May
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Resilient Ways Forward:

Climate Change Summary

DUTCHESS COUNTY
TRANSPORTATION COUNCIL
Better ways from here to there

Disclaimer

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Glossary

- **Climate**: The long-term average weather (temperature and precipitation) over time and space.
- **Climate hazard:** A potentially damaging event or phenomenon influenced by climate change that can cause harm to people and livelihoods, infrastructure, resources, and the environment. Climatic hazards are also sometimes called extreme weather events.
- **Extreme weather events:** Disruptive weather events such as floods, hurricanes, or snowstorms.
- **Drought:** A prolonged period of dry conditions; does not necessarily mean no precipitation. Droughts occur during an imbalance between precipitation and evaporation, where more moisture is leaving the environment than being added to the environment.
- **Greenhouse gases:** Gases that trap heat in the atmosphere, contributing to global warming and climate change. Common GHGs include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and fluorinated gases.
- **Hurricane:** Strong storms with heavy rainfall that form over warm tropical or subtropical waters and have wind speeds above 74 mph. The Atlantic hurricane season runs from June 1 to November 30.
- **Nor'easter:** Strong storms along the East Coast that typically occur between September and April. Nor'easters have strong winds and usually include heavy precipitation in the form of rain or snow.
- **Representative concentration pathways (RCPs):** Potential future scenarios based on how concentrations of greenhouse gases in the atmosphere behave and change as a result of human activities. These scenarios range from very low (RCP 2.6) to very high (RCP 8.5) future concentrations by 2100.
- **Sea level rise:** An increase in the level of the world's oceans due to the warming air and ocean temperatures (which causes water molecules to expand) and added water from melting ice sheets and glaciers.
- **Slow onset events:** A gradual change to existing conditions over many years, such as increasing average temperatures or sea level rise.
- **Storm surge:** When strong winds during a coastal storm push ocean water inland and cause increased waves. Sea level rise can increase the extent and depth of storm surge.

- **Tropical storm:** Strong storms with heavy rainfall that form over warm tropical or subtropical waters and have wind speeds between 39 mph and 73 mph. The Atlantic tropical storm season runs from June 1 to November 30.
- **Tropical depression:** Strong storms with heavy rainfall that form over warm tropical or subtropical waters and have wind speeds below 39 mph. The Atlantic tropical depression season runs from June 1 to November 30.
- **Urban heat island effect:** When a high concentration of pavement, buildings and other surfaces that absorb and retain heat cause urban areas to experience higher temperatures than surrounding areas.
- **Weather**: The short-term atmospheric conditions and changes throughout the day (e.g., daily precipitation and temperature fluctuations).
- **Wind gust:** A sudden, brief increase (usually less than 20 seconds) in the speed of wind.
- **Wind speed:** A sustained speed of wind.
- **Winter conditions:** Precipitation in the form of snow, ice, or sleet.

Introduction

Our changing climate is affecting Dutchess County in many ways. Some of us already feel these impacts, whether it's in how we heat and cool our homes, how much we pay for food, or even how we think about the future.

Our transportation system is no different. How and where we've built infrastructure and provided services may no longer be adequate. And while the impacts of a changing climate may not all be negative, they still require us to adjust the way we build, maintain, and think about our transportation system. These changes will present us with challenges, and if done right, opportunities to create a more resilient transportation system that minimizes disruptions to our lives and better prepares us to meet the uncertainties of a changing climate.

We can address the impacts of climate change by collecting information, educating decision makers, and advocating for changes to policies and projects. To begin this work, the Dutchess County Transportation Council is preparing a **Climate Vulnerability Assessment** of our transportation system.

The Climate Vulnerability Assessment, titled **Resilient Ways Forward**, will identify locations where our transportation system is most vulnerable to the impacts of climate change. It will also find ways to adapt to or reduce the adverse impacts of climate change on our transportation system.

This **Climate Change Summary Report** provides an overview of how climate and extreme weather events have and will continue to change in Dutchess County. It also covers past impacts of these events on our transportation system. This report is designed to inform the Climate Vulnerability Assessment and be a resource for you (decision makers and the public) to understand how the climate is changing and what the potential impacts are to our transportation system.

FIGURE 1. ROAD CLOSURES (LEFT) IN THE CITY OF POUGHKEEPSIE AND FLOODING ON MALONEY DR (RIGHT) IN THE WAKE OF TROPICAL HURRICANE IDA IN 2021. PHOTO SOURCE: DCTC

How is the Climate Changing in Dutchess County?

We are already seeing the impacts of climate change in Dutchess County. Climate change is primarily caused by an increase in the concentration of greenhouse gases in the atmosphere, which traps heat and increases global temperatures over time.[1] Higher temperatures contribute to more severe storms, longer heat waves, extended droughts, sea level rise, and more variable winter conditions.

What is the Difference Between Weather and Climate?

Weather refers to the short-term atmospheric conditions and changes throughout the day.

Climate refers to long-term average weather (temperature and precipitation) over time and space.

We have experienced several extreme weather events in the past decade, such as flooding from Superstorm Sandy (2012) and Hurricane Ida (2021), two major snowstorms in 2018, and severe drought in 2022. We are also experiencing slow onset events - these are changes that build up slowly over the years, such as increasing temperatures and sea level rise.[2] These gradual changes contribute to more frequent and severe extreme weather events. For instance, warmer temperatures lead to stronger hurricanes and accelerated sea level rise,[3] both of which can cause severe flooding. In the past, floods have caused road closures, service disruptions and outages, economic losses, and damage to homes and infrastructure.

To become more resilient to climate change, we need to better understand regional climate trends and the likely impacts on our transportation system. Table 1 provides an overview of expected future conditions in Dutchess County through the year 2080 for six different climate hazards.

FIGURE 2. BRIDGE WASHED AWAY AFTER HURRICANE IDA FLOODING. PHOTO SOURCE: DAILY VOICE.

[1] U.S. Global Change Research Program. 2018. Fourth National Climate Change Assessment: Chapter 2: Our Changing Climate. https://nca2018.globalchange.gov/chapter/2/

[2] United Nations Climate Change. 2018. The scope of work undertaken on slow onset events (SOEs) as reported by partners in the SOEs database. https://unfccc.int/sites/default/files/resource/activity_b_soe_assesment_feb_2018.pdf

[3] Warmer ocean temperatures cause water molecules to expand (also known as thermal expansion), contributing to the rate of sea level rise.

TABLE 1. CLIMATE HAZARD SUMMARY FOR DUTCHESS COUNTY

Climate hazard	Future conditions
 Temperature	• Higher average temperatures • More frequent and intense high temperature days
 Flooding	• Greater potential for flooding due to more frequent and intense heavy precipitation events • Greater potential for flooding along the Hudson River from sea level rise and storm surge
 Drought	• Longer periods without precipitation
 Wind	• Greater potential for high winds as the intensity of hurricanes, tropical storms, and tropical depressions increases
 Winter conditions	• Fewer days with temperatures below freezing (32°F) • Greater snowfall during major winter storm events
 Landslides	• Greater potential for precipitation-driven landslides and rockfalls

These six climate hazards are explored in greater detail in the sections below. Each section provides information on:

- Historical events and trends
- Future climate projections, as available
- Impacts to our transportation system

As feasible, climate projections are provided for **two time periods** relative to a baseline period (1950-2013 unless otherwise noted):

- **2050** (2036-2065) to align with the DCTC's current long-range plan; and
- **2080** (2066-2095) to understand risks that may occur at the end of the useful life of current transportation infrastructure.

The climate projections for each hazard are presented as a **range of values to help account for uncertainty in future conditions**.[4] This report provides projections based on a high emissions pathway[5], where fossil fuel emissions and greenhouse gas concentrations continue to increase, and a

[4] Climate models are used to predict how the climate will change. Climate projections are determined from an ensemble of models and provide a range of projections. Climate models create projections based on future emissions scenarios, referred to as Representative Concentration Pathways (RCPs).

[5] The high emissions pathway is known as Representative Concentration Pathway (RCP) 8.5.

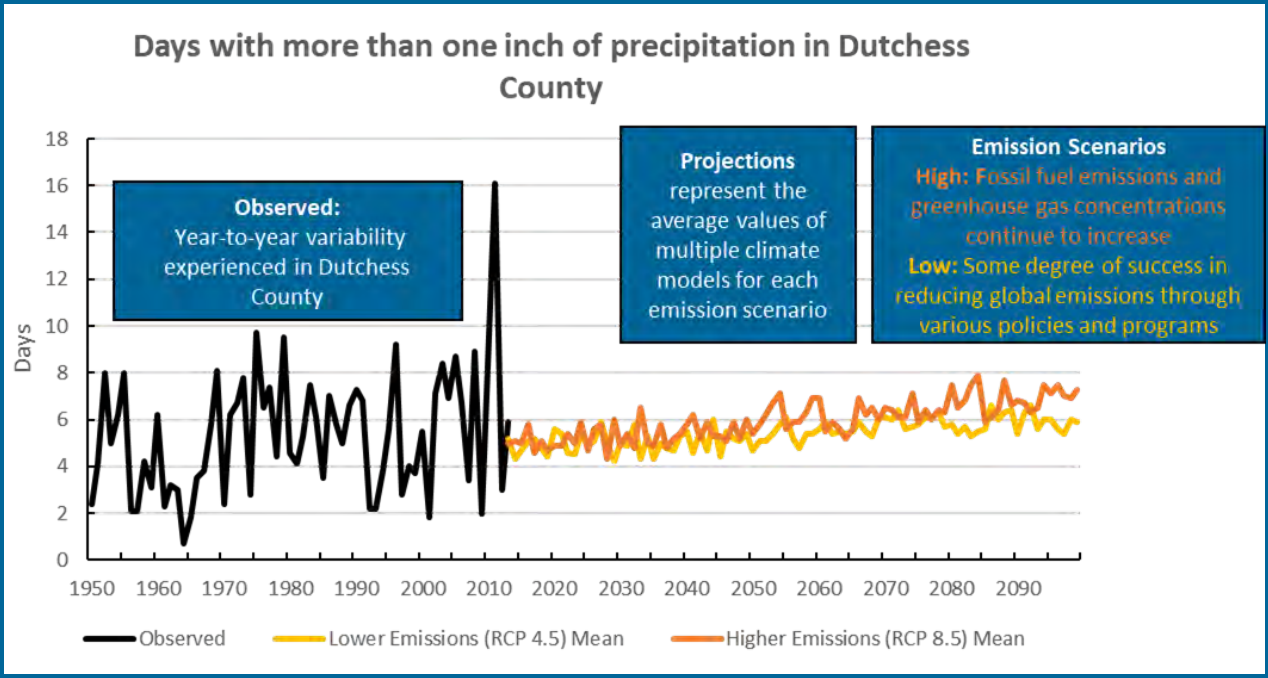
lower emissions pathway[6], which assumes some degree of success in reducing global emissions through various policies and programs. Based on current global commitments, the reality is likely somewhere in the middle. The Federal Highway Administration recommends using the high emissions pathway to account for a worse-case scenario due to the criticality of transportation infrastructure.[7]

To develop this report, ICF and DCTC collected publicly available climate data, conducted a literature review for hazards where climate projections are unavailable, and supplemented those findings with input from key stakeholders and the public as appropriate.

Understanding Climate Projections

There are several graphs throughout this report showing both observed historical data and future climate projections (see example below). The observed historical data show the **year-to-year variability** experienced in Dutchess County, while the climate projections indicate how **average climate conditions are expected to change over time.**

While average conditions will change gradually, the County will still experience variability from year-to-year through mid and late-century. In fact, precipitation is expected to become more variable each year, with some years receiving much more precipitation than other years.



