4 hurricane.

Extreme Event	System	Climate Design Assumptions[12]	Failure Mechanism	Degraded State	Customer Impact	Adaptation Options (withstand)
Nor'easter Wind gusts up to and locally exceeding 80 mph	Overhead transmission	0.75-inch radial ice and 50 mph wind concurrently	Tower or line failure due to ice/wind stress	> N-1 or N-2 transmission feeders out of service	Potential for customer impact due to loss of transmission supply to substations	• Address weak points in lines (e.g., compression fittings) • Reinforce transmission structures
Nor'easter 30–40 inches of snow in 24 hours; wind gusts up to and locally exceeding 80 mph	Overhead distribution	NESC loading district = "Heavy" NESC construction grade "B" (0.5-inch ice and 40 mph wind) 6 inches of heavy wet snow in 24 hours [22]	Widespread damage/destruction of the overhead system Snow and ice loading of overhead components	Multiple primary feeders and secondary lines out of service	Up to 850,000 customers without power across the service territory[23]	• Retrofit open-wire design with aerial cable • Stronger poles • Sectionalizing switches to reduce circuit segment size • Undergrounding • Alternate supplies to autoloops • Increase tree trimming • Increase spares (e.g., poles) to replace critical lines • Increase staff ahead of extreme event to increase recovery time
Nor'easter 30–40 inches of snow in 24 hours, followed by prolonged cold and warmup	Underground distribution	6 inches of snow in 24 hours	Salt infiltration into underground system, causing arcing and failure of underground components	Multiple secondary main burnouts; manhole events	Scattered customer interruptions	• Upgrade high-failure rate cable • Refurbish higher risk underground structures • Vented manhole covers • Grid intelligence (e.g., structure observation system)

[22] Electric Operations Emergency Response Plan
[23] Assumes 40 inches of snowfall and 80 mph wind gusts.

Outage Risks and Vulnerabilities

Hurricanes

Intense hurricanes are projected to become more common in the North Atlantic basin over the 21st century, which increases the risk to coastal areas like New York City. These extreme storms present a range of potential adverse impacts to Con Edison's electrical system. The electric system's vulnerabilities to hurricanes are largely to overhead transmission and distribution systems (due to extreme winds) and to assets such as area and unit substations, due to flooding from storm surge and heavy precipitation.

To help characterize the magnitude of risk to electrical system outages from hurricanes, the Study team used a model developed by Con Edison's meteorology team to predict the number of work crews required to service outages resulting from weather events. Using this model in conjunction with reasonable assumptions for background weather conditions (e.g., using historical average temperatures for the month of September), the number of Con Edison outages and customers affected across the service territory is very likely to exceed the number recorded during Superstorm Sandy (approximately 17,500 individual outages and 1.4 million customers affected including some 600,000 non-network customers and 800,000 network customers) during a Category 4 hurricane. This analysis reveals, in part, the potential for significant destruction of the overhead system due to a Category 4 hurricane, largely due to heavy wind and debris (e.g., tree impacts), which can directly affect overhead infrastructure.

Hurricanes also expose a range of Con Edison assets to inundation from storm surge, including area substations and critical facilities. As plausible tail-end events, Category 4 storms create larger magnitude storm surge compared to weaker storms (Table 9), which may exceed, or stress protections implemented after Superstorm Sandy.

Table 9 ■ Flood depths at the Battery tide gauge corresponding to different hurricane strengths and for an additional 3.08 ft of sea level rise by 2080 (representing RCP 8.5 83rd percentile sea level rise projections)[24] relative to MLLW. Flood depths represent the maximum simulated storm surge at high tide using SLOSH model outputs from the National Hurricane Center. Note that the values for Category 3 and 4 hurricanes are identical because Category 4 hurricanes exceed the maximum storm surge depth resolved and reported by the model.

Scenario	Category 1	Category 2	Category 3	Category 4
No additional sea level rise	14.7 ft	20.7 ft	23.7 ft	23.7 ft
3.08 feet of sea level rise by 2080	17.8 ft	23.8 ft	26.8 ft	26.8 ft

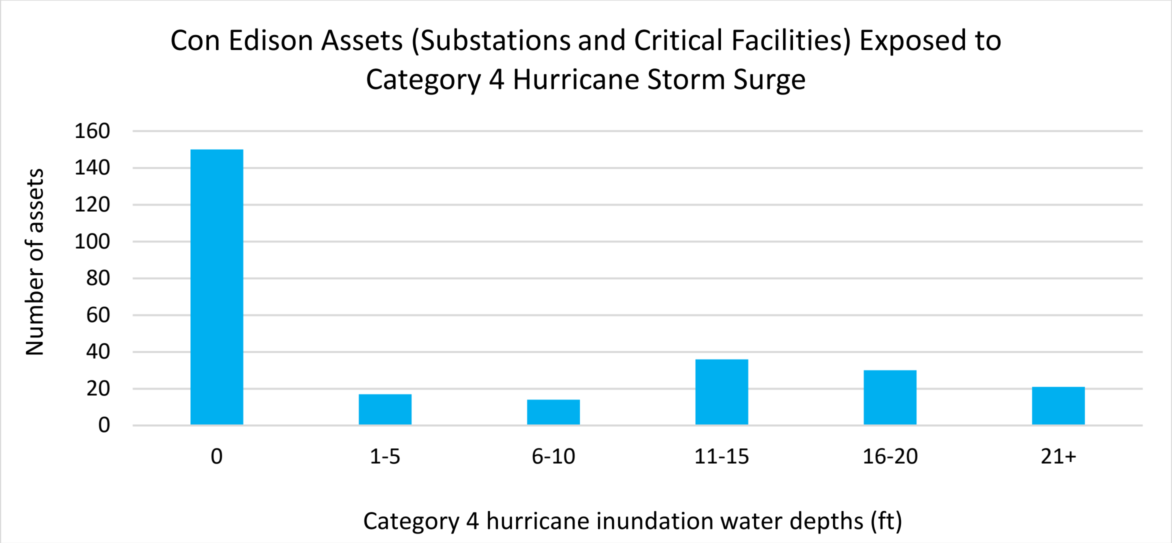
Appendix 4 of this study recommended revising design guidelines to consider both sea level rise projections and the increasing likelihood of coastal flooding. The recommendation seeks to scale design flood elevations based on the useful lifetime of an asset in order to provide higher flood protection for assets most likely to need it in the long-term, without imposing unnecessary costs on shorter-lived assets. However, hurricane-driven storm surge presents acute flooding risks that, over short periods of time, far exceed inundation associated with incremental sea level rise alone. The company's current design flood elevation is the higher of a FEMA plus 3-feet (FEMA + 3') protection or a Category 2 hurricane. The FEMA + 3' protection installed by Con Edison after Superstorm Sandy protects against storm surge associated with a Category 1 hurricane with and without an additional 3.08 feet of future sea level rise but does not protect against potential storm

[24] See Appendix 4 for detailed information on the sea level rise projections used in this study.

surge associated with stronger hurricanes (Figure 8). The recommendation to reconfigure the design flood elevations for long-lasting critical facilities (e.g., those having a useful life of 100-plus years) to FEMA + 5′ would protect against storm surge levels up to a current Category 2 hurricane, but not against additional sea level rise or stronger hurricanes. Con Edison also uses Category 3 hurricane storm surge to set the design flood elevation for long-lived assets.

As a result, Con Edison's coastal assets and infrastructure remain vulnerable to storm surge from an extreme hurricane, even with prudent design guideline revisions and the robust suite of hardening measures implemented after Superstorm Sandy. To better understand asset exposure, the Study team developed a map of the inland extent of storm surge produced by a Category 4 hurricane. A list of assets that may require new or additional hardening measures in the event of an extreme Category 4 hurricane was developed by intersecting the location of Con Edison assets with the corresponding extent of storm surge inundation.

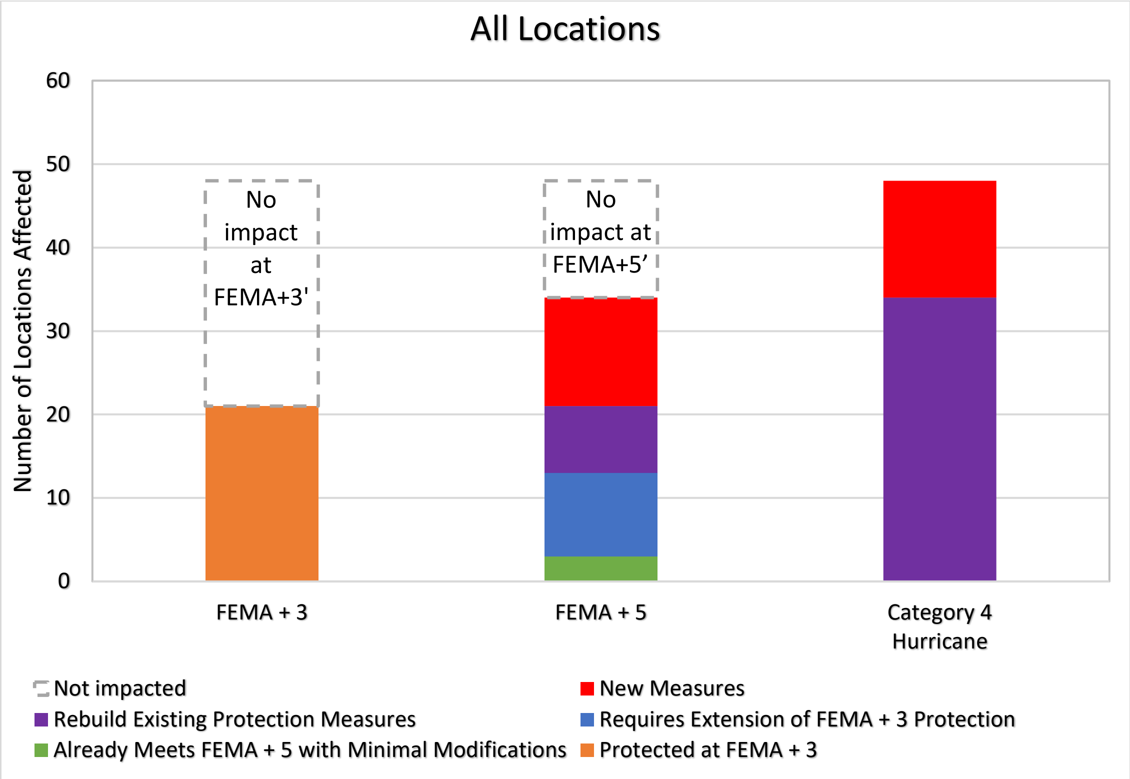
Figure 8 ■ The number of Con Edison assets (combined area and unit substations and critical facilities) exposed (or not exposed) to inundation water depths corresponding to a Category 4 hurricane storm surge. Zero inundation demotes assets that are not exposed.



Using a list of potentially exposed assets, the Study team conducted an initial screening of Con Edison substations and critical facilities locations (encompassing generating substations, area substations, PURS plants, transmission stations, and critical facilities), and found that 48 locations are exposed to potential storm surge associated with a Category 4 hurricane (Figure 8). Of these exposed locations, 34 would require rebuild of existing protection measures (e.g., existing protection measures would need to be replaced with upgraded measures) and 14 locations would require new protection measures because they would be newly inundated.

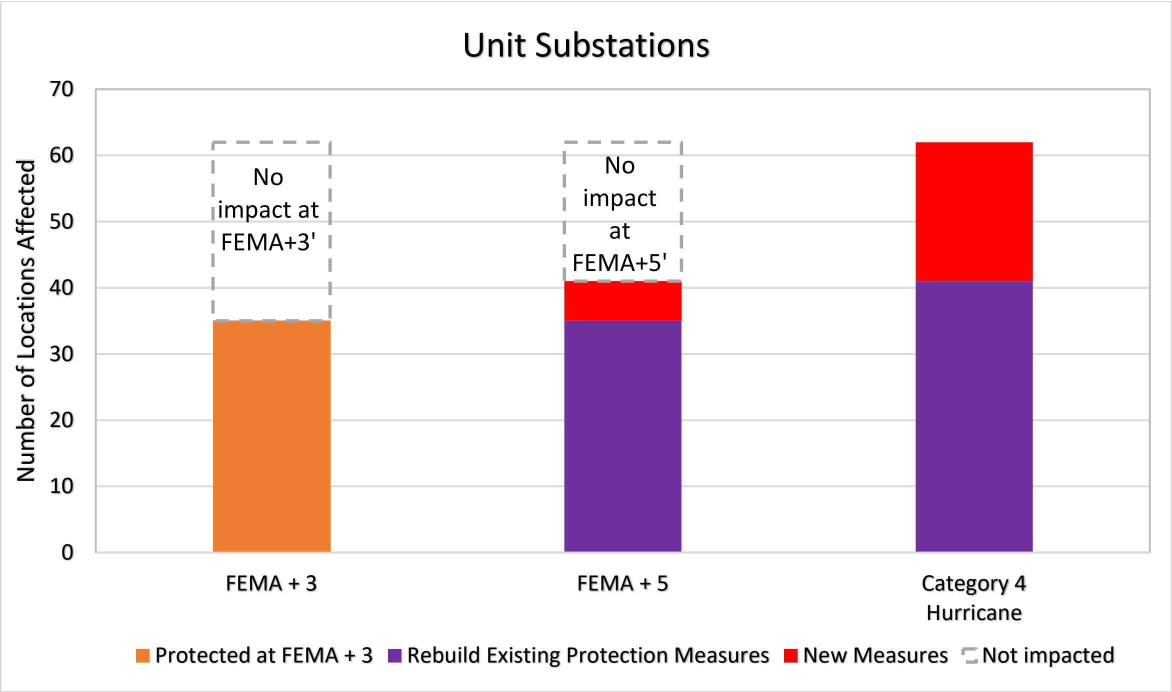
Figures 9 and 10 illustrate the degree to which asset exposure to potential storm surges could exceed the FEMA + 3′ design standard. Locations within the FEMA +3′ floodplain are either not exposed or assumed protected under the FEMA + 3′ design standard adopted by Con Edison. For example, fewer locations are exposed within the FEMA + 3′ and projected FEMA + 5′ floodplains than a Category 4 hurricane (see Figure 9). Only 8 and 13 locations would require rebuild of existing protection measures and new protection measures for the FEMA + 5′ floodplain (Figure 9). Additional assets would require extensions of FEMA + 3′ protections or already meet FEMA + 5′ with minimal modifications.

Figure 9 ■ Current protection level of Con Edison assets relative to FEMA+3' flood, FEMA+5' flood, and potential Category 4 hurricane surge scenarios, and potential for extending existing protections.



The Study team determined that, exposed to a Category 4 hurricane storm surge, 41 and 21 unit substations would require rebuild of existing protection measures and new protection measures, respectively (Figure 10). Fewer unit substations are exposed with the FEMA +3' and FEMA + 5' floodplains than for a Category 4 hurricane.

