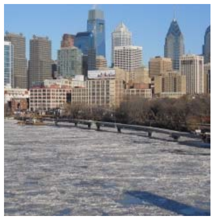

Useful Climate Information for Philadelphia: Past and Future

August 2014

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Table of Contents

1. Introduction

The Philadelphia Mayor's Office of Sustainability (MOS) is considering how changes in future climate and weather events may impact City of Philadelphia planning, investment, programming, and operations/maintenance activities. This report presents information on projected changes in climate as compared to historical norms. Information in this report provides a common starting point for entities in Philadelphia that are interested in considering impacts – positive or negative – of projected changes in climate.

This report presents climate data designed to inform decisions made by City departments and their stakeholders; climate variables chosen for this report were determined through discussions with City agencies regarding existing vulnerabilities to climatic events. Our initial review focused on climate information from the following reports: "Pennsylvania Climate Impact Assessment Report to the Department of Environmental Protection" (PACIA, 2009), "Climate Change in Pennsylvania: Impacts and Solutions for the Keystone State" (UCS, 2008), the 2012 City of Philadelphia Natural Hazard Mitigation Plan (COP, 2012)[1], and the draft science summary from "A Vulnerability & Risk Assessment of SEPTA's Manayunk/Norristown Line" (ICF, 2013). We reviewed these reports to determine their applicability (see Appendix A for a comparison of climate projection datasets potentially useful to MOS). Further, we worked with MOS along with stakeholders on the climate adaptation working group to ensure that the climate projections developed during this effort would meet the City's needs within the time and resource constraints of this project. Ultimately, MOS and the climate adaptation working group members decided to refresh information on temperature and precipitation using a newly available climate data processing tool developed by ICF for the U.S. Department of Transportation (DOT). The "CMIP climate data processing tool" provides post-processing of statistically downscaled climate data based on information provided by the "Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections" using World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) and phase 5 (CMIP5) multi-model datasets.[2] Data on temperature and precipitation derived from the CMIP climate data processing tool are supplemented with other kinds of climate data (e.g., projections of drought and sea level rise) from best available sources. The CMIP climate data processing tool includes observed data from 1961 to 1999.

This report presents climate information for Philadelphia as follows:

- Section 2. Changes in Temperature and Precipitation
- Section 3. Drought
- Section 4. Sea Level Rise
- Section 5. Summary

Sections 2 through 4 each present past and present day conditions followed by a discussion of plausible future conditions.

[1] Available here http://oem.readyphiladelphia.org/HazardMitigation

[2] "Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections" http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html; We acknowledge the modeling groups, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the WCRP's Working Group on Coupled Modelling (WGCM) for their roles in making available the WCRP CMIP3 multi-model dataset. Support of this dataset is provided by the Office of Science, U.S. Department of Energy; We acknowledge the World Climate Research Programme's Working Group on Coupled Modelling, which is responsible for CMIP, and we thank the climate modeling groups for producing and making available their model output. For CMIP the U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison provides coordinating support and led development of software infrastructure in partnership with the Global Organization for Earth System Science Portals.

2. Changes in Temperature and Precipitation

Milder winters may reduce cold-related deaths but warmer summers may increase heat-related deaths of vulnerable populations. Increased summer temperatures may lead to an increase in the formation of ground level ozone increasing the incidence of respiratory ailments. A longer summer may encourage city-residents to spend more time outdoors and enjoy recreational exercise. (USGCRP, 2009; PACIA, 2009)

2.1 Annual and Seasonal

Annual and seasonal temperature and precipitation changes can affect soil moisture, vegetation growth, the water table, and other physical parameters that can magnify or dampen the impacts of extreme weather events. Globally, climate models project an increased warming over the coming century coupled with increases in precipitation. Regionally and locally, projections may differ. Because of this, it is important to present the annual and seasonal changes in temperature and precipitation for Philadelphia as they relate to present-day conditions. This section presents past and present-day conditions followed by future projections.

Past and Present Conditions. Philadelphia is situated in a humid continental climate zone, where precipitation is well distributed throughout the year. The City of Philadelphia Natural Hazard Mitigation Plan reports that between 1981 and 2010, the city had an average annual temperature of 55.8°F, with monthly averages ranging from just below 33°F in January to above 78°F in July (COP, 2012). Annually, Philadelphia experiences approximately 41.5 inches of precipitation annually plus 20.5 inches of snow accumulation. In an analysis conducted by ICF International for the Southeastern Pennsylvania Transit Authority, temperature and precipitation data from 1930 to 1960 and 1980 to 2010 show a fairly large increase in average annual temperature and a slight increase in average annual precipitation between the two periods (ICF, 2013).