[6] The lower emissions pathway is known as Representative Concentration Pathway (RCP) 4.5 and assumes emissions peak mid-century and then decrease.

[7] Filosa, Gina, Amy Plovnick, Leslie Stahl, Rawlings Miller, and Don Pickrell. 2017. Vulnerability Assessment and Adaptation Framework, Third Edition. FHWA Office of Planning, Environment, and Realty. https://www.fhwa.dot.gov/environment/sustainability/resilience/adaptation_framework/chap00.cfm

Temperature

Historical trends and past transportation impacts:

Average annual temperatures have increased nearly 3°F in Dutchess County since 1960[8] and high temperatures are occurring with greater frequency and intensity.

We have seen record-breaking temperatures in recent years. The warmest recorded month in Dutchess County was July 2020 at an average of 77.8°F.[9] July 2020 also included a record 17 days above 90°F. The earliest 90°F day of the year on record occurred April 7, 2010 and the earliest 80°F day occurred March 9, 2016.[10]

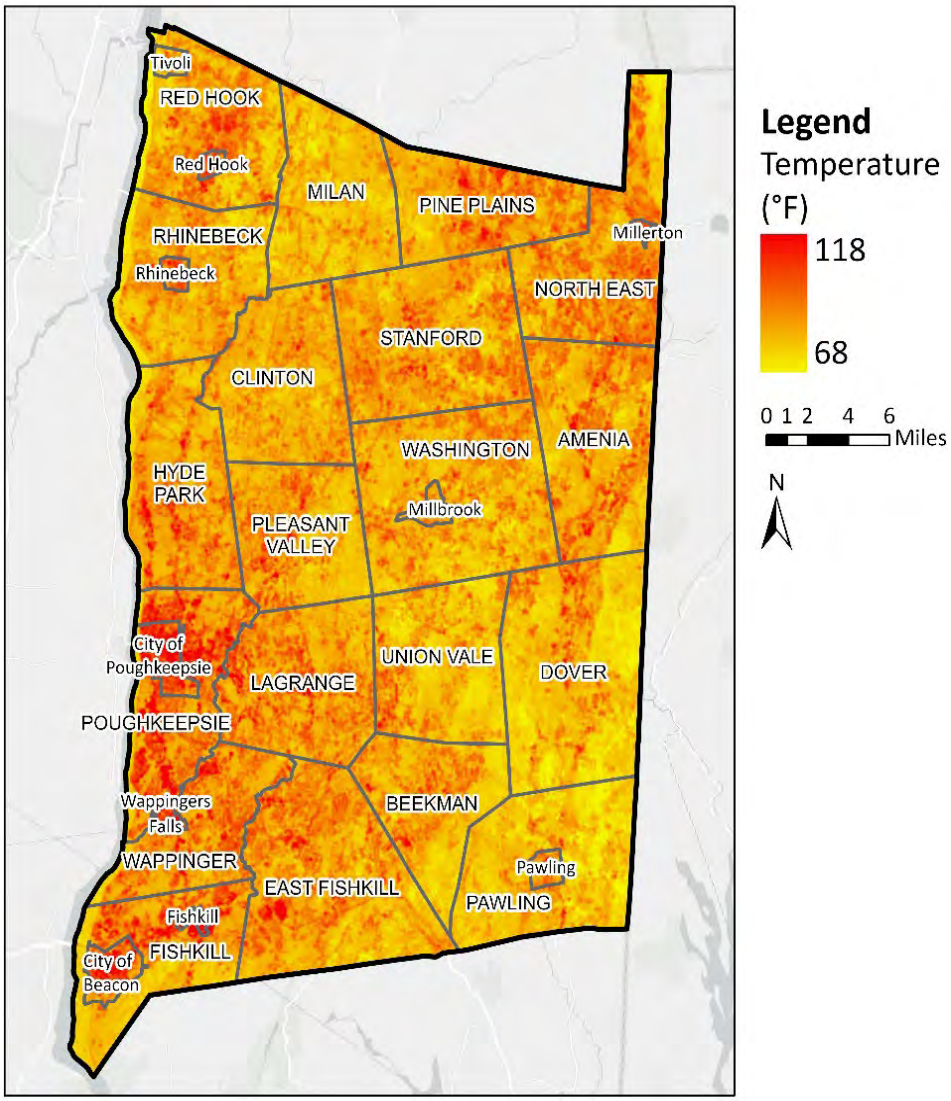


FIGURE 3. HEAT MAP SHOWING MEDIAN SUMMER LAND SURFACE TEMPERATURES IN DUTCHESS COUNTY FROM 2018 TO 2022.

Temperature is not distributed uniformly throughout the County. Rural areas and green spaces, such as forests and parks, experience cooler temperatures than urban areas. The materials that make up urban areas like cities and towns, such as concrete and asphalt, absorb the sun's heat and amplify local temperatures. This is called the urban heat island effect. Figure 3 shows heat distribution for summertime land surface temperatures in Dutchess County. Land surface temperature is how warm the ground is to the touch and is warmer than the surrounding air temperature. As shown in red in Figure 3, **urban areas like the City of Poughkeepsie, City of Beacon, and Fishkill generally see higher land surface summertime temperatures** than forested and rural

[8] Moving Dutchess Forward. Climate Change Trends. https://movingdutchessforward.com/introduction-learn/climate-change-trends/
[9] Weather.gov. All-Time Extremes for Poughkeepsie, NY, 2021. https://www.wCoeather.gov/media/aly/Climate/POU/POU_Extremes.pdf
[10] Ibid.

areas.[11] Even in less urbanized areas, there can be **pockets of urban heat island effect along development corridors**. For example, in Hyde Park, there are narrow vertical strips of higher land surface temperature for the developed areas along highways 9 and 9G.

High temperatures can cause railroad tracks and wires to expand. To avoid accidents, Metro-North reduced its operating speed on the New Haven Line during a heat wave in 2017 near New York City.[12] Amtrak has also reduced the speed of its trains in the Northeast during heatwaves to avoid damaging infrastructure.[13]

Future conditions:

Average temperatures will continue to rise, and extreme temperatures will occur with greater frequency and intensity.

Transportation concern: High temperatures can cause pavement types to soften or crack and rails to buckle. Travelers may also experience discomfort waiting at outdoor bus stops or train stations.

Higher average temperatures

Average daily and monthly temperatures will continue to rise. The average daily high temperature in Dutchess County has historically been around 60°F. Average daily highs are expected to increase to 64-65°F by 2050 and 65-68°F by 2080.[14]

Average monthly temperatures are also rising, with the greatest changes expected during summer and fall months (Table 2). For example, the average temperature during August is projected to increase from approximately 81°F historically to 87°F in 2050 and 91°F in 2080 under a high emissions scenario.

[11] This map was generated in Google Earth Engine using Landsat 8 thermal imagery. Surface reflectance values were converted into land surface temperature (LST) using methods from Ermida et al. 2020. The final image represents the median land surface temperature for June through August from 2018 to 2022. Land surface temperature is often warmer than the air temperature captured by weather sensors because it represents the temperature of the earth's surface to the touch, without added cooling effects from wind. The surface is warmer than the air because it absorbs heat directly from the sun.

[12] Shay, Jim. 2017. High Temperatures slow Metro-North trains. CTPost. https://www.ctpost.com/local/article/High-temperatures-slow-Metro-North-trains-11299935.php

[13] Kika, Thomas. 2022. Heat Wave Forces Amtrak to Slow Trains for Fear of Expanding Tracks, Wires. https://www.newsweek.com/heat-wave-forces-amtrak-slow-trains-fear-expanding-tracks-wires-1727394#:~:text=Amid%20ongoing%20heat%20waves%20around%20the%20East%20Coast,City%20and%20Philadelphia%2C%20according%20to%20ABC%207%20News.

[14] U.S. Federal Government. NOAA. 2021. U.S. Climate Resilience Toolkit Climate Explorer/Average Daily Maximum Temperature in Dutchess County, NY. https://crt-climate-explorer.nemac.org/ Accessed February 2023.

TABLE 2. PROJECTED CHANGE IN AVERAGE MONTHLY TEMPERATURES IN DUTCHESS COUNTY FROM BASELINE TO 2050 AND 2080. ALL VALUES ARE IN DEGREES FAHRENHEIT.[15]

	1950-2013	2050		2080	
Month	**Baseline (°F)**	**Low - High Emissions (°F)**	**Change (°F)**	**Low - High Emissions (°F)**	**Change (°F)**
Jan	34.3	38.0 – 39.0	+3.7 – 4.7	38.8 – 41.9	+4.5 – 7.6
Feb	37.3	40.8 – 41.8	+3.5 – 4.5	42.0 – 44.5	+4.7 – 7.2
Mar	46.2	49.8 – 50.6	+3.6 – 4.4	50.7 – 53.1	+4.5 – 6.9
Apr	59.3	62.7 – 63.4	+3.4 – 4.1	63.7 – 66.2	+4.4 – 6.9
May	70.3	74.0 – 74.9	+3.7 – 4.6	75.0 – 77.7	+4.7 – 7.4
Jun	78.5	82.5 – 83.6	+4.0 – 5.1	83.5 – 86.5	+5.0 – 8.0
Jul	83.2	87.4 – 88.9	+4.2 – 5.7	88.7 – 92.1	+5.5 – 8.9
Aug	81.2	85.9 – 87.3	+4.7 – 6.1	87.2 – 91.0	+6.0 – 9.8
Sept	73.5	78.2 – 79.3	+4.7 – 5.8	79.0 – 82.7	+5.5 -9.2
Oct	62.6	67.0 – 68.2	+4.4 – 5.6	68.1 – 71.2	+5.5 – 8.6
Nov	50.5	54.3 – 54.9	+3.8 – 4.4	54.8 – 57.4	+4.3 – 6.9
Dec	38.4	42.2 – 43.2	+3.8 – 4.8	43.2 – 45.7	+4.8 – 7.3

More extreme temperatures

Extreme high temperatures will occur with greater frequency. From 1981-2010, Dutchess County saw an average of eight days each year where the high temperature reached 90°F or above. This could increase to 30-60 days per year. Projections show 27-35 days per year with temperatures over 90°F by 2050 and 34-61 days by 2080 (Figure 4).

[15] U.S. Federal Government. NOAA. 2021. U.S. Climate Resilience Toolkit Climate Explorer/Average Monthly Daily Maximum Temperature in Dutchess County, NY. https://crt-climate-explorer.nemac.org/ Accessed February 2023.