Figure 10 ■ Current protection level of Con Edison unit substation assets relative to FEMA+3’ flood, FEMA+5’ flood, and potential Category 4 hurricane surge scenarios, and potential for extending existing protections.



Nor’easters

More frequent and intense nor’easters could present similar impacts as hurricanes, such as heavy winds and storm surge, but also unique impacts such as snow, ice-loading, and cold temperatures. The extreme nor’easter narrative considers up to 40 inches of snow and 80 mph wind gusts. Using a model developed by Con Edison’s meteorology team to predict the number of work crews required to service outages resulting from weather events, this narrative could result in more than 850,000 customers without power across the service territory. These estimates do not consider additional outages due to storm surge and should be viewed through the limitations of the model, which uses historical relationships between weather and outages that under-represent extreme events. As a result, outage and customer outputs are likely overestimates in the model.

As discussed in Appendix 3, large amounts of radial ice buildup are primary concerns for Con Edison’s overhead transmission and distribution systems. In extreme scenarios, radial ice accumulation on transmission lines and towers can result in unbalanced structural loading and transmission line failure, particularly if accompanied by strong winds. Ice-covered lines coupled with high winds can also alter wind-loading dynamics, which can cause lines to swing and lead to potential failure of suspension towers. Ice-loading on Con Edison’s overhead distribution system presents similar problems, which can also be impacted by increased tree falls caused by heavy snow-loading.

Con Edison’s transmission system currently meets the NESC standard for radial ice and is fairly robust against ice accumulation. Transmission towers are designed to withstand 1-inch of uniform radial ice combined with 20lb/ft^2 wind pressures, which is considered to reflect a 100-year event.[25] Con Edison Transmission Operations also strategically reinforce suspension towers to prevent

[25] Con Edison standard, CC-SS-2006

failure and a potential "cascade" effect, whereby an initial tower failure causes adjacent towers to fail. Similarly, Con Edison's distribution system meets the National Electrical Safety (NESC) standard, rule 250B for an area with "heavy" ice loading of 1/2-inch of radial ice and 40 mph winds.

Nor'easters also present indirect impacts on Con Edison's underground electrical system. Salt is spread by the City of New York and jurisdictions in Westchester County to mitigate ice buildup on roads. Road salt spreading is particularly extensive after large storms and during prolonged cold snaps. Warmups following winter storms and cold periods lead to rapid snow and ice melt, which flushes accumulated salt into manholes and service boxes. In turn, salt can degrade wire insulation and generate heat, causing the insulation to burn. Such events can cause manhole fires, or even explosions, leading to customer outages. The extreme nor'easter narrative highlighted in this appendix would greatly increase the likelihood of this scenario.

Extreme Heat

Projected increases in the frequency and severity of heat waves could increase the frequency and severity of impacts to Con Edison's electric system. Extreme heat can cause significant increases in load, require the derating of Con Edison's infrastructure, increase component failure rates, and limit maintenance or capital work due to workforce restrictions if the work would risk additional impacts to the system during extreme heat days.

The number of 3-day heat waves with maximum daily temperatures exceeding 90°F per year is projected to increase to 6 days by 2050 and 7 days by 2080 in New York City,[26] compared to 1.1 per year historically.[27] Con Edison's design standards focus on average ambient daily air temperatures, with 86°F as a commonly used threshold for critical infrastructure including overhead transmission conductors and transformers. Looking forward, the service territory could experience up to 15 heat waves per year by late century with average daily temperatures exceeding 86°F for 3 or more consecutive days assuming RCP 8.5 90th percentile projections, relative to 0.2 occurrences per year historically. In addition, these types of heat waves are projected to last approximately 15 days longer than those experienced historically under high-end future climate scenarios.

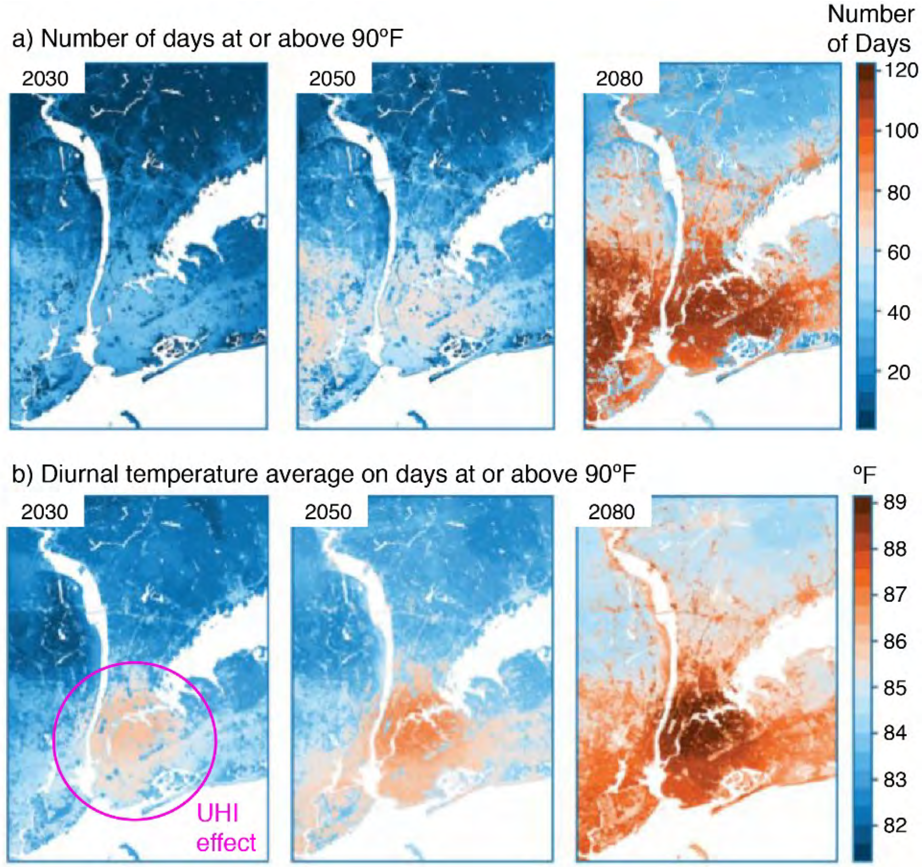
Projected temperature and heat wave increases are exacerbated by the urban heat island (UHI) effect in New York City, which forms due to the retention and emissivity of heat by the city and its building characteristics and surfaces. For example, Central Park is cooler relative to other areas of the city because it generally is covered by vegetation. As a result of UHI, the temperature difference between the city's urban areas and surrounding rural areas can be 3°–9°F (Holt and Pullen, 2007), which can amplify heat wave intensity. Figure 11 depicts both the projected number of days at or above 90°F throughout the century and the diurnal temperature average on those days using a high-resolution, down-scaled model approach These results reveal a marked increase in the number of days with average ambient temperatures above 86°F through 2050 and 2080, particularly within Manhattan, the South Bronx, Queens, and Brooklyn.

Figure 11 ■ Projected number of days at or above 90°F *(top)*, and the diurnal temperature average (i.e., average daily ambient temperature) for 2030, 2050, and 2080 *(below).* The projections use a high-resolution climate model to highlight the impact of the urban heat island (UHI) across the

[26] Projections are drawn from a 52-member bias-corrected downscaled global climate model ensemble (26 models, RCP 4.5 and 8.5) prepared by the NPCC. Projections noted here are for the 90th percentile of the full RCP 4.5 and 8.5 model ensemble to represent plausible upper-end, or extreme, changes.

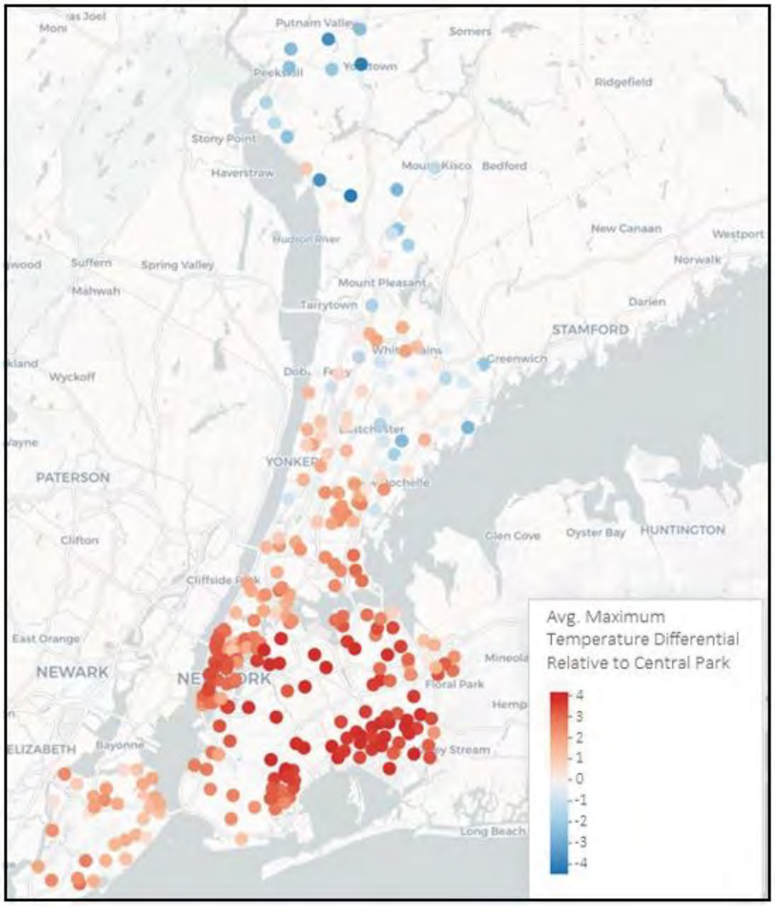
[27] Baseline refers to 1971–2000 average climate characteristics at Central Park, LaGuardia, and JFK.

territory. The core of the UHI is shown as a magenta circle, where there is a dramatic increase in the number of days with average daily ambient temperatures above 86°F by mid- and late century.



The UHI effect can cause large temperature differentials across the service territory. On average, parts of the city can experience temperatures well above those found in Central Park, while more rural areas outside of the UHI experience cooler temperatures. Figure 12 reveals that historic average maximum daily temperatures across the service territory range by approximately 8°F relative to Central Park. The warmest areas relative to Central Park are in Brooklyn and Queens.

Figure 12 ■ Historical average daily maximum temperature differentials relative to Central Park at points of interest across the service territory. Locations that are hotter on average than Central Park are shown in red, while cooler locations are shown in blue.



The UHI effect drives both amplified reductions in transformer capacity and increases in peak load in particularly hot areas of the service territory. For example, the Study team determined that transformer capacity reductions at area substations could be 10% greater relative to expected heat increases at Central Park due to the UHI effect.[28] Similarly, some network centers could experience an increase in peak load nearly 5% greater than Central Park, based on the UHI effect. As a result, load increases at network centers hotter than Central Park sum to a total of approximately 350 megawatts (MW) due to the UHI effect. These spatial heterogeneities represent important factors that could guide long-term investment planning in heat-resistant infrastructure and system components.

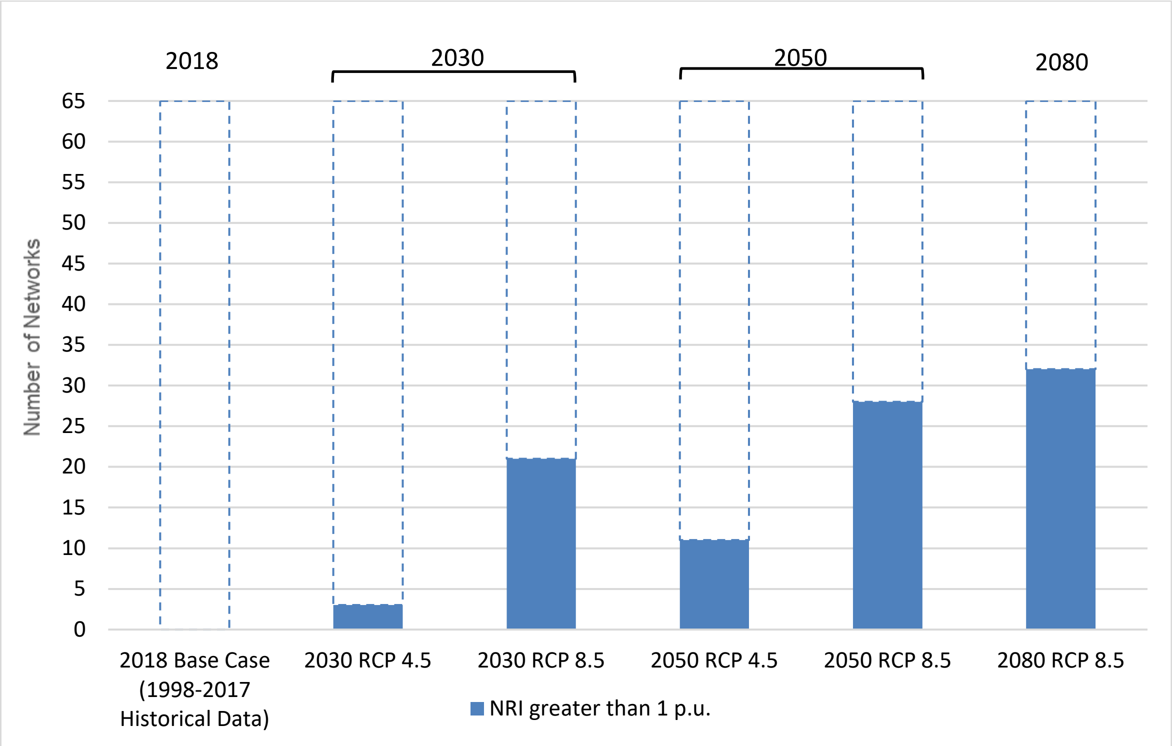
Con Edison's underground electric system is also vulnerable to extreme heat. The Study team used the NRI-DEF model to project future NRI values for each underground distribution network. NRI is a metric developed by Con Edison for assessing the reliability of its distribution networks and is a normalized index such that a value exceeding a "per unit" (p.u.) of 1 reflects a probability of failure that exceeds Con Edison's risk tolerance threshold. The forward-looking NRI analysis found significant decreases in projected network reliability associated with increases in the frequency and duration of heat waves in the coming decades based on both RCP 4.5 and 8.5 climate scenarios,

[28] These calculations use maximum 24-hour daily temperatures relative to Central Park on days when the 24-hour daily temperature in Central Park is at least 86°F.

with the largest decreases associated with the most severe warming toward end-of-century (2080) under RCP 8.5. It should be noted that the NRI analysis is based on a network system as it stands today and does not account for annual reviews and adjustments made to networks to maintain NRI year over year.