For seasonal averages of temperature and precipitation, we conducted further analysis of historical temperature and precipitation in the area using gridded 1/8 degree observational data from a nationally available dataset as analyzed in the CMIP climate data processing tool for the time period 1961 to 2000 (see Appendix B).[3] According to this new analysis, Philadelphia winters tend to be cold with an average mean temperature of 41.9°F and summers tend to be hot with an average mean temperature of 84.5°F. Seasonal precipitation tends to be relatively consistent throughout the year, with the greatest amounts occurring during the spring and summer months. These findings are consistent with those described in the Philadelphia Natural Hazard Mitigation Plan (COP, 2012).

Table 1 – Annual and Seasonal Average Temperature and Total Precipitation (1961 to 2000)

	Annual	Winter (DJF)	Spring (MAM)	Summer (JJA)	Fall (SON)
Temperature (°F)	54.4	41.9	NA*	84.5	NA*
Precipitation (inches)	44.0	9.9	11.4	12.2	10.5

**The CMIP climate data processing tool does not provide average spring or fall temperatures.*

Future Conditions. This report reflects two sets of temperature and precipitation projections: CMIP3 climate data that informed the IPCC 2007 Assessment reports and CMIP5 climate data that informed the IPCC 2013 Assessment reports. We chose 9 climate models for each of the CMIP3 and CMIP5 ensemble outputs for varying emission scenarios (see Appendix B.1 for details). These emission scenarios consider

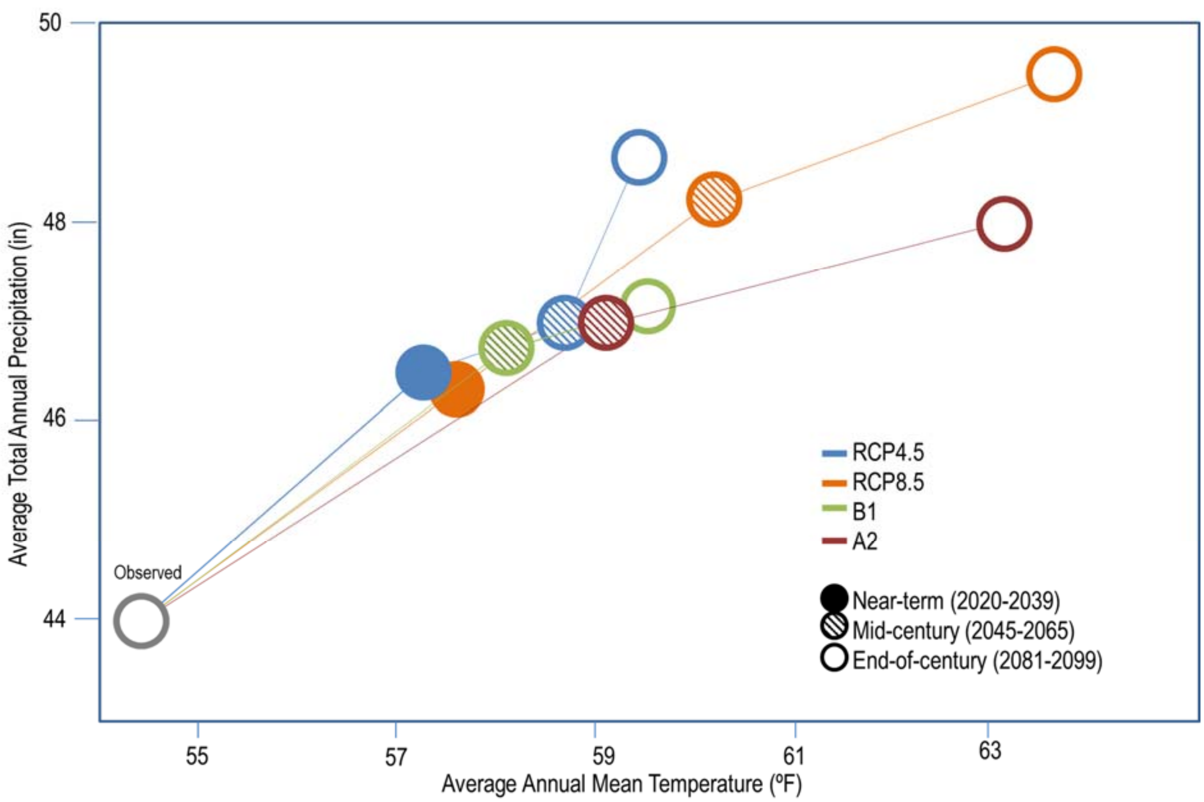
[3] http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html

various ways global society may change over the coming century (e.g., changes in population, fossil fuel consumption, migration patterns) resulting in varying emissions of greenhouse gases, particles, etc.