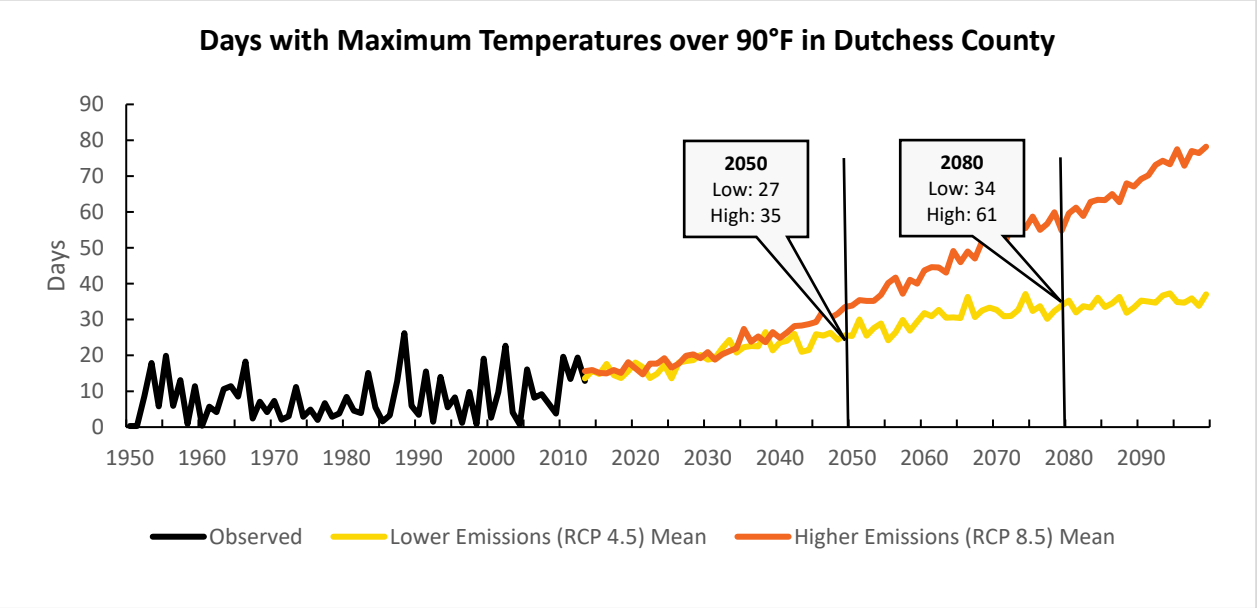


FIGURE 4. AVERAGE NUMBER OF DAYS EACH YEAR WITH MAXIMUM TEMPERATURES OVER 90°F FOR LOW EMISSIONS AND HIGH EMISSIONS SCENARIOS.[16]

[16] U.S. Federal Government. NOAA. 2021. U.S. Climate Resilience Toolkit Climate Explorer/Days with maximum temperature over 90 degrees Fahrenheit in Dutchess County, NY. https://crt-climate-explorer.nemac.org/ Accessed February 2023.

Flooding

Historical trends and past transportation impacts:

Dutchess County typically receives about 44 inches of rain each year[17] and has seen many extreme precipitation and flooding events. Sea level rise has also caused the Hudson River water level to rise more than one foot since 1900.[18]

According to our research in Moving Dutchess Forward, 71 (32%) of our bridges and 150 miles (5%) of our roads are in a FEMA flood zone, which means they have a chance of flooding each year.[19] Storm surge also poses a threat to rail services provided by the Metropolitan Transportation Authority (MTA)/Metro-North Railroad along the Hudson River.

Some examples of impacts to our transportation system from past heavy rainfall and flood events include:

- **Tropical Storm Irene** in August of 2011 produced extreme rainfall with 6-9 inches reported in Dutchess County.[20] Catastrophic flooding washed out several roads and bridges and required significant repairs (Figure 5). This lead to a Major Disaster Declaration for the County.[21]
- **Superstorm Sandy** hit New York State in 2012 with heavy rainfall and record storm surge, which caused about half

FIGURE 5. DAMAGED ROAD AND CULVERT AFTER TROPICAL STORM IRENE IN 2011. PHOTO SOURCE: DCTC

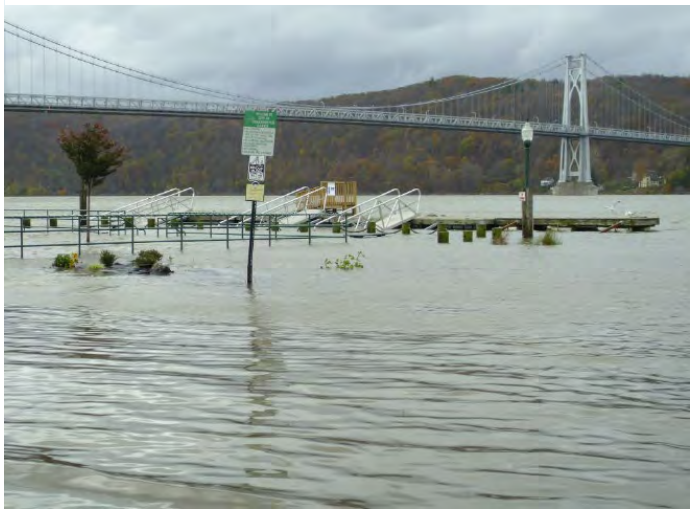


FIGURE 6. POUGHKEEPSIE WATERFRONT FLOODING AFTER SUPERSTORM SANDY IN 2012. PHOTO SOURCE: DCTC.

[17] NOAA Climate Explorer. Total Precipitation for Dutchess County, NY.
[18] Hudson River Flood Impact Decision Support System. https://columbia.maps.arcgis.com/apps/MapSeries/index.html?appid=bbefdeb3474f45e3921964bbcd64cf14
[19] Moving Dutchess Forward. Climate Change Trends. https://movingdutchessforward.com/introduction-learn/climate-change-trends/
[20] Weather.gov. 2011. Updated Storm Totals National Weather Service Albany NY. https://www.weather.gov/media/aly/Past_Events/2011/PNS_StormTotal_Pcpn_Irene.pdf
[21] National Oceanic and Atmospheric Administration. 2022. Storm Events Database. https://www.ncdc.noaa.gov/stormevents/eventdetails.jsp?id=339971

of Metro-North's Hudson River railroad line to be underwater.[22]

- During **Hurricane Ida** in 2021, 4-6 inches of rain fell overnight, and a State of Emergency was issued for Dutchess County. Most of the damage was reported in southern Dutchess County with more than 30 roads closed and many damaged from severe flooding and fallen trees. In some cases, water overtopped bridges, making them impassable.[23]

FIGURE 7. CAR DRIVING THROUGH FLOODED ROAD AFTER HURRICANE IDA IN 2021. PHOTO SOURCE: DCTC.

Future conditions:

Precipitation will become increasingly variable. More frequent and intense heavy rain events as well as sea level rise and storm surge along the Hudson River will contribute to flooding.

Transportation concern: Flooding can damage roads, bridges, and rail lines, causing closures, delays, and safety risks for travelers.

More variable seasonal/monthly precipitation

Precipitation is expected to become more variable each year, with some years receiving much more precipitation than other years. On average, annual precipitation in Dutchess County is projected to increase 1-2 inches by 2050 and 2.5-3.5 inches by 2080, with the greatest increases expected in winter and spring (Table 3).

TABLE 3. AMOUNT OF PRECIPITATION PROJECTED TO FALL EACH SEASON (INCHES) BASED ON LOW EMISSIONS AND HIGH EMISSIONS SCENARIOS.

		2050		2080	
Season	**Baseline (in)**	**Low - High Emissions Precipitation (in)**	**Change (in)**	**Low - High Emissions Precipitation (in)**	**Change (in)**
Winter (Dec, Jan, Feb)	9.4	9.9 – 10.4	+0.5 – 1.0	10.3 – 10.9	+0.9 – 1.5
Spring (Mar, Apr, May)	11.1	11.9 – 12.2	+0.8 – 1.1	12.1 – 12.6	+1.0 – 1.5
Summer (Jun, Jul, Aug)	12.4	12.3 – 12.2	-0.1 – -0.2	12.6 – 12.5	+0.2 – 0.1
Fall (Sep, Oct, Nov)	11.5	11.6 – 11.9	+0.1 – 0.4	11.9 – 11.8	+0.4 – 0.3
Total	44.4	45.7 – 46.7	+1.3 – 2.3	46.9 – 47.9	+2.5 – 3.5

[22] Poughkeepsie Journal Editorial Board. 2017. Lessons from Superstorm Sandy don't come easy: Editorial. https://www.poughkeepsiejournal.com/story/opinion/editorials/2017/11/01/lessons-superstorm-sandy-dont-come-easy-editorial/821207001/

[23] Reakes, Kathy. 2021. Storm Ida: Roadway Closure Update For Dutchess County. https://dailyvoice.com/new-york/southwestdutchess/news/storm-ida-roadway-closure-update-for-dutchess-county/815613/

More heavy precipitation

Heavy rainfall events are expected to become more frequent and intense, leading to flooding. The number of days each year where more than one inch of precipitation falls can be a good way to understand future precipitation patterns. From 1981-2010, there was an average of 5.5 days each year that received more than one inch of precipitation. As shown by the observed data in Figure 8, these heavy precipitation days have varied greatly on a year-to-year basis. By 2080, the number of days each year with more than one inch of precipitation could increase to 5.9 to 6.6 days. The projections in Figure 8 represent an average of climate model projections, showing a gradual increase in the number of days each year with more than one inch of precipitation. It is likely that the general upward trend will persist, but some years will have many days with more than one inch of precipitation and others will have far fewer.

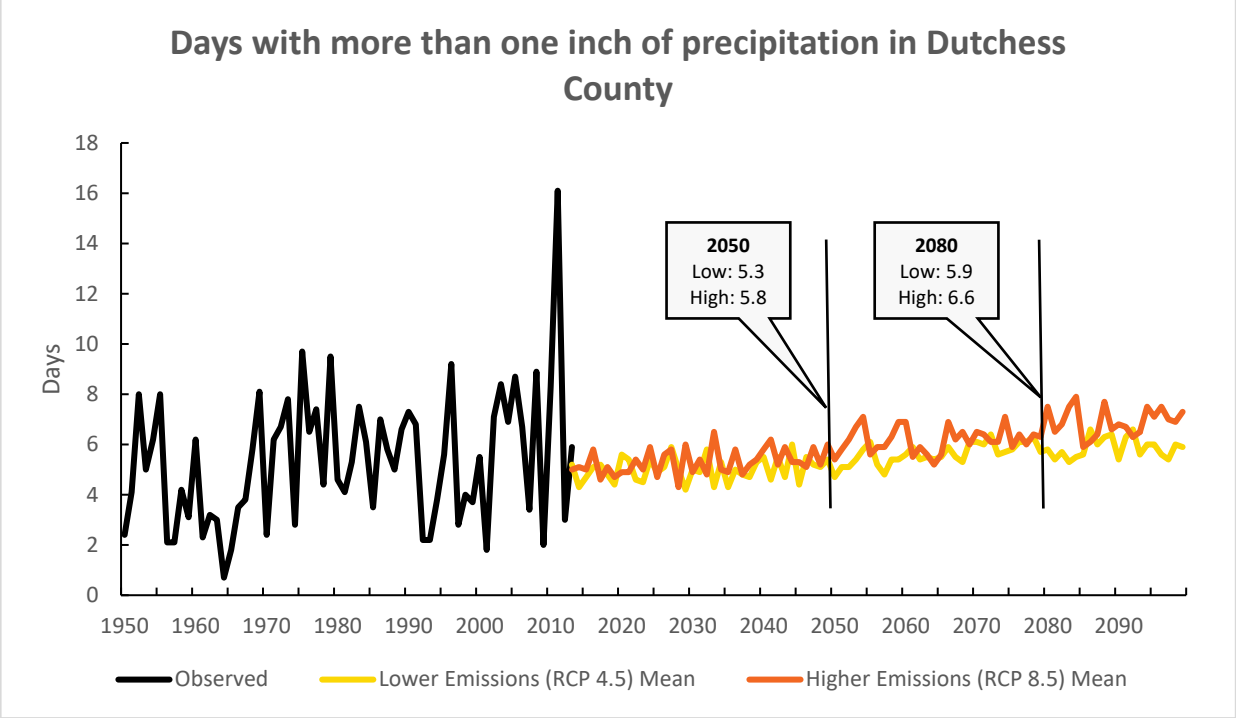


FIGURE 8. DAYS WITH MORE THAN ONE INCH OF PRECIPITATION BASED ON LOW EMISSIONS AND HIGH EMISSIONS SCENARIOS.[24]