Figure 13 shows the number of networks above the 1 p.u. NRI threshold under each climate scenario. By 2030, depending on the climate scenario in question, between 3 and 21 of Con Ed's 65 networks (5%–32%) may not be able to maintain Con Edison's 1 p.u. standard of reliability, absent adaptation. This figure increases to between 11 and 28 of the networks by 2050 (17%–43%). By 2080, holding today's network configuration constant, the number of networks exceeding the 1 p.u. standard could be as high as 33 out of 65 (49%), considering high-end heat exposure under the RCP 8.5 climate scenario.

Figure 13 ■ The number of networks above the 1 p.u. NRI threshold under each climate scenario (RCP 4.5 and 8.5) for 2030, 2050, and 2080. By 2080, holding today's network configuration constant, the number of networks exceeding the 1 p.u. standard could be as high as 33 out of 65 (49%), considering high-end heat exposure under the RCP 8.5 climate scenario.



The Study team additionally used the NRI-REV model to evaluate the likelihood of an extreme 27-day heat wave significantly stressing networks, assuming that Con Edison will have reinforced network feeders to maintain existing ratios between peak load and the normal rating of feeders, which is the company's normal practice. The simulations were conducted for both the Williamsburg (6B) and Flushing (7Q) networks to represent the impact of an extreme heat wave on networks throughout the service territory. The predicted likelihood of severe network stress arising over the course of an extreme heat wave is small, assuming that Con Edison conducts annual reviews and network adjustments to maintain NRI year over year. As might be expected, the loss of a single feeder at the beginning of a heat wave increased the likelihood of severe network stress in the model but did not increase this likelihood by an order of magnitude.

Increased heat waves also impede normal maintenance and capital work. For example, maintenance on feeders and certain networks can be restricted during high heat days. Additionally, heat waves can present substantial problems if they shut down city contractors. “Hands off days” are implemented on the declaration of a heat event because of the risk of work crews damaging critical infrastructure and inadvertently causing a shutdown during peak load. Work crews are also precluded from putting in gas mains, electric conduits, and other materials because of the risk of damaging feeders. In addition to these restrictions, Con Edison can incur costs on “hands off days” because scheduled crews must be redirected to non-sensitive activities or otherwise paid for the committed time, which counts as an operations and maintenance cost to the company.

Withstand Adaptation Options for the Electric System

Con Edison could pursue (or in many cases is already pursuing) the following strategies to increase the capacity to withstand extreme event impacts related to its electric system.

Heat Waves

- **Underground and overhead distribution:** Con Edison could conduct annual reviews and install high reliability components as needed, such as replacing paper insulated lead covered (PILC) cable with newer cables in the underground system, to maintain current underground and overhead capacity and reliability in the face of rising temperatures and projected increases in heat wave severity.

  Con Edison could continue strategically diversifying and adding redundancy to the distribution system. Many measures have been shown to lower the risk of failure and effectively reduce network stress during extreme heat events. These include splitting networks into multiple smaller networks to better handle load, creating primary feeder loops within or between networks to add redundancy, installing new distribution stations to increase the diversity of supply points to a network, and incorporating distributed energy resources.

  Con Edison is also actively engaging forward-looking technologies to further reduce the impact of extreme heat on distribution systems. These include automated splicing systems to reduce feeder processing times and demand response technologies that more efficiently regulate load and, in turn, reduce failure risks.
- **Overhead transmission:** Con Edison could replace limiting wire sections with higher rated wire to reduce overhead transmission line sag during extreme heat wave events. Additionally, Con Edison could continue other measures to mitigate line sag risks, such as clearing out vegetation and contouring terrain. Because overhead lines are critical to the operation of the electric system, there is a preference for these options over derating assets. Con Edison could continue to track line sag and areas of vegetation change via LiDAR flyovers to identify new segments that may require adaptation. Finally, the company could explore incorporating higher temperature rated conductors.
- **Area and transmission substation transformers:** Con Edison could develop a load relief plan that integrates future climate projections. Climate change projections drive asset ratings and load planning, which directly inform load relief planning processes to combat the potential for future extreme heat waves. Several adaptation options can contribute to load relief, including energy efficiency, demand response, adding capacitor banks or upgrading limiting components such as circuit breakers, disconnect switches, and buses. At increasing cost, Con Edison could gradually install transformer cooling, or replace existing limiting transformers within substations. Finally, Con Edison could expand technologies to ensure the health of transformers in the face of extreme heat, including health monitoring and trend analyses.

Hurricanes

- **Overhead transmission:** Hurricanes and other tropical storms present unique wind stress to Con Edison's system. To strengthen the overhead transmission system, Con Edison could continue and expand its existing programs to reinforce transmission structures, and address components that are known to have high failure rates (e.g. compression fittings) by upgrading infrastructure or prioritizing them in replacement planning.
- **Overhead distribution:** Con Edison's overhead distribution system could adopt a diverse set of adaption options to better plan and withstand the impacts of hurricanes, ranging from infrastructure retrofits to proactive operational planning. For example, Con Edison could invest in retrofits for open wire design with aerial cable and stronger poles, such as ductile iron poles. Ductile iron poles have been shown to be more resilient to high winds in regions traditionally susceptible to extreme weather, such as Oklahoma City (Powertech Associates, 2018) and the Florida Keys (Transmission & Distribution World, 2011). At high costs, Con Edison could underground critical sections of the overhead distribution system to ensure resilience against hurricane force winds and storm surge.

  Additionally, Con Edison can continue to explore and expand operational measures to increase resiliency of the overhead distribution system, such as increasing tree trimming efforts to limit tree-on-line events, as well as increasing spare pole inventories to replace critical lines that are compromised during extreme weather events.
- **Overhead distribution outage planning:** Con Edison could complement the existing meteorological model used to predict work crews required to service weather-driven outages with an updated model that better resolves extreme weather events and extreme weather impacts to customers in the service territory. The current model's predictive power depends on the historical relationship between weather events and workforce requirements, however the lack of historical information on extreme weather in the service territory limits model capability. An updated model could run Monte Carlo simulations of extreme weather and its impact on Con Edison assets to better resolve outages under the types of extreme events (e.g., hurricanes) that lack historical precedent in the service territory. Finally, the model could resolve customer counts at the distribution level so that Con Edison can better anticipate and prepare for customer impacts under extreme weather scenarios.
- **Substations:** Substations are potentially vulnerable to storm surge and heavy rainfall during extreme hurricanes. To withstand storm surges from a Category 4 hurricane, Con Edison would need to address the 48 substations and critical facilities locations (including generating substations, area substations, PURS plants, transmission stations, and critical facilities) identified as vulnerable by either extending existing protection or constructing new protection measures as appropriate. To withstand flooding and secondary effects such as spillover of contaminated moat water during storms, Con Edison could raise the heights of transformer moats, install additional oil-water separator capacity, or increase "trash pumps" behind flood walls to pump water out of substations, as a last resort.

Nor'easters

- **Overhead transmission:** To combat extreme wind, snow, and ice-loading, Con Edison could continue to expand its programs to reinforce transmission structures, and expand the number of compression fittings used to address weak points in transmission lines.
- **Overhead distribution:** Con Edison could invest in adaptations to better withstand against nor'easters similar to those listed above for hurricanes. These measures could include sectionalizing switches to reduce circuit segment sizes.

- **Underground distribution:** Con Edison could employ a number of adaptation options to better withstand against the impacts of large snowmelt events after extreme nor'easters and coincident saltwater infiltration into the underground distribution system. These options include upgrading high failure rate components, installing vented manhole covers, and continuing to invest in underground observation systems to identify and preempt high-risk areas of the system.

Gas

Con Edison provides gas service to approximately 1.1 million customers. The gas distribution system includes approximately 8,000 miles of pipes with 4,000 miles of local gas distribution lines.[29] The distribution system operates at three pressures: 33% operates at high pressure, 11% at medium pressure, and the remaining 56% at low pressure.

Asset Sensitivity and Vulnerability

Con Edison's gas system is primarily situated below ground, which makes it more resilient than the electric system to sub-aerial extreme weather events such as heat waves, high winds, and lightning. The vulnerabilities of the gas system to extreme events are largely within its gas transmission and distribution systems. These vulnerabilities arise from heavy precipitation and storm surge intrusion. The gas system is also vulnerable to demand increases during cold snaps, potentially concurrent or consecutive with nor'easters, which can potentially exceed system capacity. These vulnerabilities, and potential adaptation measures to withstand them, are highlighted in the discussion and Table 10 below.

Flooding and water intrusion into the gas distribution system due to heavy rainfall (up to 10 inches in 24 hours) or storm surge during hurricanes can interrupt gas flow to customers. Water can enter low-pressure mains through joints, or through open excavation and work sites, causing low gas pressure for customers or interruption in gas service. To alleviate the impacts of water infiltration, Con Edison's low-pressure gas distribution system includes over 8,000 "drip pots" that collect water at low points in the system. Currently Con Edison uses a standard of 1/2-inch of forecast precipitation in a single day to trigger pumping of select drip pots prior and during heavy rain events, although Gas is exploring the option of installing a remote monitoring program to select the timing and location of pumping. Water in the system is difficult to locate and remove, and generally requires excavation and construction. Where and when possible, main replacement to higher pressure can eliminate future impact.

Heavy precipitation and flooding during an extreme Category 4 hurricane may also pose a risk to gas regulator vents, particularly if they are within storm surge inundation footprints, or flood-prone areas (geographic lows). Flooding of regulator stations can result in higher than normal pressure in gas mains, which can lead to scattered customer interruptions and require long repair times due to the nature of the infrastructure.

Finally, Con Edison's gas system is designed to supply demand down to 0°F, which may be compromised during intense stand-alone cold snaps, or cold snaps occurring concurrently or consecutively with nor'easters when energy demand generally increases. Low temperatures during such events cause high demand which can exceed system capacity. Under an extreme scenario, this chain of events can lead to the loss of service for a significant number of customers.

[29] https://www.coned.com/en/about-us/corporate-facts

Withstand Adaptation Options for the Gas System

Con Edison could pursue (or in some cases is already pursuing) the following strategies to increase the capacity to withstand extreme event impacts related to its gas system.

Hurricanes

- **Gas Distribution:** Con Edison can reduce depressurized gas mains brought on by heavy precipitation or storm surge flooding by continuing its targeted main replacement program. This program targets 1,900 miles of pipes that are potentially prone to water intrusion, leaks, or other concerns, based on an engineering assessment. Assets prioritized for replacement include low-pressure mains in low-lying areas (e.g., FEMA + 3′ flood zones). The present accelerated plan would complete main replacement by 2036. Con Edison can additionally explore and implement ways to elevate system pressure during low flow (pressure) conditions.

  As part of these efforts, Con Edison is currently developing a program using machine-learning and remote monitoring capabilities to identify leak-prone areas of the gas distribution system and sensors that will more efficiently, episodically drain drip pots. Continued investment in this program will help withstand future extreme precipitation and storm surges, as well as reduce the workforce effort required to monitor drip pots.
- **Gas Regulators:** Con Edison could also strategically expand its program to elevate gas regulator vent line termini above the FEMA + 3′ flood elevation to include additional regulators exposed to floodplains associated with stronger storms. Additionally, Con Edison could transition to more frequently using compressed natural gas tank stations.

Nor'easters

Gas Transmission: Con Edison could employ similar adaptation options to counteract the risk of high gas demand exceeding system capacity during extreme cold events, as might follow an extreme nor'easter. These options include adding additional gate stations, constructing larger and/or additional transmission mains, and adding larger ties between mains to diversify gas transmission. In addition, Con Edison could work to install remote operated valves to more efficiently isolate load for load-shedding.

Table 10 ■ Gas system asset sensitivity to extreme events and corresponding adaptation options

Extreme Event	System	Climate Design Assumptions[30]	Failure Mechanism	Degraded State	Customer Impacts	Adaptation Options (Withstand)
Hurricane **10 inches of rainfall within 24 hours; storm surge up to 20 feet above MLLW**	Gas Distribution	½-inch of rain in 24 hours for the low-pressure gas distribution system. Regulators must have their vent line terminus above FEMA + 3' elevation or install a vent line protector (VLP)	Flooding results in water infiltration into gas mains, interrupting flow; flooding of regulator stations results in higher than normal pressure	Numerous gas mains with water infiltration; overpressure of mains	Scattered customer interruptions with prolonged restoration	• Main replacement (program ongoing) • Deploy "drip pot" monitoring technology • Raise regulator stations • Elevate system pressure • Compressed natural gas tank stations
Nor'easter **30–40 inches of snow in 24 hours; potential for subzero temperatures over multiple days**	Gas Transmission	Gas transmission system designed to supply demand down to 0ºF	Low temperature causes high demand which exceeds system capacity	System pressure below design; load-shedding required to maintain pressure	Loss of service to significant numbers of customers	• Additional gate stations • Larger transmission mains • Additional transmission mains • Additional and/or larger ties between mains • Remote operated valves to isolate load (load-shedding)

[30] Design assumptions reference assumed weather conditions.

Steam

Con Edison's steam system provides service to more than 3 million Manhattan residents, from lower Manhattan to 96th Street. Like the gas system, much of the steam system is below ground, which generally makes it more resilient to extreme events such as heat waves and strong winds. To further strengthen resilience, Steam Operations considers various operational moves to protect the integrity of the system ahead of a large storm. These measures primarily work to mitigate the impacts of flooding from large storms, including steam main shutdowns that isolate and depressurize flood-prone locations,[31] segmentation of the steam system, and the temporary shutdown of steam generation stations that are not designed to operate in forecasted storm conditions.

Con Edison has also invested in a range of hardening measures, including hardening of steam production stations, waterproofing and/or relocation of critical equipment, installation of a new steam main tie-in that ensures continued service to the Lower East Side hospital corridor. Ultimately, Con Edison is mindful of flooding sources such as rainfall deluges and storm tides and has established appropriate physical and operational risk mitigation strategies, which are periodically reviewed and updated.

Asset Sensitivity and Vulnerability

The vulnerabilities of the steam system to extreme events are largely within the steam generation and distribution systems. Critical vulnerabilities arise from flooding within these systems, either through heavy rainfall during hurricanes or coastal storm surge driven by hurricanes and potentially nor'easters as outlined in the extreme event narratives in Section 4. These vulnerabilities, and potential adaptation measures to withstand them, are highlighted in the discussion and Table 11 below.

Steam generation stations are particularly vulnerable to flooding from storm surge associated with a Category 4 hurricane. Steam generation stations are currently built with flood protections accommodating a FEMA 100-year storm plus 3 feet of freeboard, which would likely be exceeded by a Category 4 hurricane storm surge. Future risks posed by extreme hurricane storm surge could be exacerbated by sea level rise. In turn, flooding of generating station equipment could degrade plant capacity, or force unit or plant outages. Vulnerabilities to storm surge flooding pose a range of downstream impacts to customers, including preemptive customer outages and load-shedding to maintain pressure within the steam system and steam function limitations due to low system pressure. Significant flooding damage to generating stations could require significant repair times, further increasing the duration of customer impacts.