Hurricanes, tropical storms, and tropical depressions are one cause of heavy precipitation events in the county. These systems can bring intense rainfall, high winds, and flooding.[25] Although the total number of hurricanes, tropical storms, and tropical depressions are projected to remain approximately the same or even decrease, the intensity of these storms is expected to increase along

[24] U.S. Federal Government. NOAA. 2021. U.S. Climate Resilience Toolkit Climate Explorer/Days with more than one inch of precipitation in Dutchess County, NY. https://crt-climate-explorer.nemac.org/ Accessed February 2023.
[25] Climate Change Effects and Impacts. 2022. Depart of Environmental Conservation. https://www.dec.ny.gov/energy/94702.html#Extreme

the East Coast.[26] A warmer, moister atmosphere is expected to produce more precipitation and sea level rise will cause more severe storm surge.[27]

Greater sea level rise and storm surge

Rising seas intensify storm surge depth and extent, which could threaten areas along the Hudson River during a coastal storm. Under a high emissions scenario, sea levels at the Battery in New York City, the closest tide gauge to Dutchess County, are projected to rise approximately 1.7 feet by 2050 and 4.3 feet by 2080. Figure 9 shows the extent and depth of flooding along the Hudson River under blue sky (an average, sunny day with low winds and clear skies and expected sea level rise) and 100- and 500- year storm conditions in 2050 and 2080 with expected sea level rise.[28] Figure 10 and Figure 11 provide a closer look at the extent and depth of flooding near the City of Poughkeepsie and Staatsburg, respectively as an example. A 100-year storm has a 1-in-100 (or 1-percent) chance of occurring each year and a 500-year storm is even rarer, with a 1-in-500 (or 0.2-percent) chance of occurring each year.

The following assets are projected to experience flooding from each scenario. There could also be ripple effects to the larger transportation network:[29]

- **2050 blue sky conditions with 1.5 feet of sea level rise:** 4 bridges, 1 mile of bus routes, and 3 miles of roads.
- **2050 100-year storm with 1.5 feet of sea level rise:** 10 bridges, 1 dam, 1 mile of bus routes, 4 railroad junctions, 28 miles of railroad lines, 2 railroad passenger stations, and 8 miles of roads.
- **2050 500-year storm with 1.5 feet of sea level rise:** 12 bridges, 1 mile of bus routes, 1 dam, 1 culvert, 4 railroad junctions, 34 miles of railroad, and 10 miles of roads.
- **2080 blue sky conditions with 4 feet of sea level rise:** 5 bridges, 1 mile of bus routes, 1 mile of railroad, and 4 miles of roads.
- **2080 100-year storm with 4 feet of sea level rise:** 13 bridges, 1 mile of bus routes, 6 railroad junctions, 35 miles of railroads, 4 railroad passenger stations, and 11 miles of roads.
- **2080 500-year storm with 4 feet of sea level rise:** 16 bridges, 1 mile of bus routes, 1 culvert, 6 railroad junctions, 4 railroad passenger stations, and 12 miles of roads.

[26] Chung, Maya, et al. 2021. Climate change is probably increasing the intensity of tropical cyclones. Climate.gov. https://www.climate.gov/news-features/understanding-climate/climate-change-probably-increasing-intensity-tropical-cyclones
[27] Deroberts, Nicole. 2019. Climate change is destroying a barrier that protects the U.S. east coast from hurricanes. State of the Planet. https://news.climate.columbia.edu/2019/05/24/wind-shear-hurricanes-east-coast/
[28] Hudson River Flood Impact Decision Support System. 2018. www.ciesin.columbia.edu/huson-river-flood-map/
[29] Ibid

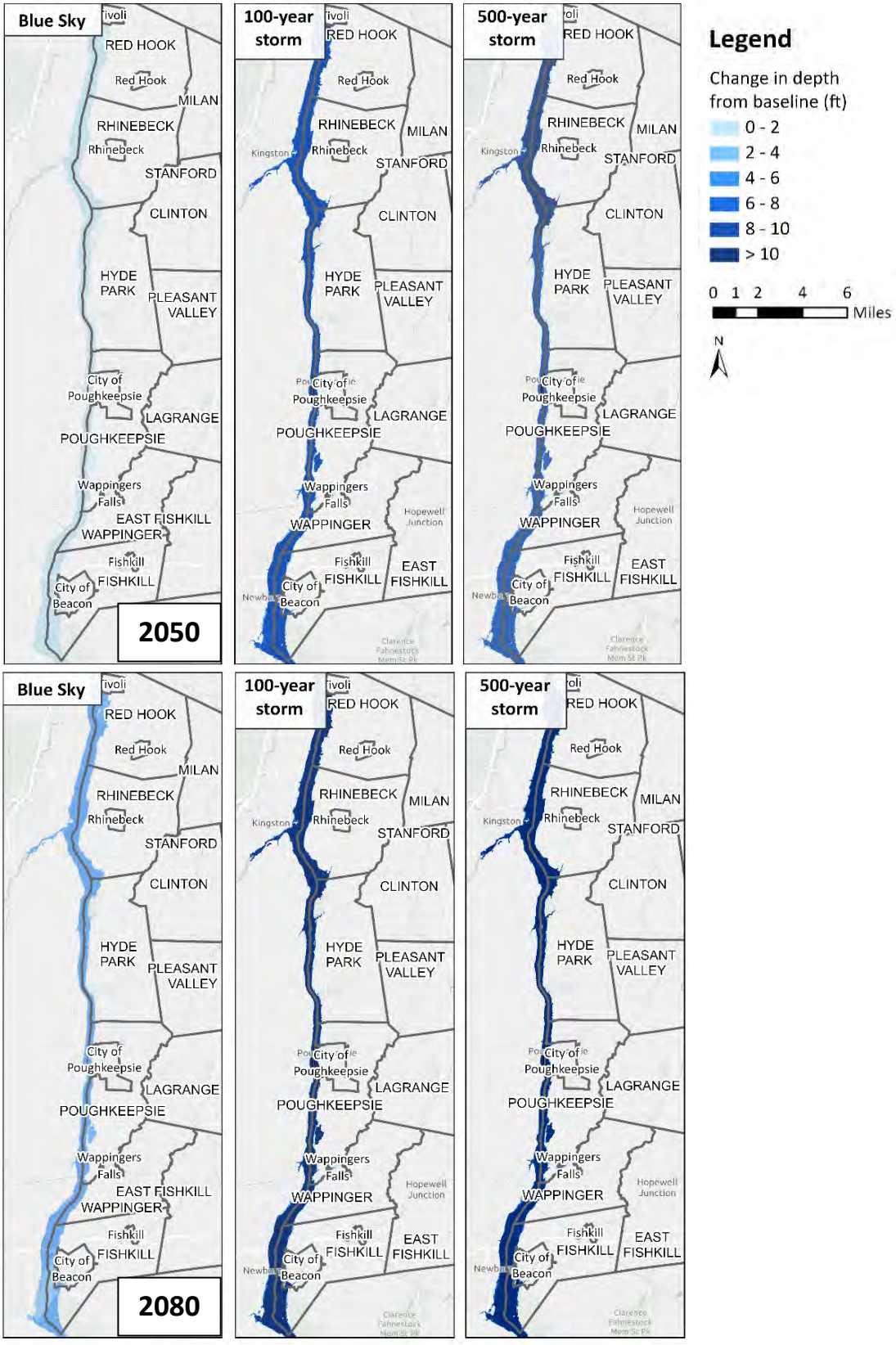


FIGURE 9. CHANGE IN FLOOD DEPTHS ALONG THE HUDSON RIVER UNDER BLUE SKY (NO STORM), 100-YEAR STORM, AND 500-YEAR STORM SCENARIOS FOR SEA LEVEL RISE EXPECTED IN 2050 (1.7 FEET) AND 2080 (4.3 FEET) BASED ON A HIGH EMISSIONS SCENARIO.

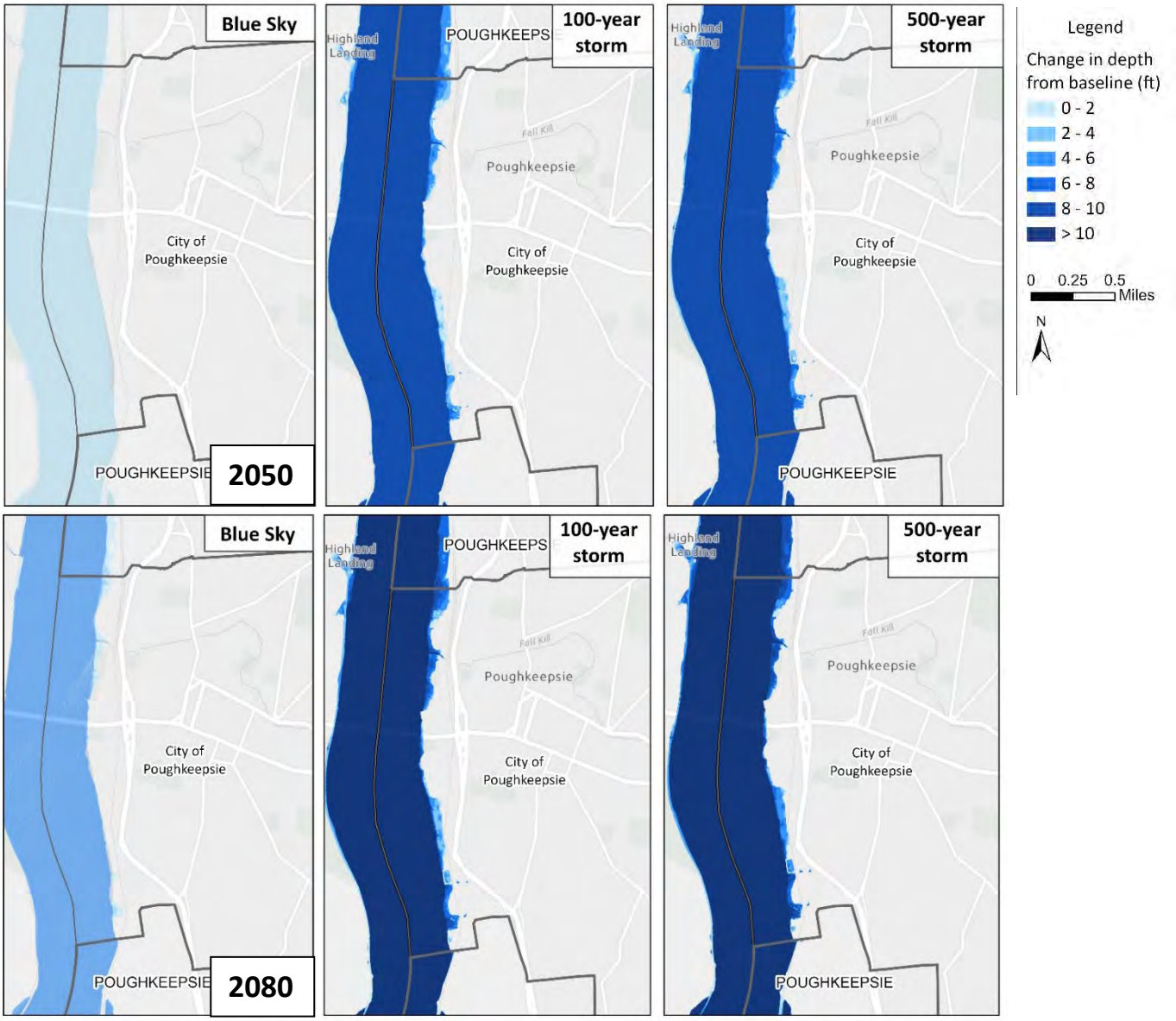


FIGURE 10. CHANGE IN FLOOD DEPTHS ALONG THE HUDSON RIVER IN POUGHKEEPSIE UNDER BLUE SKY (NO STORM), 100-YEAR STORM, AND 500-YEAR STORM SCENARIOS FOR SEA LEVEL RISE EXPECTED IN 2050 (1.7 FEET) AND 2080 (4.3 FEET) BASED ON A HIGH EMISSIONS SCENARIO.

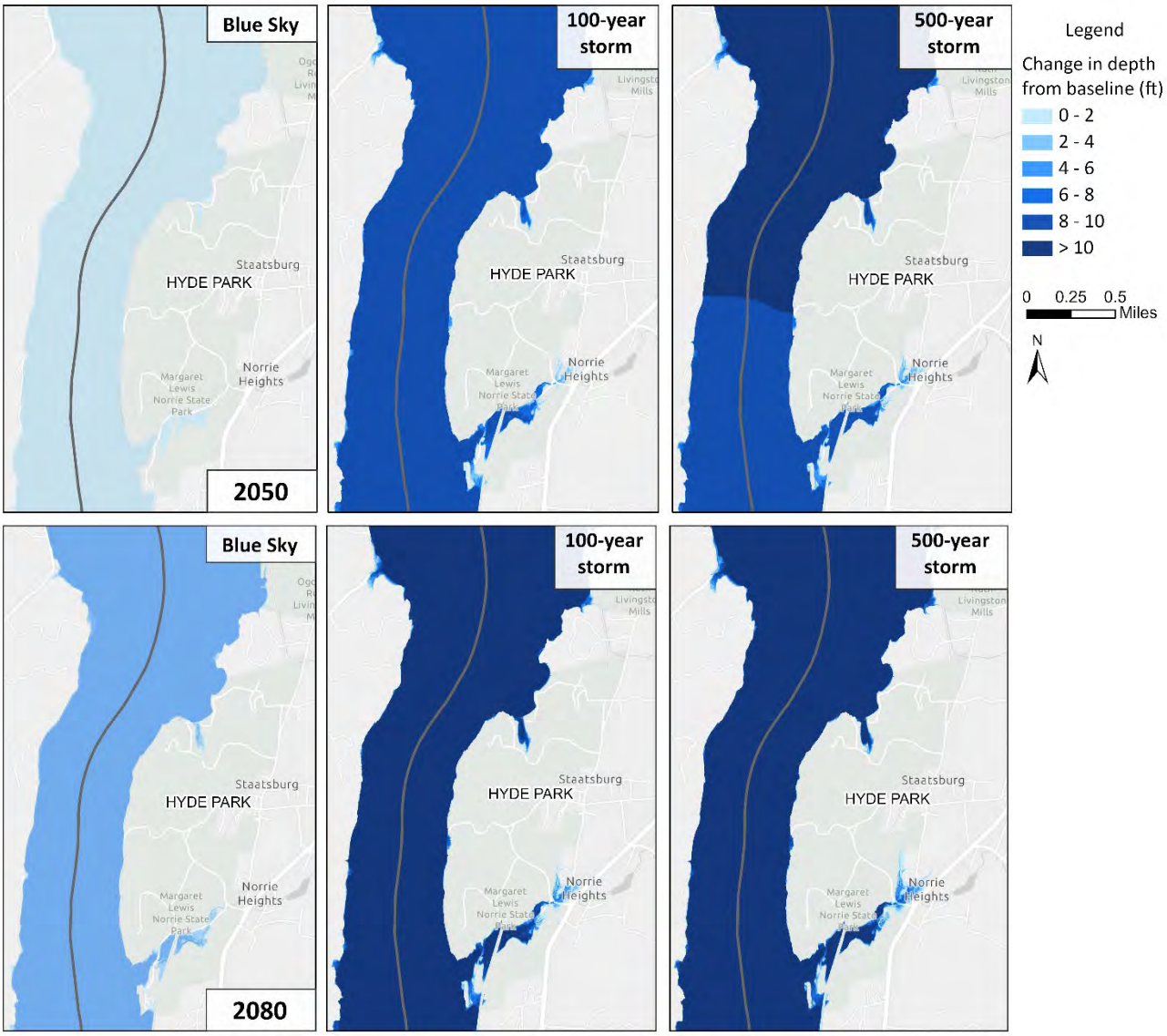


FIGURE 11. CHANGE IN FLOOD DEPTHS ALONG THE HUDSON RIVER NEAR STAATSBURG UNDER BLUE SKY (NO STORM), 100-YEAR STORM, AND 500-YEAR STORM SCENARIOS FOR SEA LEVEL RISE EXPECTED IN 2050 (1.7 FEET) AND 2080 (4.3 FEET) BASED ON A HIGH EMISSIONS SCENARIO.

Drought

Historical trends and past transportation impacts:

Dutchess County has experienced multiple flash droughts since 2000, most notably in 2002, 2017, and 2022.

Although the Northeast is generally a wetter region than other parts of the United States, New York still experiences damaging droughts. Droughts are prolonged periods of mostly dry conditions, where some precipitation may still occur. The Northeast frequently experiences "flash" droughts, a short term (2-6 months) intense dry period that can follow a period of normal or above-normal precipitation.[30] Figure 12 shows the percent of land area in Dutchess County that experienced various levels of drought between January 2000 and February 2023.[31]

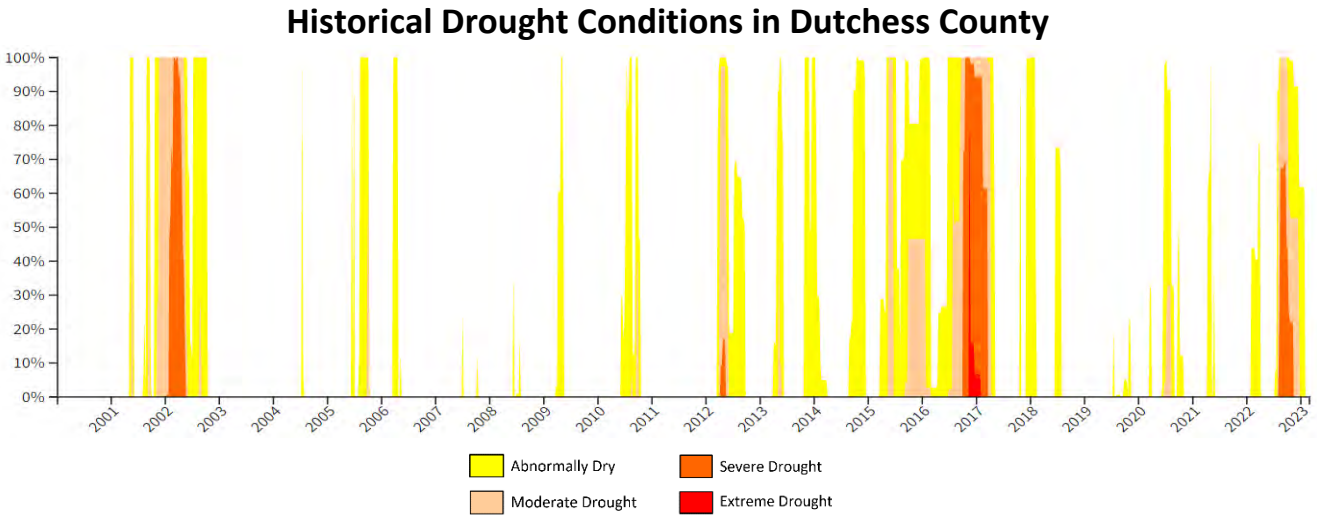


FIGURE 12. PERCENT LAND AREA OF DUTCHESS COUNTY IN VARIOUS STAGES OF DROUGHT FROM 2000 TO 2023.

Some examples of past droughts in the county include:

- From October 2016 to March 2017, Dutchess County experienced Moderate to Severe Drought conditions. This drought peaked in November 2016 where **86% of the county reached Extreme Drought** (shown in red in Figure 13). Figure 14 summarizes the percentage of Dutchess County in each drought

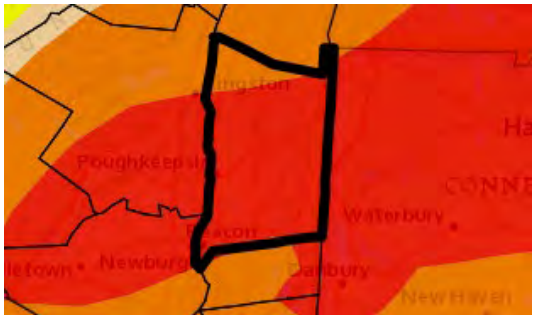


FIGURE 13. DROUGHT CONDITIONS IN DUTCHESS COUNTY THE WEEK OF NOVEMBER 15, 2016 (RED = EXTREME DROUGHT; ORANGE = SEVERE DROUGHT).

[30] Drought.gov. 2022. Northeast. https://www.drought.gov/dews/northeast
[31] Drought.gov. 2022. Dutchess County Drought Monitor. https://www.drought.gov/historical-information?state=new-york&countyFips=36027&dataset=0&selectedDateUSDM=20110712

level during the week of November 15, 2016, as well as the types of impacts that can be expected from each drought level.[32]