The steam system includes 3,000 manholes within the service area, through which water can enter and disrupt the steam system. Large amounts of precipitation falling over a short time during an extreme Category 4 hurricane (e.g., an inch of rain per hour for several hours), or storm surge flooding during a hurricane or nor'easter, presents potential risks to Con Edison's steam system due to condensate collection leading to "water hammer events." For example, water collecting in significant quantities in a manhole can pool around a steam pipe and cause the steam inside to cool and form condensate. A buildup of condensate can interact with steam in ways that can lead to catastrophic rupture in a steam pipe. These vulnerabilities could be exacerbated by a city sewer and stormwater drainage system overwhelmed by heavy rainfall and storm surge during a Category 4 hurricane. In turn, flooding around the steam distribution system can cause a range of customer

[31] Following S-11995 Procedure for Steam Distribution Coastal Storm Plan.

impacts, including preemptive customer outages to prepare for flooding events, and steam supply disruptions resulting from the risk of or actual water hammer event.

Withstand Adaptation Options for the Steam System

Con Edison could pursue (or in some cases is already pursuing) the following strategies to increase the capacity to withstand extreme event impacts related to its steam system. In general, options that address flooding vulnerability from extreme hurricanes are also applicable to nor'easters.

Hurricanes

Steam generation: Con Edison could consider additional storm hardening investments over and above measures introduced post-Superstorm Sandy to protect steam generation sites against extreme hurricane-driven storm surge. These investments could leverage new innovations and advancements in flood protections over time, as well as raise moated walls around current generation sites.

Steam distribution: Con Edison could take several steps to mitigate vulnerabilities to heavy precipitation or storm surge flooding to the steam distribution system. These include continuing to segment the steam system to limit customer outages in flood-prone areas, expanding programs to harden steam mains (e.g., waterproofing pipes and raising mains), and prestaging a greater number of drain pumps at critical or flood-prone manholes.

In order to limit water hammer events and steam pipe ruptures, Con Edison could continue to collaborate with the city to improve citywide stormwater design, maintenance, and hardening. A more efficient stormwater drainage system could alleviate flooding impacts and make adaptation measures implemented by Con Edison, such as drain pumps at manholes, more effective. Coordination on system hardening with city engineering activities (e.g., hardening steam mains at the same time as water mains) could expedite the process.

In addition, Con Edison could incorporate New York City initiatives in coastal resiliency plans for Lower Manhattan to re-evaluate storm response plans and stages of preemptive main shutoffs.

Nor'easters

In general, the options that address vulnerabilities from flooding during hurricanes are relevant to extreme nor'easters that present flooding risks either through heavy rainfall or rapid snowmelt following heavy snow accumulation.

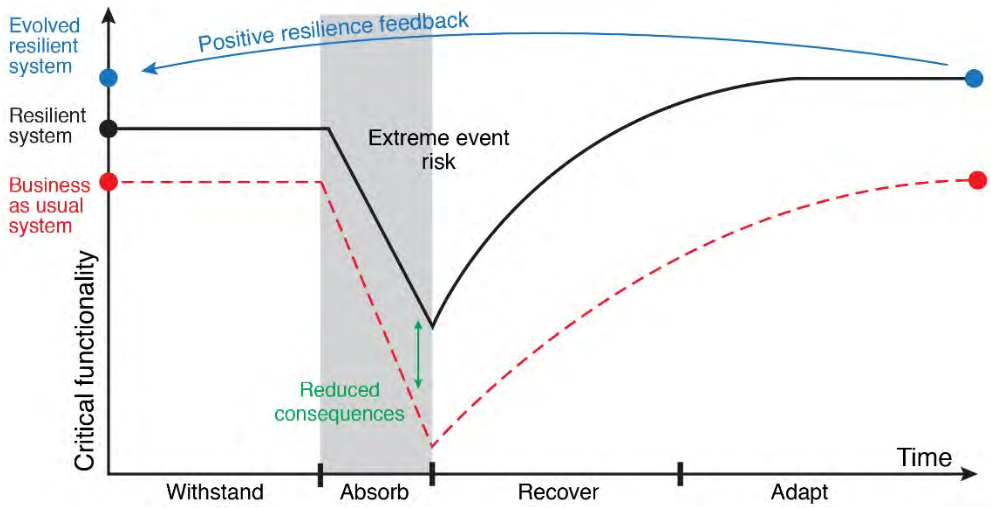
Table 11 ■ Steam system asset sensitivity to extreme events and corresponding adaptation options

Extreme Event	System	Climate Design Assumptions [32]	Failure Mechanism	Degraded State	Customer Impacts	Adaptation Options (Withstand)
Hurricane or Nor'easter **Category 4 hurricane with significant storm surge exacerbated by sea level rise**	Steam generation	Flood protection assumes FEMA 100-year storm, plus 3 feet of freeboard	Storm surge causes flooding of generating station equipment	Damage to generation plant that degrades capacity or forces unit or plant outage(s);system operating at reduced online capacity	Preemptive customer outages and additional customer load-shedding to maintain pressures; limitations of steam functions due to low system pressure	• Additional storm hardening over and above post-Sandy hardening (e.g., raise moated walls)
Hurricane or Nor'easter **Category 4 hurricane with significant storm surge exacerbated by sea level rise; regional flooding due to significant rainfall**	Steam distribution	System design recognizes potential for flooding from storm surge and precipitation. At points where flooding cannot be managed by design, it is managed operationally	Flooding of manholes and inability to discharge condensate to overwhelmed sewer system increases the potential of a "water hammer event"	Multiple steam mains preemptively shut down	Preemptive customer outages and customer load shedding to maintain pressures; limitations of steam functions due to low system pressure	• Further segment steam system to limit customer outages to flood-prone areas • Expanded steam main hardening (e.g., raising mains, waterproofing) • Pre-stage drain pumps at designated manholes

[32] Design assumptions reference assumed weather conditions.

7.2. Absorb

Figure 14 ■ The "absorb" component of a resilient energy system minimizes the consequences of extreme events.



As discussed, Con Edison cannot and should not harden its energy systems to try to withstand every possible future extreme weather event. However, there are actions, categorized here as “absorb,” that can reduce the consequences of extreme weather events on the energy systems. These actions, many of which Con Edison is already implementing, reduce damage during extreme events by reducing demand and therefore helping to protect exposed systems from further damage.

Demand Response Programs

One way that Con Edison prepares for high load and/or limited capacity days is by asking commercial and residential customers enrolled in the demand response program to limit their electricity use (during the summer) or gas use (during the winter) during peak hours and/or during system critical events. During extreme weather events, these programs can be used to reduce energy use (either systemwide or in specific networks), thus reducing the likelihood of an outage and system damage, or a drop in gas pressure. In return, customers receive monetary incentives for participating in the program. While rates vary based on the network (i.e., networks where load is closer to capacity have higher incentive rates than networks with excess capacity) and specific program, a pledge to reduce 100 kW during an event could earn a commercial customer up to $18,000 a year.[33]

Specifics on the current Con Edison contingency programs and peak shaving programs are provided in the following tables (12 and 13).

[33] For more information on the demand response program, see https://www.coned.com/en/save-money/rebates-incentives-tax-credits/rebates-incentives-tax-credits-for-commercial-industrial-buildings-customers/smart-usage-rewards/smart-usage-rewards-for-reducing-electric-demand

Table 12 ■ Contingency programs (Con Edison, 2018b)

Program	Sub Program	General Information	Incentive
Distribution Load Relief Program (DLRP)	DLRP	Activated during a system critical situation. Events last 4 or more hours.	Reservation Payment Option: $18 or $25 (location-dependent) per kW pledged per month. Additional performance payment of $1 per kW reduced. Bonus payments if five or more events in a single season. Voluntary Option: $3 per kW reduced during actual events.
Direct Load Control (DLC)	Bring Your Own Thermostat (“BYOT”) Direct Install	Activated during a system critical situation (and peak shaving events). Participation limited to residential, religious, and small business customers (demand less than 300 kW) with central air conditioning. Allows Con Edison to remotely adjust thermostat settings.	$85 enrollment payment and an annual payment of $25 after 3 years of participation. $50 rebate for the thermostat at the time of enrollment.

Table 13 ■ Peak shaving programs and pilots (Con Edison, 2018b)

Program/ Pilot	Sub Program	General Information	Incentive
Commercial System Relief Program (CSRP)	CSRP	Event activated when both day-ahead and same-day forecast is 92% or greater of forecasted summer system peak to relieve distribution network peak loads.	Reservation Payment Option: $6 or $18 (depending on location) per kW pledged per month. Additional performance payments of $1 per kW reduced. Bonus payments if five or more events in a single season. Voluntary Option: $3 per kW reduced during actual events.
Direct Load Control (DLC)	DLC	Event activated when a CSRP event is called to relieve peak load. Participation limited to residential, religious, and small business (demand less than 300 kW) customers with central air conditioning. Allows Con Edison to remotely adjust thermostat settings.	$85 enrollment payment and an annual payment of $25 after 3 years of participation. $50 rebate for the thermostat at the time of enrollment.
	Smart AC	Event activated when a CSRP event is called to relieve peak load. Participation limited to residential, religious, and small business (demand less than 300 kW) customers with a standard room air conditioner. Customers are provided a kit that allows Con Edison to control demand.	Participants earn points redeemable for gift cards. 1,000 points are converted to $1. Points are earned for connecting eligible devices (10,000 points) and participating in demand response (2,500 points per event). Returning customers earn a bonus incentive of 2,500 points. Customers earn 10,000 points for referring a friend.
Connected Devices Pilot Program	CDP	Event activated when a CSRP event is called to relieve peak load. Con Edison pilots technology and program models to better manage demand from residential appliances. In 2018, this included several Wi-Fi-enabled room A/Cs and PTACs with temperature setback capability.	Participants earn points redeemable for gift cards. 1,000 points are converted to $1. Points are earned for connecting eligible devices (ranging from 10,000 to 50,000 points) and participating in demand response (5,000 points per event). Returning customers earn a bonus incentive of 2,500 points. Customers earn 10,000 points for referring a friend.

This strategy has been effective at reducing electricity demand during high heat/humidity events, and in contingency events. In 2018, the programs were activated 4 times for peak load shaving and 4 times for contingency events.

These programs will continue to play a role in Con Edison's ability to absorb the impacts of extreme weather events like heat waves. Also, as Wi-Fi-connected thermostats and devices become more commonplace, more residential customers are likely to enroll in these programs.

However, as heat waves grow longer and more frequent, it is unclear if the successful load reduction seen in short-term events will persist during the longer events. Customers may grow fatigued with the program. For example, there is some evidence from other utilities that opt-out rates for residential programs are higher when a utility calls a consecutive event day (Navigant, 2018) but there is no evidence of attrition of commercial customers at this point. To ensure continued participation during longer events, the Study team identified these options for Con Edison to consider:

- **Stagger consecutive event days across different customer groups.** This approach will help distribute the responsibility to reduce demand across the enrolled customer population and thus decrease the likelihood of fatigue. Curtailing energy usage may be more acceptable on an every-other-day basis than every day over a multi-week heat wave.
- **Ensure that program participants understand the purpose/cause of the event.** San Diego Gas & Electric found that program participants were more accepting of events on hot days or consecutive days when they understood the cause and purpose of the events. When faced with the alternative of an increased risk of an outage, customers are much more willing to curtail their energy usage.
- **During load relief planning, consider if extreme events could reduce the demand response programs' effectiveness.** Demand response programs have allowed Con Edison to defer investments in the capacity of select networks, thus reducing overall costs. However, if program monitoring demonstrates that demand response can no longer be relied on during long heat waves, load relief planning should take that into account.

Enhanced Energy Efficiency Programs

Energy efficiency programs can help reduce load by improving the efficiency of appliances and the thermal efficiency of buildings. Reducing load can reduce the strain on exposed systems, thus reducing the likelihood of damage and outages during all types of extreme weather events.

Many of Con Edison's current energy efficiency programs focus on increasing customer uptake of energy-efficient lighting and appliances through a variety of rebates and incentives. The programs for Con Edison include:

- HVAC upgrade programs, which incentivize customers to take advantage of rebates for appliances like circulator and pool pumps, as well as for tune-ups for appliances such as gas furnaces and boilers
- Retail lighting programs, aimed at increasing the market share of ENERGY STAR-certified lighting appliances and incentivizing customers to purchase them using rebates
- The Appliance and Smart Thermostat program, Smart Room Air Conditioner (RAC) program, and Bring Your Own Thermostat (BYOT) program, focused on incentivizing customers to purchase and use energy-efficient appliances and home devices, or enroll in Con Edison's demand response program
- A voluntary-enrollment Direct Load Control (DLC) program that enables Con Edison to manage load during peak-demand events

- The Multifamily Bulk Appliance Recycling program, which makes it easier for customers to change over to more energy-efficient appliances and responsibly recycle their old, inefficient appliances.

Con Edison also offers some incentives for building envelope efficiency, which can reduce heating and cooling loads, and increase the passive survivability of the building during an outage event (see Section 7.3 – Recover for more information on passive survivability). Table 14 and Table 15 summarize the current incentives for commercial/industrial and multifamily residential clients.

Table 14 ■ Building envelope incentives for commercial and industrial clients

Measure	Eligibility Criteria	Incentive
Window film	Buildings with electric A/C and gas heat only	$1 per square foot
Cool roof	Buildings with electric A/C and gas heat only	$50 per 1,000 square feet

Source: Con Edison, 2019b

Table 15 ■ Building envelope incentives for multifamily gas buildings[34]

Measure	Insulation type/measure description	Incentive
Roof and wall insulation	R-11 added	$0.50 per square foot
	R-19 added	$1.00 per square foot
	R-38 added	$1.50 per square foot
Air sealing	This package includes repair and weather sealing of louver vents, exterior doors, common area windows, and the general perimeter of the basement	$3 per therm for market rate housing Free installation for affordable housing

Source: Con Edison

Con Edison could consider continuing to support these energy efficiency programs and further expanding its energy efficiency program portfolio to include additional incentives for energy-efficient building envelope upgrades. Window, wall, floor, and ceiling upgrades that improve building insulation or tighten a building's envelope, for example, can reduce load, lower customers' energy costs, and enable buildings to maintain their internal temperatures for longer in an extended power outage. Additionally, the availability of these incentives could be better advertised on the Con Edison website and in promotional materials.