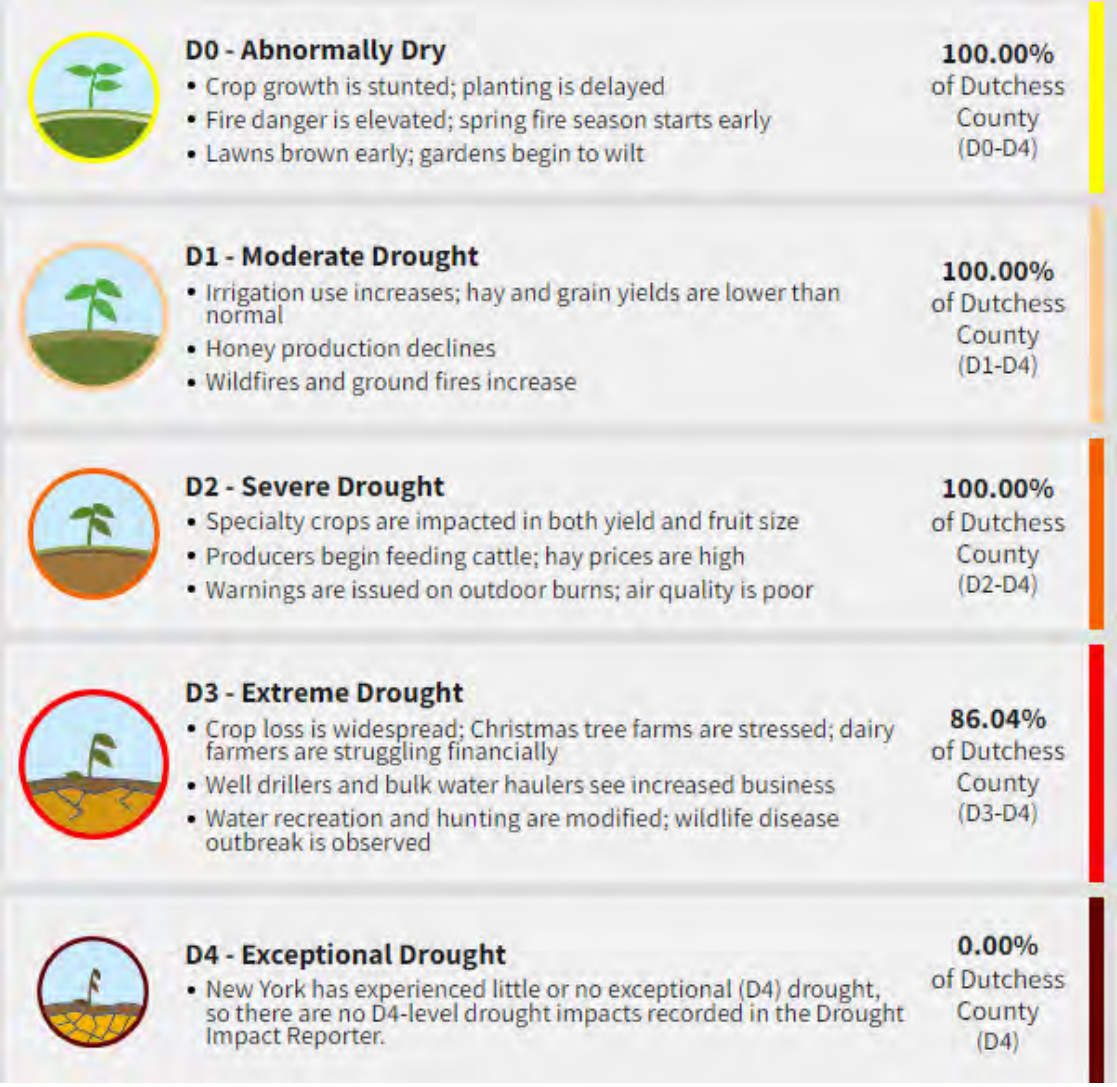


FIGURE 14. POTENTIAL DROUGHT IMPACTS PER LEVEL.

- Most recently, Dutchess County experienced drought conditions from August 2022 to December 2022. The most intense conditions occurred the week of September 13th where **69% of the county was in a Severe Drought** and the remaining 31% was in a Moderate Drought.[33]

Drought is not expected to directly affect transportation assets and there have been no reported impacts to date. However, drought can have indirect effects such as increasing the risk of erosion from dry soil and weakened vegetation. It can also increase the risk of wildfires as soil and vegetation

[32] Ibid
[33] Ibid.

are drier and increase the risk of mudslides and flooding after heavy precipitation events, especially in areas that have been burned in the past five years.[34]

Future conditions:

Dutchess County is expected to experience longer periods without precipitation, increasing the risk of drought. However, the specific timing or duration of future droughts remains difficult to predict.[35]

Transportation concern: Drought is not expected to directly affect transportation assets.

More dry days

Precipitation patterns are shifting – heavy rainfall events are expected to become more frequent and more severe, **and longer periods of dry conditions are expected between those heavy rainfall events.** The total number of dry days each year can be used as a proxy for understanding drought. Dry days are days where less than 0.01 inches of precipitation falls. From 1981-2010 Dutchess County saw an average of 169 dry days each year, though this number fluctuates greatly year to year (Figure 15). The average number of dry days is projected to increase slightly to 171-173 days by 2080.

As noted in the flooding section, precipitation can vary significantly from year to year and there is a range of uncertainty in future projections. While the average number of dry days shows a gradual increase, the year-to-year variability experienced in the past is likely to persist.

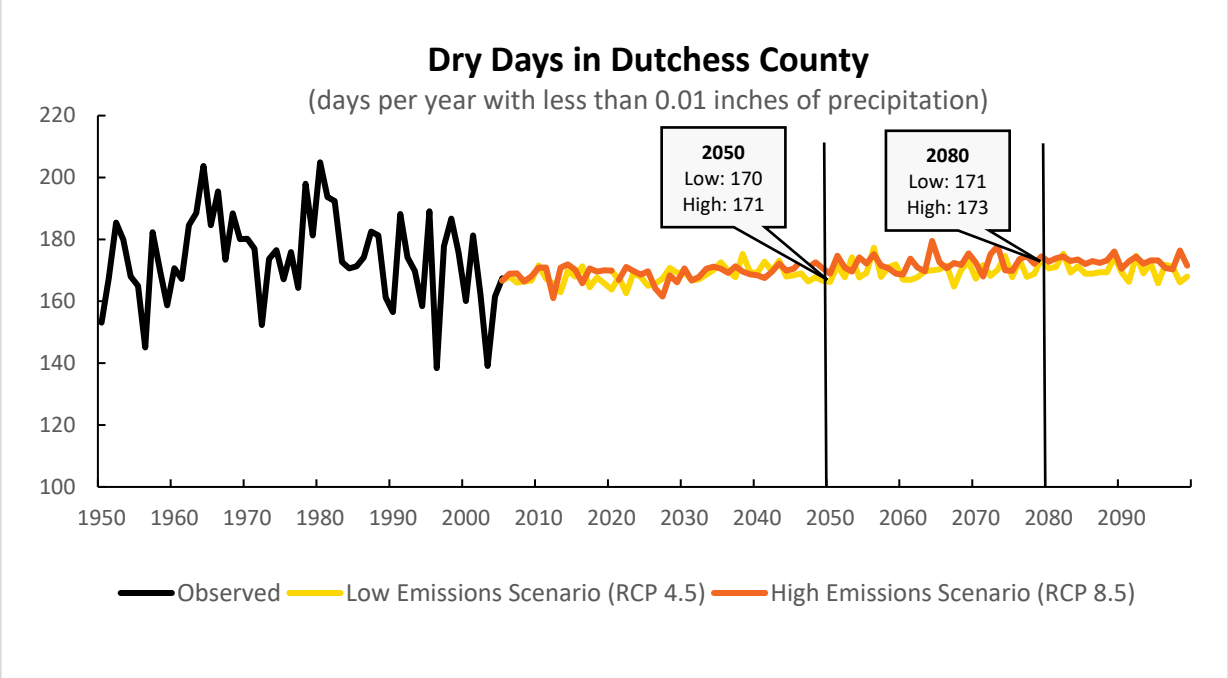


FIGURE 15. DRY DAYS PER YEAR BASED ON LOW EMISSIONS AND HIGH EMISSIONS SCENARIOS. DRY DAYS HAVE LESS THAN 0.01 INCH OF PRECIPITATION.[36]

[34] FEMA. 2021. Flood Risks Increase After Fires. https://www.fema.gov/fact-sheet/flood-risks-increase-after-fires
[35] Krakauer, Nir, et al. 2019. Trends in Drought over the Northeast United States. MDPI. https://www.mdpi.com/2073-4441/11/9/1834
[36] U.S. Federal Government. NOAA. 2021. U.S. Climate Resilience Toolkit Climate Explorer/Dry Days in Dutchess County, NY. https://crt-climate-explorer.nemac.org/ Accessed February 2023.

Wind

Historical trends and past transportation impacts:

Dutchess County has experienced multiple high wind events, including Tropical Storm Irene in 2011 and Tropical Storm Isaias in 2020.

Dutchess County has had multiple reports of high sustained wind speeds and winds gusts from past storm events. The National Weather Service defines damaging high wind as sustained wind speeds of 40-50 mph.[37]

Some specific examples of impacts to our transportation system from severe wind events include:

- **Tropical Storm Irene** in 2011 recorded wind speeds of 35 to 55 mph, and strong wind gusts exceeding 60 mph. The combination of strong winds and flooded land caused many downed trees and power lines in the area, resulting in road closures.[38] One week after Tropical Storm Irene, 1,500 customers were still without power in Dutchess County.[39]
- In May 2018, a **severe thunderstorm** recorded intense winds up to 105 mph. Travel restrictions were issued along the I-84 corridor in southern Dutchess County due to fallen trees and malfunctioning traffic lights from severe wind. In addition, Amtrak and Metro North suspended their service in the county.[40]
- **Tropical Storm Isaias** in 2020 recorded wind speeds of 57-61 mph in Dutchess County and caused severe wind damage. A State of Emergency was issued for Dutchess County. Damage occurred to many trees and utility poles and caused more than 50,000 reported outages throughout the county.[41] In addition, a portion of I-84 was closed due to a downed tree that blocked two lanes of the

FIGURE 16. FALLEN TREES AND UTILITY WIRES AFTER A SEVERE THUNDERSTORM AND HIGH WINDS IN 2018. PHOTO SOURCE: POUGHKEEPSIE JOURNAL.

[37] National Weather Service. 2022. Wind. https://www.weather.gov/safety/wind
[38] National Oceanic and Atmospheric Administration. 2022. Storm Events Database. https://www.ncdc.noaa.gov/stormevents/eventdetails.jsp?id=339972
[39] Daily Freeman. 2011. About 2500 Central Hudson Customer without Power. https://www.dailyfreeman.com/2011/09/05/about-2500-central-hudson-customers-without-power/
[40] Ibid
[41] Ibid

highway.[42] During high wind events, truck restrictions have occurred along Hudson River bridges due to the severity of wind speeds.[43]

Future conditions:

Dutchess County could experience higher winds as the intensity of hurricanes, tropical storms, tropical depressions, and other extreme weather events (e.g., thunderstorms) increase.

Transportation concern: High winds can lead to speed or travel restrictions, road closures from fallen trees and utility poles, and damage to supporting infrastructure like traffic signals and road signs.

Average and extreme wind speeds are difficult to project due to the localized scale at which they occur.[44] Existing literature on average wind speeds for the Northeast does not suggest significant expected changes.

However, existing literature does support an increase in the intensity of hurricanes, tropical storms, and tropical depressions along the East Coast.[45] These events are defined by wind speed and atmospheric pressure, so it is possible that hurricanes, tropical storms, and tropical depressions could result in higher wind speeds and gusts in the county.[46]

[42] Hudson Valley Post. 2022. Downed tree on I-84 in Hudson Valley closes down part of highway. https://hudsonvalleypost.com/downed-tree-on-i-84-in-hudson-valley-closes-down-parts-of-highway/?utm_source=tsmclip&utm_medium=referral&fbclid=IwAR2TisirfxewNLrA8eeNp4GYw8rUF91K4jf6m4hm3QNLmBxQS8Z9ta45ti8

[43] Moving Dutchess Forward. 2020. Climate Change Trends. https://movingdutchessforward.com/introduction-learn/climate-change-trends/

[44] Komurcu, M. and S. Paltsev. 2021. Toward resilient energy infrastructure: Understanding the effects of changes in the climate mean and extreme events in the Northeastern United States. Joint Program Report Series Report 352, June, 16 p. http://globalchange.mit.edu/publication/17608

[45] Chung, Maya, et al. 2021. Climate change is probably increasing the intensity of tropical cyclones. Climate.gov. https://www.climate.gov/news-features/understanding-climate/climate-change-probably-increasing-intensity-tropical-cyclones

[46] Seneviratne, S.I., et al. 2021. Weather and Climate Extreme Events in a Changing Climate. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1513–1766, doi:10.1017/9781009157896.013

Winter conditions

Historic trends and past transportation impacts:

Winters in the Northeast have warmed three times faster than summers, leading to later snowfall and earlier snowmelt.[47]

Although winters are generally warming, Dutchess County has had several significant winter storms in the recent past. Some examples of impacts to our transportation system from past winter storms include:

- In March 2017, the **Pi Day Blizzard** heavily impacted Dutchess County, as snow fell at 1 to 4 inches per hour for most of the day.[48] Across Dutchess County, snowfall averaged 21 inches, with some regions experiencing 24-26 inches.[49] Travel bans were issued on all county roads, tractor-trailers were banned on most interstates, and schools were closed for two days.[50,51]

FIGURE 17. A ROAD IN DUTCHESS COUNTY DURING A 2010 SNOWSTORM. PHOTO SOURCE: WIKIMEDIA COMMONS.

- In March 2018, Dutchess County experienced **two major winter storms** within one week of each other. Snow accumulation reached 20 inches and portions of I-84 were closed after dangerous conditions lead to several vehicle crashes.[52,53] The Taconic State Parkway reported low hanging trees due to the heavy weight of the snow, creating difficult driving conditions and limited visibility.[54]
- In December 2020, a **winter storm** caused Dutchess County to suspend the County's Public Transit service for 1 day. Snow accumulation totaled 12-14 inches across the county and

[47] Dupigny-Giroux, L.A., et al. 2018. Northeast. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II. U.S. Global Change Research Program, Washington, DC, USA, pp. 669–742. doi: 10.7930/NCA4.2018.CH18
[48] National Centers for Environmental Information. 2022. Storm Events Database. https://www.ncdc.noaa.gov/stormevents/eventdetails.jsp?id=686364
[49] National Weather Service. 2020. Major Winter Storms. https://www.weather.gov/aly/MajorWinterStorms
[50] Ibid.
[51] DutchessNY.gov. 2017. Dutchess County Storm Update – March 14th 5pm. https://www.dutchessny.gov/Departments/County-Executive/34410.htm
[52] Daily Freeman. 2018. Updated Snow Totals, Accumulation topped 20 inches in parts of Ulster, Dutchess, Columbia counties. https://www.dailyfreeman.com/2018/03/08/updated-snow-totals-accumulation-topped-20-inches-in-parts-of-ulster-dutchess-columbia-counties/
[53] Lewison, Dave. 2018. Interstate 84 shutdown, heavy snow and accidents. Hopewell, NY, Storm Chasing Video. https://www.stormchasingvideo.com/2018/03/07/interstate-84-shutdown-heavy-snow-accidents-hopewell-ny-3-7-2018/
[54] Ibid.

highway crews had difficulty keeping up with plowing, resulting in dangerous driving conditions.[55]

- In December 2021, **freezing rain** accumulated from a light glaze to 0.25 of an inch, resulting in icy road conditions, vehicle crashes and spin outs, and school closures.[56]
- In March 2023, a **Nor'easter** produced 8-16 inches of snow in Dutchess County, falling 1-2 inches per hour.[57] Heavy, wet snow combined with 40 mph wind gusts caused numerous downed trees and wires. Dutchess County Public Transit suspended all service for the following day and travel and parking restrictions were in place for drivers.[58]

Future conditions:

Dutchess County will experience fewer days each year below freezing (32°F) which will cause precipitation to fall more often in the form of rain rather than snow. However, when winter storms do occur, they are projected to be more severe and include greater snowfall.

Transportation concern: Winter storms can cause dangerous driving conditions and low visibility. This may result in road closures, travel restrictions, and increased maintenance costs during and after the event. Frequent melting and freezing of water can also cause cracking and buckling in roads.

Changes in snowfall and winter storm events are difficult for climate scientists to project. There is uncertainty about how these events may change over time, especially in specific areas. General trends for the Northeast suggest:

- As the climate warms, the frequency of winter conditions (i.e., snow, ice) across the Northeast could decrease since warmer temperatures will cause more precipitation to fall in the form of rain. This could lead to shorter snow seasons and decreased snow depth.[59,60]
- Although the frequency of winter conditions may decrease, when these storms do occur, there is potential for greater snowfall.[61] Warmer temperatures increase the atmosphere's ability to hold moisture and thus produce more snow.

[55] DutchessNY.Gov. 2020. Winter Storm Update. https://www.dutchessny.gov/Departments/County-Executive/Winter-Storm-Update-Thursday-December-17th-2020.htm

[56] . National Oceanic and Atmospheric Administration. 2022. Storm Events Database. https://www.ncdc.noaa.gov/stormevents/eventdetails.jsp?id=996888

[57] Randall, Mike. 2023. How much snow did we get? Recordonline.com. https://www.recordonline.com/story/news/2023/03/14/snowfall-totals-dutchess-orange-ulster-sullivan-mid-lower-hudson-valley-ny/70006957007/

[58] Mid Hudson. 2023. State of Emergencies being declared in advance of storm. https://midhudsonnews.com/2023/03/13/state-of-emergencies-being-declared-in-advance-of-storm/

[59] Zarzycki, C. M. 2018. Projecting Changes in Societally Impactful Northeastern U.S. Snowstorms. Geophysical Research Letters, 45(21), 12,067-12,075. https://doi.org/10.1029/2018GL079820

[60] Demaria, E. M. C., Roundy, J. K., Wi, S., & Palmer, R. N. 2016. The Effects of Climate Change on Seasonal Snowpack and the Hydrology of the Northeastern and Upper Midwest United States, Journal of Climate, 29(18), 6527-6541. Retrieved Jan 18, 2023, from https://journals.ametsoc.org/view/journals/clim/29/18/jcli-d-15-0632.1.xml

[61] Dupigny-Giroux, L.A., et al. 2018. Northeast. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II. U.S. Global Change Research Program, Washington, DC, USA, pp. 669–742. doi: 10.7930/NCA4.2018.CH18

Fewer days with temperatures below freezing

The County will experience fewer days each year with temperatures below freezing (32°F). Historically, Dutchess County has experienced about 151 days each year where **daily low temperatures** dip below 32°F. The number of days with minimum temperatures below freezing is expected to decrease to 121-127 days by 2050 and 96-117 days by 2080 (Figure 18).[62]

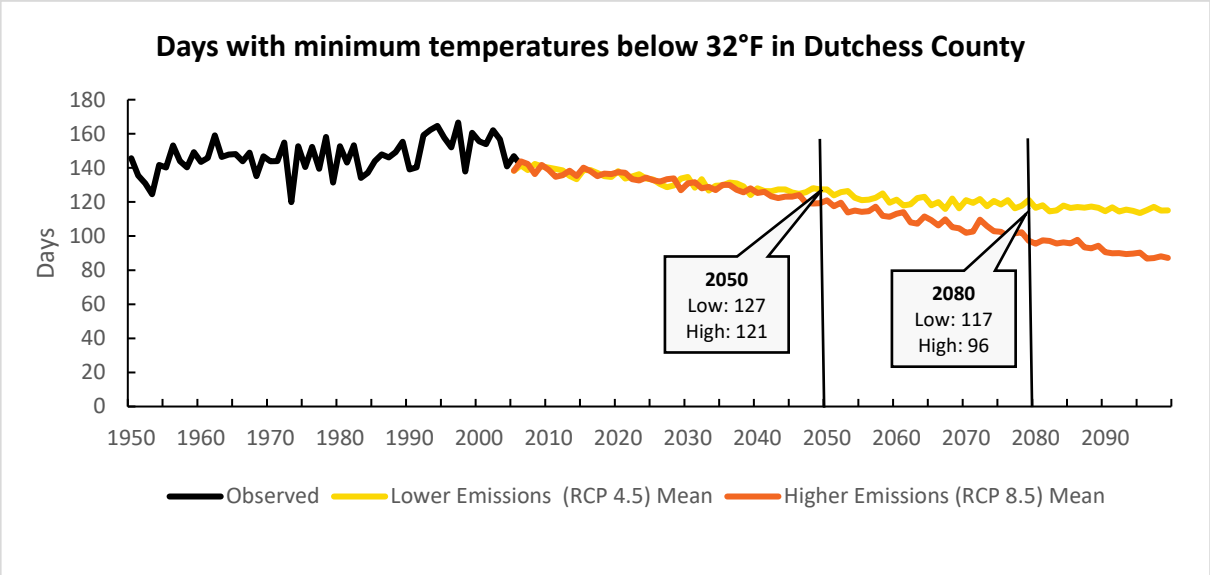


FIGURE 18. DAYS PER YEAR WITH MINIMUM DAILY TEMPERATURES BELOW 32°F BASED ON LOW EMISSIONS AND HIGH EMISSIONS SCENARIOS.

Dutchess County has historically experienced an average of 30 days each year where **daily high temperatures** remain below 32°F. The number of days with maximum temperatures below 32°F is also projected to decrease to 14-19 days by 2050 and 5-15 days by 2080 (Figure 19).

[62] U.S. Federal Government. NOAA. 2021. U.S. Climate Resilience Toolkit Climate Explorer/Days each year with minimum daily temperatures below 32 degrees Fahrenheit in Dutchess County, NY. https://crt-climate-explorer.nemac.org/.

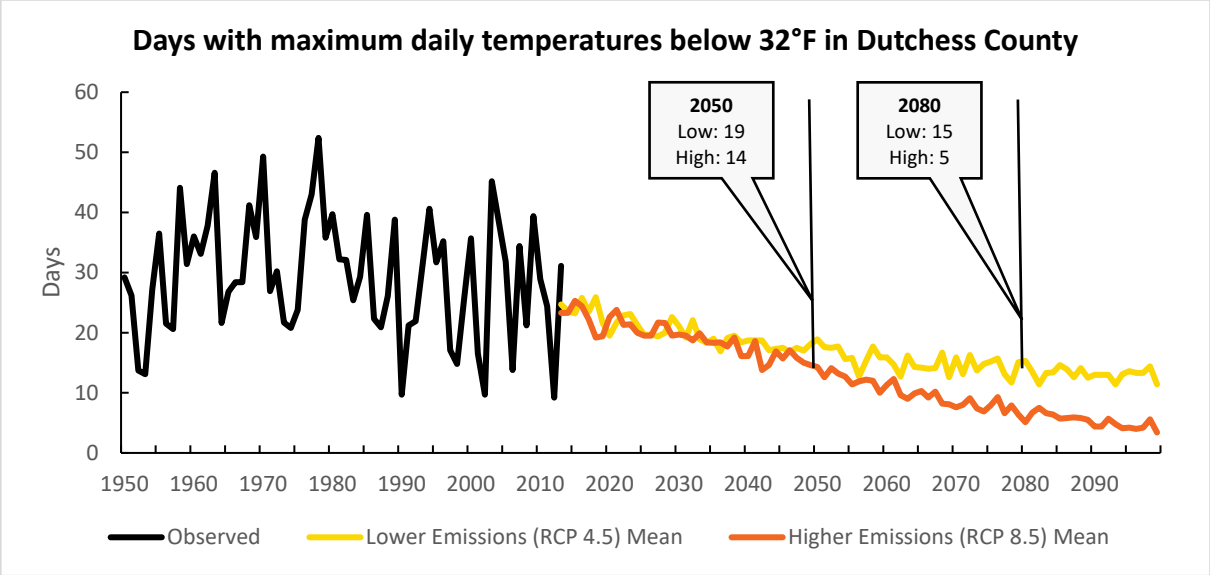


FIGURE 19. DAYS PER YEAR WITH MAXIMUM DAILY TEMPERATURES BELOW 32°F BASED ON LOW EMISSIONS AND HIGH EMISSIONS SCENARIOS.[63]

Fewer freeze-thaw days

A freeze-thaw day occurs when the maximum air temperature is above freezing, and the minimum temperature is below freezing. This quick shift in temperature causes water to melt and then freeze again. Water expands when it freezes, so freezing, thawing, and re-freezing can significantly damage pavement and infrastructure. Successive freeze-thaw cycles can lead to expansion, cracking, and buckling of roads, causing potholes, road closures and long-term damage.[64]

In general, **fewer freeze-thaw days are expected to occur as average temperatures increase**. From 1981-2010, Dutchess County saw an average of 117 freeze-thaw days each year. The number of freeze-thaw days is projected to decrease to 91-98 days by 2050 and 76-90 days by 2080 (Figure 20). It is important to note that these projections are only available for air temperatures, not ground temperatures. Pavement freeze-thaw reacts to ground temperatures, which are likely to lag air temperatures.