Selective Load-Shedding

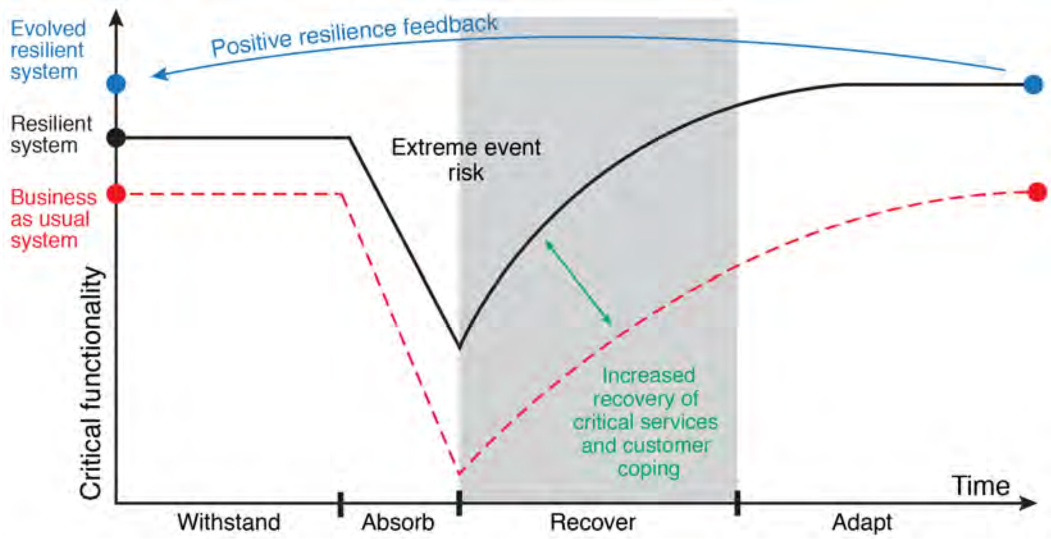
Con Edison is partway through deployment of advanced metering infrastructure (i.e., AMI or smart meters) with full deployment anticipated in 2022. These meters have several benefits for customers and Con Edison (e.g., daily usage data and associated cost control assistance, accurate bills, easier connection to solar, easier activation). They also have high potential benefits for helping to absorb the impacts of extreme weather events.

[34] Information available at conEd.com, Multifamily Energy Efficiency Programs: Gas Incentives: https://www.coned.com/-/media/files/coned/documents/save-energy-money/rebates-incentives-tax-credits/rebates-incentives-for-multifamily-customers/multifamily-building-incentive-offer-gas.pdf?la=en

In the future, AMI can also be used to rapidly shed load on a targeted network to help ensure demand does not exceed supply, thus reducing potential damages and the likelihood of network-wide outages. Today, Con Edison can shed load at a gross level by de-powering an entire network to avoid damages. With AMI, it will be able to selectively disconnect portions of the network or even individual customers, to bring the load in line with the current or projected energy supply.

7.3. Recover

Figure 15 ■ The "recover" component of a resilient energy system increases the rate of recovery and increases customer ability to cope with impacts.



In extreme events, Con Edison aims to recover service to customers as quickly and safely as possible. In an event that has the potential for widespread and long-duration outages, such as those discussed in this appendix, this recovery will need to consider how to pre-plan to increase customers' ability to cope, and how to quickly and efficiently restore energy system functionality.

Improved Customer Coping

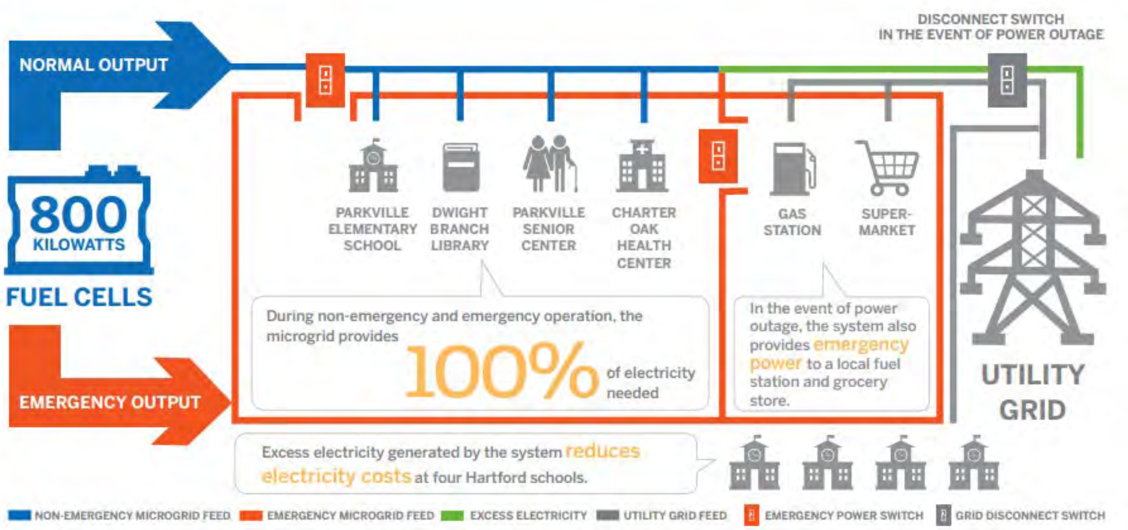
Even with investments to create resilient energy systems and to facilitate a quick recovery of energy systems, Con Edison customers are still likely to experience outages, and potentially prolonged ones, after extreme weather events. While it is primarily the City of New York's role to coordinate resident emergency response efforts, Con Edison can have a role in increasing how well customers cope and prioritizing the continued function of critical services. Resilient customers are those who are prepared for outages and better able to cope with reduced energy service through measures such as having on-site energy storage, access to locations in their community with power, the ability to shelter in place without power, and/or prioritized service restoration for vulnerable customers.

Resilience Hubs

Resilience hubs are an emerging idea in resilience planning. The hubs focus on building community resilience by creating a space or spaces to support residents and to coordinate resources before, during, and after extreme weather events (Baja, 2018). A key requirement for a resilience hub is continued access to energy services. The objective of a resilience hub is to be able to provide a range of basic support services for citizens during extreme events. To accomplish this, resilience hubs may require a hybrid energy solution that includes multiple generation sources (e.g., solar and natural-gas generation) and energy storage (i.e., batteries), plus dispatching controls, similar to the functionality of a microgrid. A traditional on-site diesel-powered generator is generally considered insufficient because they are typically only sized for life safety needs and require a continuous supply of fuel, which may not be available during and after extreme weather events. Figure 16 and Figure 17 demonstrate how a fuel cell-based microgrid can be used to power key community locations during normal operating conditions and during emergency events.

Figure 16 ■ A fuel cell-based microgrid supplies energy to key community locations. Source: Constellation Energy

Figure 17 ■ Diagram of the microgrid operations during normal and emergency operations. Source: Constellation Energy



Con Edison is currently facilitating a pilot resilience hub at Marcus Garvey Apartments in Brooklyn. The pilot project includes a lithium-ion battery system, fuel cell, and rooftop solar. This system will provide backup power during extreme weather events to a building that houses a community room with refrigerators and phone-charging. The project is the first renewable-energy-plus-storage system in an affordable housing development (Con Edison, 2018a).

New York City is also supporting resilience hubs through its Resiliency Innovations for a Stronger Economy (RISE: NYC) competition. The systems they are funding consist of a combined heat and power (CHP, or cogen) generator, solar panels, and batteries. Three systems are currently being installed: at an apartment building in the Bronx, a commercial property in Brooklyn, and an apartment building in Queens (Morris, 2018).

For the future, Con Edison may consider additional deployment of hybrid energy generation and storage systems at critical community locations and resilience hubs. Pending the success of the current pilot programs, Con Edison should work with New York City to identify locations to support the implementation of renewable-energy-plus-storage systems. Con Edison could contribute to this discussion by providing the city with information on hot neighborhoods according to the urban heat island analysis, and information on more vulnerable networks, such as those designed as N-1 contingency rather than N-2, and those with higher NRI values.

Additionally, when fully deployed in 2022, Con Edison could use its AMI technology (see Section 7.2 – Selective Load-Shedding for background on AMI) as a “virtual resilience hub” via selective load-shedding. This selective load-shedding could be targeted to enhance the resilience of a community by prioritizing continuous electricity supply to critical facilities and sensitive customers—effectively creating services similar to a physical resilience hub.

Con Edison defines critical facilities by the following tiers:

- *Critical Facility Level 1* includes the facilities that are critical to public health and safety, including:
  - Hospitals and Emergency Medical Facilities
  - Emergency Shelters and Cooling Centers
  - Fire, Police, Paramedics, and Rescue Facilities
  - Emergency Management Offices
  - Water and Wastewater
  - Critical Utility and Communications Facilities
  - Fuel Transfer and Fuel Loading Facilities (ports)
  - Mass Transit (tunnels, bridges, ferry terminals, major rail facilities)
  - Airports
  - Military Bases
  - Critical Flood Control Structures
- *Critical Facility Level 2* may include some of the same types of facilities described for Level 1 depending on the event type. These facilities provide significant public services but are considered to some extent less critical by government agencies. They include:
  - Nursing Homes and Dialysis Centers
  - Facilities to support other critical government functions
  - Prisons and Correctional Facilities
  - Communications Facilities (radio, TV, etc.)
- *Critical Facility Level 3* includes facilities that provide public services but that are considered, to some extent, less critical than Level 2 by government agencies:
  - Event-Specific Concerns
  - High-Rise Residential Buildings
  - Customers providing key products and services (food warehouses)
  - Managed Accounts, Large Employers, and Other Key Customers
  - Other Government Buildings, Schools, and Colleges

Sensitive customers currently include those with life-saving medical equipment or other serious illnesses, the elderly, vision-impaired, hearing and speech-impaired, and mobility-impaired.

As part of Con Edison's process of responding to and preparing for the effects of climate change, the Company **can continue to plan for community and stakeholder outreach, as well as to work with public officials, community boards, municipal officials, and other stakeholders in local communities** to develop appropriate resilience strategies that improve adaptation before and after extreme events.

No community is alike, which means no single solution is practical or appropriate everywhere. Input from individual communities will help us address regional or local needs. Con Edison could continue to directly reach out to communities to understand their needs through regular consultation with public officials and community stakeholders. Ultimately, **with more and better data, while working alongside public officials, the definition of critical facilities and sensitive customers could be expanded to broaden the impact of solutions and strategies.**

Energy Storage

Con Edison is currently investing in several other energy storage projects that can increase its ability to serve customers during outages caused by extreme weather events, thus helping to recover from impacts. For the electric system, these include (Con Edison, 2018a):

1. *Storage on Demand*: This project includes three mobile battery trailers (500 kW/1.34 MWh each) and one mobile electrical switchgear trailer (see Figure 18). Prior to an event or after an event, these trailers can be moved to support the distribution system.

Figure 18 ■ Con Edison storage-on-demand trailers

2. *Transportable Energy Storage System* (TESS): Con Edison is working with a technology partner to develop and demonstrate a customer-sited, front-of-the-meter TESS (4 MW/4 MWh) within its service territory. The system will include lithium-ion batteries, a power conversion system unit, and an integrated thermal management system. If demonstrated to be a success, the trailer-mounted system could take the place of mobile diesel systems.
3. *Clean Virtual Power Plant* (VPP): The VPP demonstration project aggregates fleets of solar panels and storage assets to collectively act as a controllable power generation source. The VPP pilot envisions that the pilot customers will be able to use their battery during a grid outage.

For the gas system, Con Edison also has energy storage strategies. Con Edison's liquified natural gas (LNG) plant, which is refilled during warm months and used to help meet peak demand days during the winter, can provide the gas system with up to 4 days of supplies during a zero degree-day. As winter progresses and LNG is used, the LNG plant could serve fewer zero degree-days. Similarly, Con Edison currently has one compressed natural gas (CNG) tank station that can be used during gas shortages to directly feed the distribution system. Con Edison is currently planning to procure three additional CHG tank stations.

Moving forward, Con Edison can continue to enhance customer resilience through continued **installation of energy storage strategies, including on-site generation at substations or mobile storage-on-demand/TESS units, and CNG tank stations**. Pending the success of these pilot programs, Con Edison should continue to develop and deploy on-site generation at substations and/or mobile storage systems to allow for support of baseline service loads after extreme events. Con Edison could also consider investing in additional CNG tank stations.

With regard to solar and other distributed generation projects like VPP, Con Edison should continue to explore (e.g., through pilots) ways to help customers install, maintain, and make use of distributed energy resource assets for power backup, self-sufficiency, and resilience.

On-Site Generation

While the combined renewable energy-plus-storage systems in a resilience hub offers the most robust and longest-lasting backup power capabilities, they may not be affordable or appropriate at all locations. For smaller businesses and individual homes, Con Edison can continue to support on-site backup generation systems. These generators can provide life-safety support during outages. They can also help reduce business interruption insurance premiums. Business interruption insurance covers the loss of income that a business experiences after a disaster, including lost sales and rebuilding costs.

After Superstorm Sandy, Con Edison committed to considering two programs that would increase customer resilience through on-site generation and potentially increase Con Edison's access to distributed generation resources (Con Edison, 2013).

Today, the company facilitates programs, in collaboration with The New York State Energy Research and Development Authority, that provide incentives for commercial facilities and multifamily and single-family homes. These include rebate and performance incentives for on-site residential and commercial photovoltaic solar generation, incentives for behind-the-meter wind turbines, as well as incentives for combined heat and power (CHP) projects. The CHP program identifies "targeted zones" where CHP installations receive additional incentives. Con Edison also has a program for energy storage installations.

Con Edison has also participated with other New York utilities in a working group that ultimately developed and implemented standardized interconnection requirements and a standardized interconnection process with the goal of reducing the total time required to complete an interconnection.

The company developed and implemented an online application called "Power Clerk," which allows distributed generation applicants to apply for, update, and track their applications from initiation to implementation. Power Clerk has simplified and reduced the overall time required to apply for and get distributed generation installations online.

Moving forward, Con Edison should continue to **encourage on-site generation for individual businesses and residential buildings.** Promoting distributed generation increases customer resilience, while helping New York meet its greenhouse gas emissions reduction goals.

Energy Efficiency

Another way to enhance customer coping is by supporting improved passive survivability—or the ability to shelter in place for longer periods of time—through enhanced energy efficiency programs. Because many people choose to remain in their homes during extended blackouts, the performance of buildings during power outages is a key factor in community resilience. Convened in 2013 at the request of the City of New York following Superstorm Sandy, the Building Resiliency Task Force was tasked to provide recommendations for improving the resilience of New York buildings. As part of this Task Force, the Urban Green Council conducted an analysis of temperatures inside six representative New York City residential building categories over extended summer and winter blackouts (Urban Green Council, 2014).

The study found that during an extended winter power outage, typical single-family homes would experience temperatures below freezing on the 4th day, while all other typical buildings would be between 32° and 43°F after 7 days. In contrast, high-performing buildings would be 18° to 27°F warmer than the equivalent typical building. All high-performing buildings remained above 54°F after 7 days. (See Figure 19 for modeled indoor temperatures for all typical and high-performing building categories during an extended winter power outage.)