[63] U.S. Federal Government. NOAA. 2021. U.S. Climate Resilience Toolkit Climate Explorer/Days each year with maximum daily temperatures below 32 degrees Fahrenheit in Dutchess County, NY. https://crt-climate-explorer.nemac.org/. Accessed February 2023.
[64] Siddique, Z., Hossain, M., Meggers, D. 2005. Temperature and Curling Measurements on Concrete Pavement. Research Gate. https://www.researchgate.net/publication/228678490_Temperature_and_Curling_Measurements_on_Concrete_Pavement

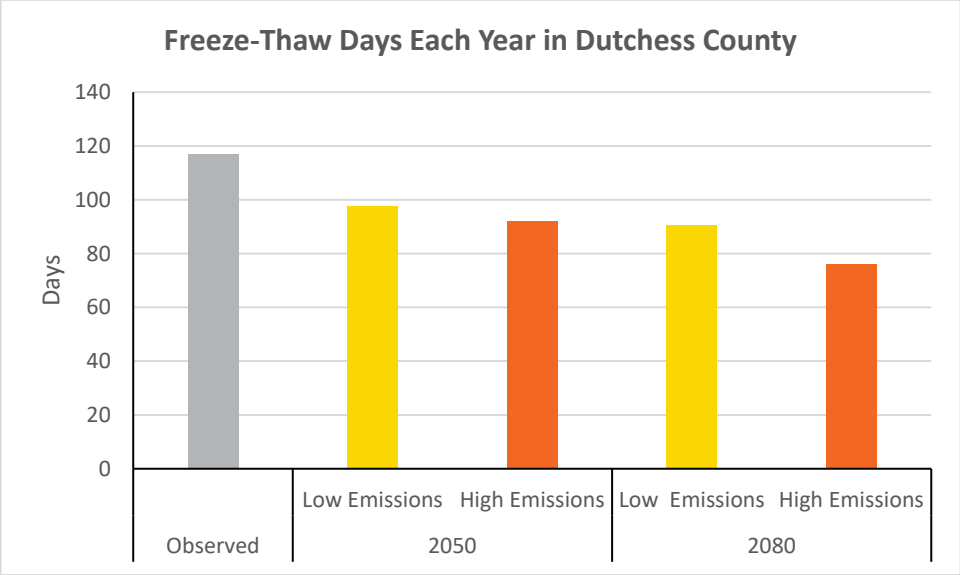


FIGURE 20. FREEZE-THAW DAYS EACH YEAR BASED ON LOW EMISSION AND HIGH EMISSION SCENARIOS.[65]

[65] Source: ICF Climate Sight.

Landslides

Historical trends and past transportation impacts:

The southwest and eastern parts of Dutchess County have steep slopes where landslides or rockfalls are most likely to occur.

Figure 21 shows landslide susceptibility for Dutchess County, which is highest in the southwest and eastern parts of the county. Landslide susceptibility ratings reflect the likelihood of a landslide occurring based on historical rainfall, history of past landslides, slopes, rock and soil type, vegetation, seismic conditions, and human activities.

There have not been any reported landslide or rockfall impacts to our transportation system to date.

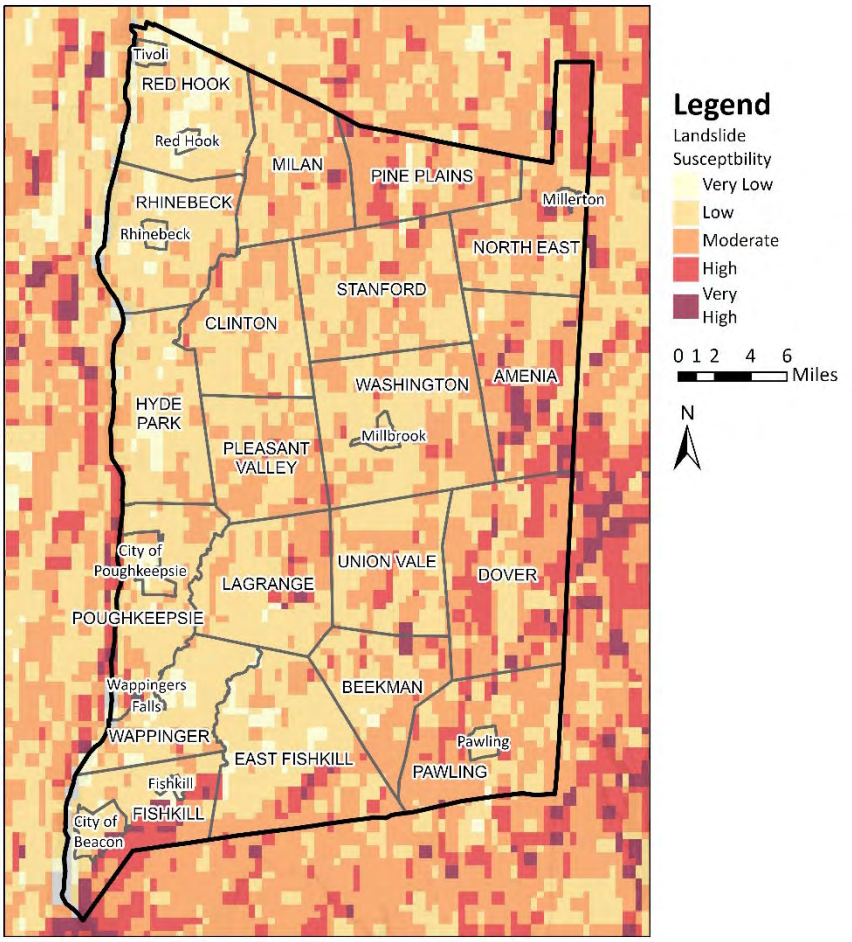


FIGURE 21. LANDSLIDE SUSCEPTIBILITY IN DUTCHESS COUNTY.

Future conditions:

Precipitation-driven landslide and rockfall events could occur more frequently.

Transportation concern: Landslides and rockfalls have the potential to cause major damage to transportation infrastructure and pose safety risks for travelers.

Landslide susceptibility calculations do not account for changing precipitation patterns due to climate change. As noted in the flooding section, precipitation events are becoming more frequent and intense in Dutchess County. This could increase the potential for precipitation-driven landslide events, especially in areas of the county with steep slopes and higher landslide susceptibility.

What's Next?

This report summarizes the best available climate change data and trends for Dutchess County. While the primary purpose is to provide base level climate information for Resilient Ways Forward, it is also intended to be an informational resource to help decision-makers and agencies address climate change in their capital priorities and operational processes; and the public to better understand how the climate is changing and how that could impact the transportation system.

Our next step is to analyze how and where our transportation system is most vulnerable to the impacts of climate change summarized in this report. Resilient Ways Forward will also identify ways to adapt to or reduce the adverse impacts of climate change on our transportation system, including roads and bridges, buses and trains, sidewalks and rail trails, and other strategic transportation assets.

Figure 22 provides a timeline and overview of the Resilient Ways Forward development process.

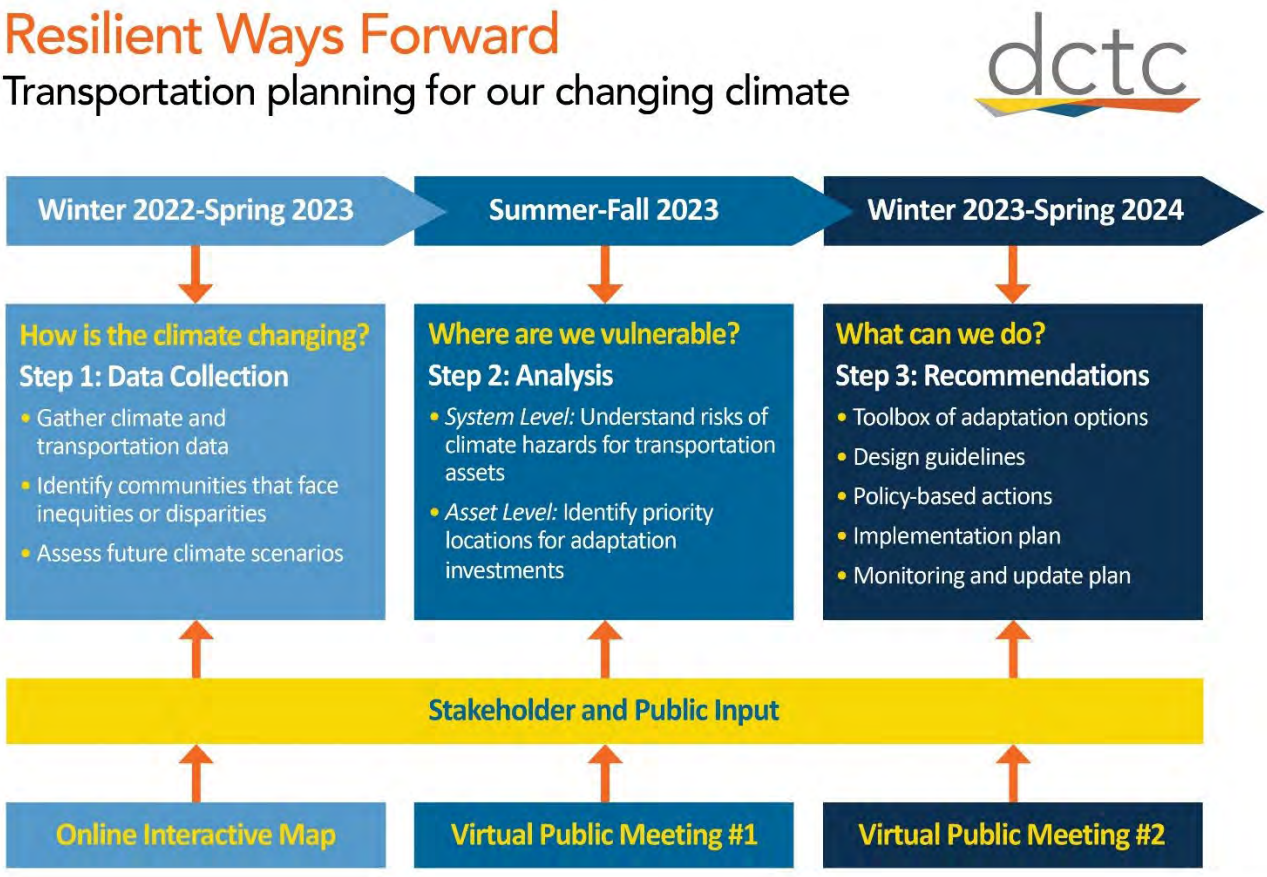


FIGURE 22. RESILIENT WAYS FORWARD PROCESS OVERVIEW.