During an extended summer power outage, even the coolest typical buildings (brick) reach temperatures above 85°F after 7 days. The study found that high-performing brick buildings maintained temperatures below 80°F for the first half of the week and never exceeded 85°F (Urban Green Council, 2014).

Figure 19 ■ Modeled indoor temperatures for all typical and high-performing buildings during an extended summer power outage.

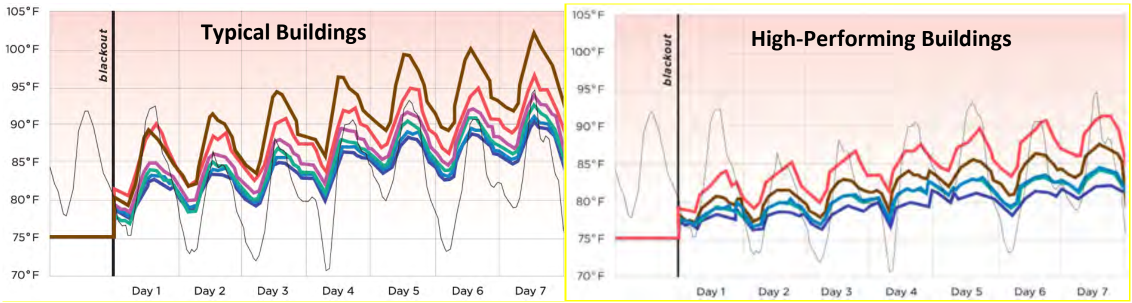


Figure 20 ■ Modeled indoor temperatures for typical and high-performing buildings during an extended winter power outage (Urban Green Council, 2014).

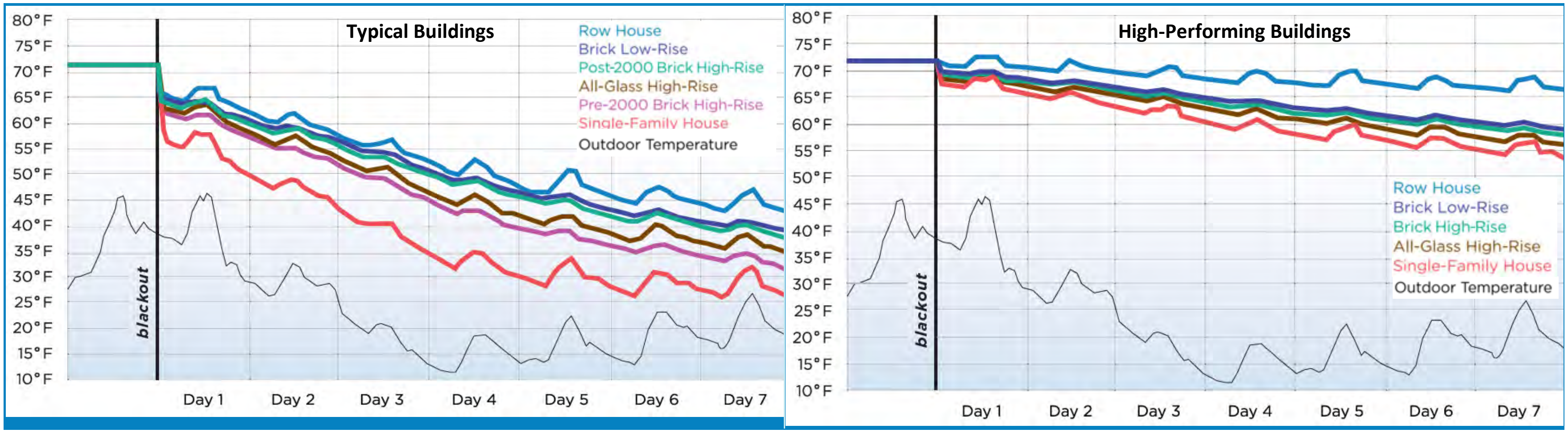
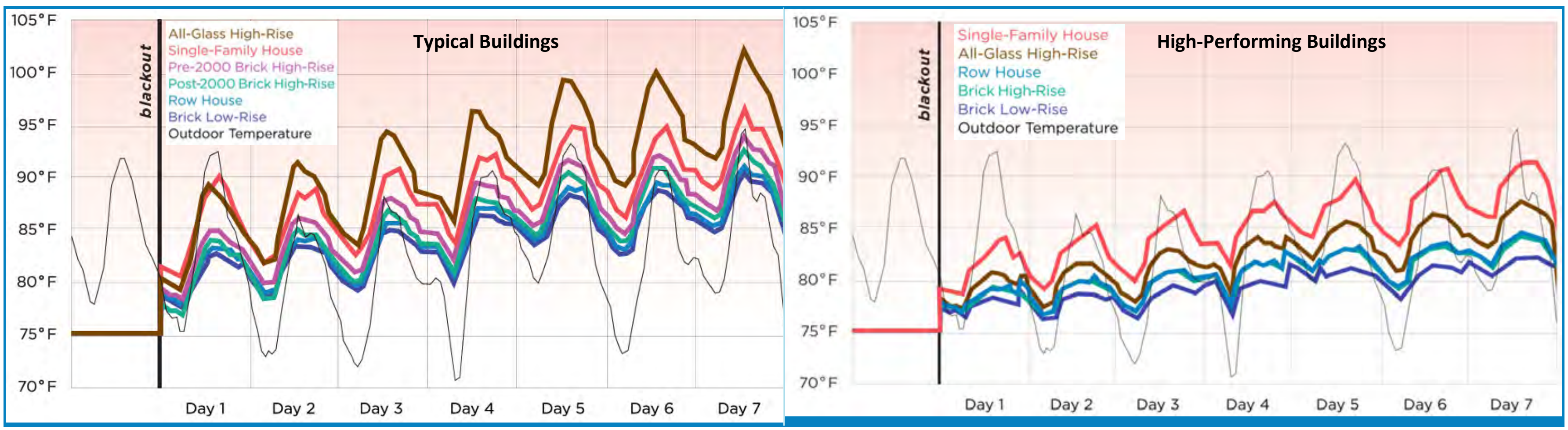


Figure 21 ■ Modeled indoor temperatures for typical and high-performing buildings during an extended summer power outage (Urban Green Council, 2014).



Encouraging energy efficiency is one way that Con Edison is contributing to an enhanced number of well-insulated buildings that allow people to shelter in place during long outages, while simultaneously reducing customers' energy costs. As discussed in Section 7.2 – Absorb, Con Edison could continue to support its existing energy efficiency programs and further expand its program portfolio to include additional incentives for energy-efficient building insulation upgrades.

Emergency Preparedness and Full System Recovery

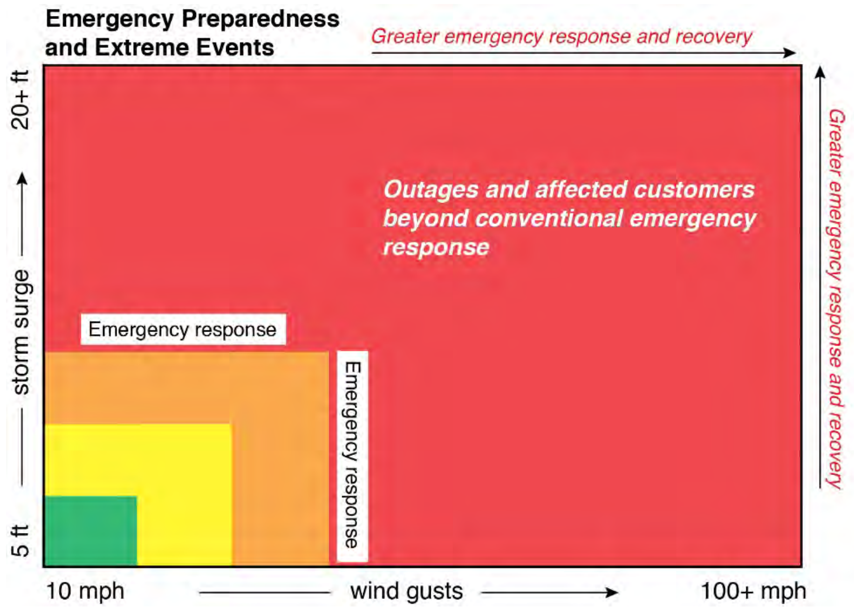
Con Edison currently uses several robust strategies to recover from extreme weather hazards, which are specified in the company's hazard-specific Emergency Response Plans (ERPs) and Coastal Storm Plans (CSPs) for electric, steam, and gas systems. All emergency plans are enacted through the Incident Command System (ICS), which serves as the primary organizational structure to safely and efficiently mobilize and administer personnel, equipment, and facilities during emergency response. Using ICS for every notable incident allows Con Edison to improve skills and procedures needed to prepare and respond to a range of hazards through time.

The Corporate Coastal Storm Plan (CCSP) supplements the ERP by providing guidance on the unique challenges posed by significant coastal storms. Each CSP has a decision matrix that provides a comprehensive checklist of organization-specific actions to be taken at strategic times prior to storm arrival, including storm monitoring (> 120 hours), planning (96 to 72 hours), pre-arrival (24 to zero hours), and during and post storm. Common strategies to prepare for large coastal storms include:

- Switching segments of the overhead system to radial mode.
- Preparing for controlled shutdowns of the underground system in flood-prone areas.
- Relocating stock of poles, transformers, voltage regulators, and switches from flood-prone storage areas.
- Reviewing the possibility for shutdown of electric utilities in specific areas, identifying what may be de-energized and providing relevant information to the appropriate stakeholders.
- Ceasing LNG liquefaction operations and preparing for possible vaporization.
- Isolating steam mains in flood-prone areas.

Levels of risk and response correspond to the magnitude of the extreme event. While Con Edison currently initiates "full scale" responses that require all Con Edison resources and extensive mutual assistance when the approximate number of customers out of service reaches ~100,000, low probability extreme events can increase customer outages and outage durations by order of magnitude, outpacing current levels of emergency planning and preparedness.

Figure 22 ■ This schematic diagram illustrates the increasing impacts during an extreme event (e.g., hurricane with extreme wind gusts and storm surge) that demands correspondingly large emergency response efforts that may exceed those experienced historically.



In case of such events, Con Edison should consider a range of adaptation strategies to increase capacity for an efficient recovery process. The adaptation strategies discussed below are designed to increase Con Edison's ability to improve recovery during extreme events, representing a paradigm for system management when measures such as hardening individual system components are insufficient or cost- and time-prohibitive. These strategies help address the complexities of Con Edison's large integrated system and include an emphasis on emergency preparedness, workforce, supply chains, communications, and dependencies with City infrastructure.

Workforce

When responding to extreme weather events and the damages they cause, it is essential that Con Edison has access to the personnel required to get the job done. That includes Con Edison employees, contractors with pre-existing emergency response purchase orders, and mutual aid deployments from other utilities. After Superstorm Sandy, Con Edison established new emergency contracts with line workers and others that provide Con Edison with the first right of refusal for support during emergency events. However, there is a continued need to balance the costs of retaining support contracts versus planning to hire spot support. As extreme weather events affect larger geographic areas and/or there are multiple events that require mutual aid around the country, Con Edison will have a harder time securing the support it needs.

One way to ensure a sufficient workforce is through a workforce development program. Con Edison invests significant resources each year into the Learning Center, its state-of-the-art educational campus, which offers more than 450 courses in a variety of highly specialized fields including electric, gas, and steam operations; customer operations; information technology; leadership; and environmental, health, and safety compliance. By training employees and external clients, Con Edison is helping to ensure that there are sufficient numbers of workers available to help in emergency situations.

Some recommendations to help ensure access to a sufficient workforce during emergency events and workers' strategic deployment to areas of highest need are:

- **Increase workforce transportation options, including ferries or opening closed roads for priority repairs/restoration.** Many Con Edison employees rely on the subway system to get them to and from work. If the subway or major bridges close, it would be very difficult to get workers to the areas where they are required. Developing alternative transportation plans (e.g., ferries) and prioritized transportation options for utility workers (e.g., access to roads only open for emergency services) would help ensure the mobility of the workforce.
- **Equip external crews with GPS capabilities to increase efficiency.** Because mutual aid workers are less familiar with the service territory, providing them with GPS units to help them navigate the area—and to help Con Edison keep track of them—can increase efficiency.
- **Increase use of LiDAR and drones to assess damage and reduce manual labor.** This practice could help ensure that the workforce that is available is more efficient and can be better deployed to areas of high need.
- **Review the Learning Center courses to ensure they are developing the skills required for emergency response.** With the wide range of courses offered through the Learning Center, it is likely that they cover emergency response skills. However, Con Edison may consider (1) ensuring that courses address skills that are frequently required during extreme weather events, and (2) offering these courses on a regular basis. It may be beneficial to offer these courses at low or reduced costs for non-employees as well.

Supply Chains

Con Edison depends on several supply chains for equipment and materials when responding to extreme weather events. These supply chains are critical because Con Edison's ability to warehouse spare supplies (or ask its suppliers to hold and warehouse supplies) is limited to a specific quantity. For example, a Category 4 hurricane would likely down nearly every pole in the overhead electric system. While Con Edison has spare poles, it does not have an inventory that could cover every pole. As another example, Con Edison keeps a select inventory of substation transformers. But this equipment is expensive and there are several types of substation transformers throughout the Con Edison system. This makes it infeasible to maintain a set of spares for every configuration that may be needed. Con Edison determines the minimum inventory it will maintain (or require its vendors to maintain) based on experience during past events and through consultation with each Con Edison operating group. In recent years, Con Edison has moved to an integrated supply model, whereby a single "integrator" assumes responsibility for procuring and stockpiling frequently used materials. This integrator also assists other utilities and can help obtain materials during emergency events.

Con Edison, and the industry as a whole, has made changes to increase the resilience of their supply chain. For example, the Edison Electric Institute (EEI) coordinates a database of large spare equipment, such as transformers, so utilities can reach out in a time of need. There are similar networks for sharing resource materials at the state level for distribution-level supplies (e.g., poles and cables), but due to differences in materials and design specifications, there is limited ability to share. After Superstorm Sandy, Con Edison set up agreements with General Electric for faster acquisition of transformers in emergency situations. In early 2019, Con Edison invested in six new mobile medium-voltage substations that can be deployed during emergency response efforts (Power Grid International, 2019). These mobile units allow Con Edison to fully operate a substation within days rather than the months it may take to acquire and replace damaged equipment.

To continue to strengthen the resilience of supply chains to extreme weather events, Con Edison could consider:

Standardize parts, where possible. Increased standardization (internally and with neighboring utilities) can increase the likelihood of part availability after an extreme weather event. It also potentially decreases the costs of procuring smaller quantities of more parts. Some procurement is currently being accomplished through Con Edison's integrated supply model. The integrator is reviewing Con Edison specifications to determine if there may be acceptable alternatives that are either used by a different group at Con Edison or are more common in the industry. As part of this strategy, Con Edison could push for industrywide standardization of select asset types.

Develop a resilience checklist for resilient sourcing. This checklist could be referenced when developing contracts with new suppliers, when renewing existing contracts, and when deciding if additional suppliers are needed to ensure redundancy in the event of an emergency. The checklist could include elements such as:

- When possible, increase the geographic diversity of vendors.
- Increase redundancy in vendors to increase operational flexibility.
- Ask vendors to report on climate change and extreme weather supply chain risks. Like Con Edison, vendors also have their own supply chains and their own vulnerabilities.
- Ensure that vendors have an active extreme event preparedness plan. Put in place monitoring and risk mitigation approaches over the life of the contract.
- Include emergency provisions in equipment, materials, and service contracts that provide Con Edison with a first right of refusal during emergency events.

While some of these recommendations are currently being implemented (e.g., increasing vendor diversification, emergency provisions), they could be enhanced with consideration given to future climate conditions and associated raised risk levels for supplies and services providers. **Ensure that parts inventories are housed out of harm's way and in structures that can survive extreme weather events.** As Con Edison continues to shift to vendor-held inventories of materials and equipment, it should request that those vendors ensure their inventories are held in locations and structures that are resilient to extreme weather events. Failing to screen storage locations for extreme weather risks could result in supplies being unavailable just when they are needed the most.

Incorporate supply shortages into emergency planning exercises. These drills help to identify weaknesses in Con Edison's preparedness plans and ensure that staff are prepared to handle a range of events. Incorporating inventory shortages into the exercises could illuminate additional supply chain resilience needs.

Communications

Con Edison primarily relies upon its private Corporate Communications Transmission Network (CCTN) for secure communication including voice and video, and for operation of their supervisory control and data acquisition (SCADA) system. This system is supported by network cables, many miles of which have been replaced with fiber-optic cable over the past few decades, which is more resilient during extreme weather events. The CCTN network also supports a radio system used by field crews and smart-grid applications. The radio network operates via an antenna infrastructure, like that used by wireless cellphone companies. The continued operation of the CCTN is essential for day-to-day operations, and even more critical during extreme weather events, during which it is used for coordination of large-scale restoration efforts and for understanding the state of the system.

After Superstorm Sandy, Con Edison committed to several upgrades to the CCTN, including:

- Building a new CCTN fiber loop to provide telecommunications services to the bulk power transmission substations in Lower Manhattan.
- Replacing two vulnerable CCTN huts at critical facilities in Staten Island.
- Evaluating the antenna system and reinforcing it where necessary.
- Implementing backup generators and fuel storage at key CCTN radio sites and procuring mobile generators for deployment at other locations as needed.

Con Edison also ensures some resiliency by engaging with two major telecommunications providers.

To prepare for more extreme weather events, Con Edison may consider:

- **Ensuring that all new emergency response apps and systems that are meant to improve restoration times are designed with communications resilience in mind**. In addition, staff should be trained on the backup systems to use if the technology-based solution is unavailable.
- **Installing fiber-optic communication and control systems to additional pieces of equipment.** Continuing to re-assess where existing copper cables may be prone to flooding and replacing them with fiber-optic cable will help ensure the resilience of the CCTN network.
- **Continued coordination with telecommunication providers.** Improving coordination can help improve restoration activities for Con Edison’s services and the services of the telecommunications companies. This coordination can also establish the relationships required to better consider restoration priorities in a joint manner.
- Continue conducting joint drills with telecommunication providers. These drills will help to improve emergency planning.

Upstream Dependencies

Con Edison’s day-to-day and emergency response system operations rely on the functionality of several upstream city sectors. For example, Con Edison’s system operations are highly dependent on New York City’s transportation sector (NPCC, 2019). Day to day, employees and supplies rely on the functionality of this sector to be transported to their relevant facilities. During an extreme weather event, this dependence is heightened as Con Edison dispatches restoration crews. If the city’s transportation is compromised during extreme weather such as a hurricane or nor’easter, Con Edison will be unable to move crews and supplies to necessary locations, causing longer power outages and potentially exacerbating system damage. As mentioned earlier in this appendix, Con Edison could consider expanding the transportation options available for moving people and supplies following an extreme weather event.

The reliability of Con Edison’s underground systems during extreme weather events is highly dependent on the city’s above-ground practices. During a nor’easter, the Con Edison underground system may be compromised by the city’s snow management procedures. Prior to and throughout heavy snow events, the New York City Department of Sanitation salts city roads and sidewalks to prevent freezing (City of New York, n.d.). As a result, salt-saturated snowmelt later flows into manholes and surrounds electric cables. If the salt burns through cable insulation and comes into contact with the wire, it can generate heat and ignite, damaging critical underground equipment and, in some cases, causing manhole fires and explosions (Con Edison, n.d.).

During an extreme precipitation event, Con Edison's system operations are dependent on the City of New York's management of stormwater. Ineffective stormwater management can lead to flooding of Con Edison's above-ground facilities and inundation of underground facilities. Con Edison's steam system is particularly at risk during high-precipitation events, as water pooling around steam pipes can cause condensate buildup inside the pipe and result in water hammer events. Additionally, stormwater often carries oils, chemicals, trash, and other pollutants that can significantly damage manholes and other equipment, worsening system disruption (City of New York, n.d.). During major storms, Con Edison pumps water out of manholes and into the city sewer, making the sewage sector another upstream dependency for Con Edison. If the sewer system is overwhelmed or if pumping cannot keep up with the influx of water, Con Edison is forced to take steam mains out of service.

The city is moving toward expanding its capabilities in stormwater management by undertaking several initiatives:

- Green Infrastructure—Expanding greenspace throughout the city and building more rain gardens to absorb stormwater during extreme precipitation events.
- Bluebelt—Preservation of natural drainage corridors to better manage excessive runoff.
- Long-Term Control Plans—Reducing combined sewer overflows through a waterbody-specific approach.

Con Edison depends on the continuous function of the power-producing companies from which it buys electricity and natural gas (e.g. The New York Independent System Operator [NYISO]). If generation facilities at these producer companies are compromised during an extreme weather event, Con Edison is at risk of decreased or lost power supply. There are also interdependencies between the energy systems. For example, 57% of Con Edison's electricity supply (mostly located within New York City) is sourced from natural gas generation, though many of those generating stations can also use oil during emergencies (only 10% of electricity supply is obtained from gas-only generating stations). However, if access to shipping is constrained, as happened after Superstorm Sandy, it may be difficult to obtain the oil needed for continued electricity generation if there is a disruption in the natural gas transmission or distribution system.

In the future, Con Edison could pursue the following actions to protect assets and mitigate customer impacts during extreme weather events:

- **Improve collaboration with the City of New York on stormwater design, maintenance, and hardening.** Con Edison's ability to protect its system from inundation is linked to the city's stormwater management design and maintenance. Improved coordination with the city on design standards and problem locations could reduce risks. Additionally, Con Edison could increase its coordination with the city's flood design innovations to manage increased precipitation, including strategies such as reducing the use of impervious surfaces, increasing water infiltration where appropriate, and detaining rainwater to delay drainage.
- **Improve collaboration with the City of New York on management of wintertime road salting.** The functioning of Con Edison's manhole operations is linked to the location, quantity, and timing of the city's road salting. Collaboration with the city on road salt management and problem locations could reduce risks by encouraging coordination of service crews and targeted use of resources. Additionally, technical hardening measures that protect equipment by resisting salt infiltration could lower the chance of asset damage in at-risk locations. This could be codified through MOUs.
- **Diversify and expand electricity and natural gas sources.** Consistent with Con Edison's distributed energy resources planning, increasing the diversity of electric and gas sources would give Con Edison alternative energy pathways during extreme weather events. In the case of generation failure at one or more power-producing companies, Con Edison could reduce the risk of total power loss by sourcing more energy from these alternative pathways.

Enterprise Risk Management

Con Edison has an established enterprise risk management (ERM) program to identify, assess, manage, and monitor major business risks. The range of risks currently under consideration include regulatory/compliance risks, operations risks, environmental risks, financial and market risks, and "other risks". Within the environmental risk category, Con Edison includes a focus on climate change, but to date, that risk factor has emphasized Con Edison's greenhouse gas emissions and increasing regulations to transition to cleaner energy sources. The 2018 Annual Report includes a brief discussion of the physical risks of climate change, focused primarily on extreme weather events and actions taken post-Superstorm Sandy:[35]

> *"Climate change could affect customer demand for the Companies' energy services. It might also cause physical damage to the Companies' facilities and disruption of their operations due to more frequent and more extreme weather-related events. In late October 2012, Superstorm Sandy caused extensive damage to the Utilities' electric distribution system. Superstorm Sandy interrupted service to approximately 1.4 million of the Utilities' customers—more than four times the number of customers impacted by the Utilities' previous worst storm event (Hurricane Irene in 2011) and resulted in the Utilities incurring substantial response and restoration costs. CECONY invested $1 billion in its infrastructure in order to improve its resilience against storms like Superstorm Sandy."*[36]

In the last year, the ERM program has taken additional steps to address climate change by introducing "emerging issues/trends" into the ERM. For these emerging issues, Con Edison

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[35] Con Edison. 2018 Annual Report. Available at: https://investor.conedison.com/static-files/a8641489-b9bf-492a-ae46-5ac52085d483

[36] Ibid.

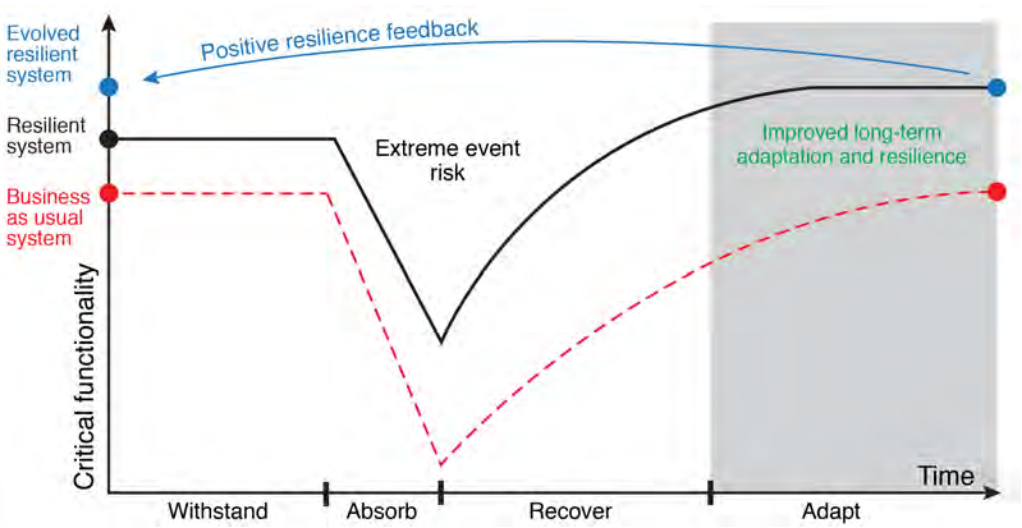
conducts due diligence to determine what is changing in the internal and external environment. Climate change is one of these emerging issues.

Within the ERM process, Con Edison typically considers probable risks that could occur within a 3- to 10-year time period. While this approach helps to focus the ERM process on key risks, it means that the worst-case extreme weather events are not included. Con Edison may consider **expanding the ERM framework to include lower probability extreme weather events and long-term issues (e.g., 20-plus years).** This modification would ensure that extreme weather events and climate change are appropriately considered and thoughtfully addressed.

Emergency plans and procedures are informed, in part, by tabletop exercises facilitated by Emergency Preparedness, which explore a range of potential hazards impacting Con Edison, including risks from major storms. For example, in September 2019, Con Edison conducted a tabletop exercise on major storm mutual assistance. **Con Edison could consider conducting additional extreme weather tabletop exercises informed by the future narratives outlined in this appendix, and consecutive extreme weather events.** These exercises help Con Edison look at recovery procedures and how they would be executed during an actual event.

7.4. Adapt

Figure 23 ■ The "adapt" component of a resilient energy system includes building back stronger after extreme weather events and updating standards and procedures based on lessons learned.



Adapting Con Edison's infrastructure, planning, and operations to new and future risks while incorporating learning from extreme events will allow for a more effective and efficient transition to greater resiliency. Con Edison has taken this approach in the past, including investing $1 billion in storm hardening measures after Superstorm Sandy. These investments significantly strengthened the system's resilience to future storm events, including higher levels of surge and wind.

Restoring service after an extreme event to a better adapted, more resilient state (i.e., building back better/stronger) begins with effective pre-planning for post-event reconstruction. Even with proactive resilience investments, extreme events can reveal system or asset vulnerabilities. Where assets need to be replaced during recovery, **having a plan already in place for selection and procurement of assets designed to be more resilient in the future can help ensure Con Edison is adapting to future extremes in a continuously changing risk environment.** For example, it may not be cost-effective to preemptively replace select assets before the end of their useful life to address gradual changes in climate and probabilities of extreme weather events. However, predetermining that damaged assets should be upgraded to address mounting risks can be much more cost-effective because the incremental cost of the upgrade will be relatively low. Essentially, this approach can turn a damaging situation into a resilience opportunity. Pre-planning may also include pre-approved revised design or procurement standards, as well as the ability to recover any additional incremental costs the new assets may have beyond like replacement.

Extreme events also provide important opportunities to measure the performance of adaptation investments, helping to inform additional actions that further resilience. Post-event assessments that include empirically assessing resilience in the wake of natural disasters that can overcome deficiencies of model-based and indicator-based approaches for understanding vulnerability, resilience, and effectiveness of adaptation. Information gathered from a post-event assessment process—that begins in the immediate aftermath—helps identify opportunities for Con Edison to better prepare for, respond to, and rebuild from disasters in fundamentally more resilient ways. This post-event assessment approach also provides a unique lens on the effectiveness of prior adaptation and resilience approaches intended to decrease impacts from climate-related disasters. Information contained in the final report of the final Climate Change Vulnerability Study can provide a baseline for comparison in post-event assessments. **Con Edison can consider establishing clear protocols for this form of resilience assessment, building on its existing approach to post-event reporting.**

8. Costs and Benefits of Adaptation and Resilience Options

The adaptation and resilience options discussed in this report all come with unique combinations of costs and benefits. These costs and benefits, when viewed through a resilience lens, are experienced by Con Edison, as well as their customers. Ideal options will not only achieve measurably greater grid resilience and robustness, but also do so cost-efficiently for Con Edison and ratepayers.

8.1. Costs and Benefits: Internal Company Perspective

The array of impacts an extreme event may cause will likely include both direct and indirect costs and benefits. Some will be experienced primarily by Con Edison, while others will likely be experienced together by the Company, customers, and stakeholders.

Types of Costs

Extreme events can lead to a variety of direct costs, including those related to:

- Restoring or repairing infrastructure (new parts and labor costs associated with assembly or construction) (U.S. Department of Energy 2016).
- Replacing infrastructure damaged to an extent not worth repairing or restoring (cost includes new parts and associated labor costs) (U.S. Department of Energy 2016).
- Relocating infrastructure (labor costs and new parts as needed), either if damaged by the event or revealed to be vulnerable by the event (U.S. Department of Energy 2016).
- Facing negative earnings adjustments due to event-related costs. In particular, this may occur in the event that Con Edison is unable to recover costs through ratepayer changes due to ratemaking policy (U.S. Department of Energy 2016).
- Facing direct penalties from regulators if Con Edison cannot prove that it has done its due diligence to address known vulnerabilities in its system.

Due to the uncertainty inherent in extreme events' impacts and management, Con Edison may not know, in advance, whether it will be able to recover certain costs (U.S. Department of Energy 2016). Extreme events may also draw attention to liabilities, such as viability of certain insurance claims, previously regarded at a lower magnitude, leading to potentially significant costs to the Company. Recent climate-related extreme wildfire events in California, for example, have left utility companies such as Pacific Gas & Electric (PG&E) with significant liability to pay wildfire-related insurance claims due to California Public Utilities Commission regulations (Morris 2018). PG&E filed for bankruptcy in 2019 in reaction to the cost of those claims (Brickley 2019).

Types of Benefits

Con Edison, its customers, and its shareholders can also benefit from Con Edison's prudent resilience investments following extreme events. Such benefits may be related to:

- Avoided costs to Con Edison from non-recoverable costs, negative earnings adjustments, or penalties
- Lower costs incurred to rebuild after storms due to investments in withstand, absorb, recover, and adapt
- Avoided costs to Con Edison shareholders from any unrecoverable recovery costs
- Lower cost of capital
- Reputational benefits with customers and investors

Context on Investment Levels

To provide context on how much other companies have spent to prepare for extreme climate events, Table 16 portrays the total amounts, in U.S. dollars, that several U.S. utilities have invested in hardening their systems.

Table 16 ■ System hardening spending by U.S. utility companies with significant spending listed for resilience programs

Utility Company	Total Spending on Storm Hardening Projects ($M)	Number of Customers	$ Per Customer	Length of Project
Public Service Electric & Gas (PSE&G)* (N.J. Board of Public Utilities, 2018)	$2,500	4,000,000	$625	5 years
Hawaiian Electric (Hawaiian Electric, 2019)	1,500	304,948	4,919	7 years
Florida Power & Light+ (Florida Public Service Commission, 2019)	2,200	4,700,000	468	3 years
Tampa Electric (Tampa Electric, 2015)	No information	765,000	No information	2013–2015 2016–2018
Dominion Virginia Power+ (Virginia State Corporation Commission, 2018)	910 approved of originally proposed 6,000	2,600,000	350	10 years
Avangrid* (Avangrid, 2018)	2,500	3,100,000	806	10 years
Pepco+ (D.C. Public Service Commission, 2017)	500	883,000	566	6–8 years

* Indicates projects that have been proposed; +Indicates projects that have been approved; no superscript indicates that projects have been completed.

Of the $2.7 billion that Duke Energy invested in system resilience, about $700 million went toward distribution hardening and resiliency efforts, including replacing deteriorated cables, conductors, and poles, and retrofitting assets such as transformers (Duke Energy, 2018). Duke is also keeping track of the number of Major Event Days that impact its systems (Ibid). Con Edison could mirror this type of monitoring if it chose to have statistics on Major Event Days to serve as an indicator for flexible adaptation pathways.

The $2.5 billion listed for PSEG is the amount proposed to fund its Energy Strong resilience program, intended to enable a slate of hardening work. This would include investment in technology that would make restoration work faster, modernization of critical equipment in regions prone to flooding, and installation of stronger energy distribution infrastructure to reduce outages from strong winds and tree breakage, among other efforts (N.J. Board of Public Utilities, 2018).

For Hawaiian Electric, the $1.5 billion investment was allocated to meet the region’s unique needs (Hawaiian Electric, 2019). Because Hawaii is a relatively small island, a portion of the funding went toward disaster trainings and other investments to ensure strong partnerships with mainland utilities that could support Hawaiian Electric and other local utilities in the event of extreme need. The funding is also being used for infrastructure hardening measures, such as replacing normal wooden poles with concrete-anchored steel poles and working to replace “potentially defective” equipment and upgrade old equipment before it can malfunction (Ibid). Another portion was dedicated to paying for technology that could control output of electricity generated by rooftop solar panels—widely used in Hawaii—onto the power grid to improve the grid’s baseline stability, and to building more resilient power plants further from the coastline to minimize their vulnerability to extreme weather impacts.

As with Con Edison’s service region in New York, all of these utilities’ service regions are particularly vulnerable to impacts of extreme storms due to their coastal locations. Beyond that similarity, however, the measures that each utility invested in were unique based on specific system needs.

8.2. Costs and Benefits: Customer Perspective

Con Edison customers may experience a variety of costs and inconveniences as a result of extreme events. These costs include issues to which all customers could potentially be exposed, from daily inconveniences to safety concerns to ratepayer changes. Costs are also dependent on customer type, such as inventory spoilage for commercial and industrial (C&I) customers in a long outage. The form and severity of costs will also depend on the type and intensity of the event.

Managing the costs that are particularly impactful to customers will benefit both customers and the company, because those costs could significantly influence customers' perception of Con Edison's service quality (FEMA 2017). The value of reducing customer costs and improving customers' capacity to cope by investing in energy service resilience is also underscored by the magnitude of Con Edison's investment in resilience and rebuilding after Superstorm Sandy. When Con Edison takes resilience measures that minimize or avert outages when extreme events do strike, customers will experience the inverse of these costs: smooth service and renewed confidence in their service provider.

Costs that may impact all Con Edison customers include:

- Inconveniences—such as shifts in indoor temperatures (e.g., colder temperatures during an extended winter outage), lengthier travel times (e.g., longer commutes if traffic signals stop functioning), and additional stress caused by the uncertainty and potential danger in outage situations.
- More severe costs—such as safety concerns, including loss of communication for vulnerable and disconnected populations (e.g., elderly people living alone), or potential endangerment of hospital patients if care centers lose power and backup generators are insufficient.
- Changes in business practices—such as increasing ratepayer prices-per-month if needed to manage high equipment repair costs. An example of the ratepayer increase is visible in a recent petition submitted by Duke Energy to the North Carolina Utilities Commission requesting deferral of "incremental storm damage expenses," where Duke stated: "We are asking … to reserve the costs that exceeded what is a normal range of storm costs reflected in what we are currently collecting from customers for storm response and to consider the costs in a future rate change request" (Smart 2018). The costs of extreme storms Florence, Michael, and Diego were so high that normal cost payment became difficult for Duke and the utility noted the potential for increased costs to ratepayers.

Costs more dependent on customer type include:

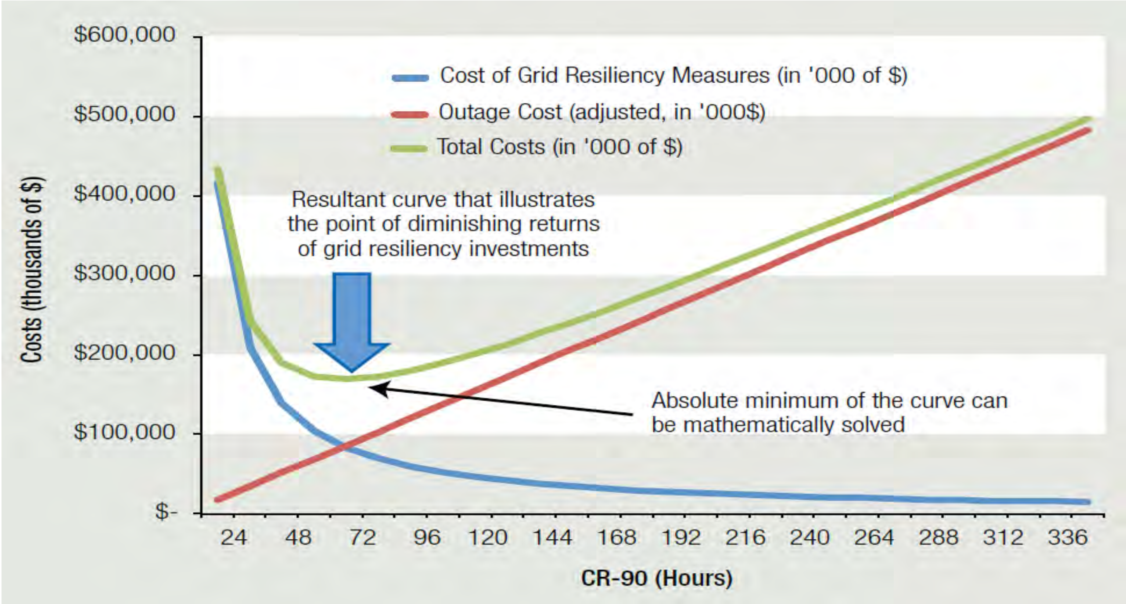
- Large C&I customers: Encountering "lost output and wages, spoiled inventory, delayed production, inconvenience and damage to the electric grid" following extreme storms (Department of Energy and White House Council of Economic Advisors 2013). In areas less resilient to extreme events, C&I customers may also face higher business interruption insurance premiums.
- Residential customers: Needing to stock up on additional household items and adjust daily schedules in order to change family routine to take (U.S. Department of Energy 2016) age-related uncertainties into account.

Estimating Customer Costs and Benefits

Calculating projected customer costs or the value of the benefit of avoiding them is complex and imperfect, as demonstrated through various analytical approaches (NARUC and MPSC 2013, Department of Energy and White House Council of Economic Advisors 2013, Office of Governor Martin O'Malley 2012, LBNL 2009). However, identifying a plausible range of costs to customers could help Con Edison estimate the value of potential or implemented investments, or run cost-benefit analyses or other business case evaluations for these investments. If Con Edison estimates a range of values of the costs and benefits that extreme events could bring to the company, users, and relevant stakeholders, it can use those values to inform decisions on investments in resilience measures.

Con Edison can apply the cost-benefit calculation model it developed after Superstorm Sandy as a starting point to estimate the value of storm hardening activities. The model uses "service class customer information, commodity data (kWh), and a range of potential commodity-to-cost conversion factors" to produce "preliminary estimates of the monetary benefits anticipated from the storm resiliency work being carried out" (Con Edison, 2014). For example, studies on how much customers valued reliable service (based on willingness to pay) were used to develop a database on the "value of electric service reliability," which enabled an estimation of "interruption costs for different types of customers and or different duration"—essentially, a conversation from potential kW or kWh not serviced in an outage into a value indicating customer cost of that outage (Con Edison, 2014).

Figure 24 ■ Total Cost Curve developed by ICF for "What Price, Resiliency?" (Mihlmester and Kumaraswamy, 2013).



Cost and benefit estimates could also be used to support Company leaders and stakeholders in determining how Con Edison should strike a balance between investment in proactive system hardening, system recovery following an event, and targeted customer-focused actions. The total cost curve developed by ICF's Mihlmester and Kumaraswamy (Figure 24) is one example of such an approach.

9. Implementation of Adaptation Options Over Time

Given the potential costs and benefits to both Con Edison and its customers, adaptation actions that improve the resilience in Con Edison service and customer resilience have the potential to be more cost-efficient and effective than only taking actions on the utility side of the equation. As Con Edison considers implementation of adaptation options over time, particularly in the context of extreme events, it will need to consider several key factors related to these shared costs and benefits, such as:

- For adaptation options that require collaboration with outside entities, such as advancing resilience hubs across the city, do sufficient processes or frameworks exist to guide roles and responsibilities, including distribution of costs and benefits?
- In instances where Con Edison desires to invest proactively in adaptation measures related to the withstand, recover, absorb, and adapt elements of the resilience management framework, what is the appropriate method for defining an agreed upon risk tolerance for both Con Edison and their customers?
- Based on the risk tolerance, how should Con Edison make proactive investments over time, while balancing cost impacts to customers?

Con Edison can continue to work closely with stakeholders to address these issues and develop an appropriate investment framework as it moves forward with implementation of adaptation actions.

Monitoring Signposts

Con Edison is committed to a flexible adaptation pathways approach to investment over time. Sections 7.1–7.4 and Section 8 describe vulnerabilities and adaptation options related to extreme events, which can be organized as part of a flexible adaptation pathway. As there remains significant uncertainty about what events will occur, when they will take place, and the degree of damages they will incur, Con Edison could continually monitor and assess characteristics of extreme events over time and incorporate updated extreme event projections into its plans as they are published. Examples of potential indicators to monitor over time as signposts of the impacts of extreme storms are:

- Frequency of events, event characteristics, and damages incurred by events with different combinations of extreme weather (e.g., concurrent extreme flooding and precipitation, or concurrent extreme wind and heat). This could be measured in Major Event Days, in MWh lost, etc.
- Number, spatial extent, and duration of outages caused by extreme weather, especially noting outages experienced by critical infrastructure (e.g., hospitals and shopping centers)
- Number of customer complaints received relative to extreme events
- Level or costs of keystone asset damages (e.g., substations or power lines downed)

Below are other signposts that Con Edison could use.

Climate Variable Observations

An awareness of past and present climate conditions is key when determining potential asset exposure and risk. Extreme event variables that may be monitored include—but are not limited to—storm surge levels, frequency of various storm types in the greater region, wind speeds, heat wave intensity and duration, and precipitation levels. Con Edison currently operates a number of stations that monitor climate variables and is finalizing plans to expand the number of monitoring locations. With accurate and up-to-date data on these variables, Con Edison can monitor both changing conditions and points of vulnerability in its systems.

Con Edison could also monitor the frequency and intensity of "near misses," or extreme weather events that are observed regionally, even if they missed the Con Edison service territory. These neighboring events provide insights into evolving risks and the need for new adaptation measures.

Best-Available Climate Projections

Access to the most recent and best-available climate projections and expert knowledge is important when planning for potential future scenarios. Models indicating the potential intensity and frequency of future nor'easters, hurricanes, and heat waves may inform the ways in which Con Edison updates its infrastructure. As a supplement, recently published, credible expert knowledge such as from the IPCC and the NPCC can act as key resources for understanding the greater mechanisms behind climatic shifts and extreme event projections.

Political, Industrial, Societal, and Economic Conditions

A broader understanding of evolving political, industrial, societal, and economic conditions can provide insight on climate-related decision-making and areas of need throughout the service territory. Relevant information may include population statistics (growth, movement), patterns of development, legislative activities, and decarbonization financing.

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