- For CMIP3 climate projections, we considered a low emission scenario (B1) and a moderately-high emission scenario (A2). In this report, we present future conditions for mid-century (2045-2065) and end-of-century periods (2081-2099) relative to baseline conditions (1961-2000).[4]
- For CMIP5 climate projections, we considered a low emission scenario (RCP4.5), similar to the CMIP3 B1 scenario, and a moderately-high emission scenario (RCP8.5), similar to the CMIP3 A2 scenario. In this report, we present future conditions for near-term (2020-2039), mid-century (2045-2065) and end-of-century periods (2081-2099) relative to baseline conditions (1961-2000).

Figure 1 below shows the results for projected average annual temperatures and total annual precipitation across all emission scenarios and time periods, characterizing how Philadelphia's climate changes under each scenario.

Figure 1 – Projected Changes in Average Annual Temperature and Total Annual Precipitation in Philadelphia



As Figure 1 suggests, Philadelphia is expected to face a warmer and wetter future across all scenarios for the near-term and mid-century time periods compared to historical observations. Average annual temperatures in Philadelphia are projected to increase for all time periods. The maximum projected change in annual temperatures from the observed value is 9.3°F by 2081-2099. Annual precipitation is projected to increase for all time periods in all scenarios. The warmest and wettest future is projected by the RCP8.5 scenario by the end of the century.

[4] Note that comparable CMIP3 statistically downscaled data are not available for the near-term; thus, this report presents only mid- and long-term CMIP3 results.

The seasonal temperature and precipitation projections suggest the greatest increases in both variables in the winter months. The average seasonal temperatures for both summer and winter are expected to increase across all time periods and scenarios. The changes in the average winter temperature are projected to be greater than changes in average summer temperature. This is consistent with other available projections based on the CMIP3 climate data, which suggest that near-term temperatures in the Northeast may rise an additional 2.5 to 4°F in winter and 1.5 to 3.5°F in summer (USGRP, 2009). Total seasonal precipitation is projected to increase across all seasons for all time periods and scenarios. Average seasonal precipitation is expected to increase the most, both in terms of inches and percent, during the winter.

2.2 Temperature Extremes

Heat events may increase electricity demand through high air conditioning use, potentially leading to power outages. Hot summers may increase the need of roadwork to repair buckling of highways, thermal expansion of bridge joints, deforming rail tracks. Increases in hot days and heat waves may limit city construction activities. (USGCRP, 2009; PACIA, 2009)

Past and Present Conditions. Philadelphia routinely experiences hot summer days. On average from 1981 to 2010, 27 days per summer reached or surpassed 90°F, but less than 1 summer day reached or surpassed 100°F (COP, 2012). In the center of the city, the number of these hot summer days during 2003 to 2012 was higher, with 37 days at or above 90°F and 3 days at or above 100°F (COP, 2012). During this same time period, the city periphery experienced a lower number of hot days with 24 days reaching 90°F and 1 day reaching 100°F (COP, 2012).[5]

Using the observations analyzed by the CMIP climate data processing tool from 1961 to 1999, Table 2 presents present-day statistics for hot weather. The data show that a "very hot" day (representing the 95th percentile) in Philadelphia is when the daily maximum temperature is about 90°F, which occurs about 18 days a year, while an "extremely hot" day (representing the 99th percentile) is about 95°F and occurs about 4 days per year. From 1961 to 1999, the hottest seven day period has an average maximum daily temperature of 92°F. The "very cold" day (representing the 5th percentile) is when the daily minimum temperature is about 18°F and the "extremely-cold" day is about 9°F.[6] The coldest temperature of the year is estimated to be 4°F. The data further suggests about 93 days per year on average when minimum temperatures are below freezing.

Table 2 – Extreme Hot and Cold Days in Philadelphia (1961-1999)

Variable	"Extremely-hot/cold" day	Average Annual Days Exceeding Threshold	"Very hot/cold" Day	Average Annual Days Exceeding Threshold
Hot Temperature	94.7°F	4	90.2°F	18
Cold Temperature	9.0°F	NA	17.8°F	NA

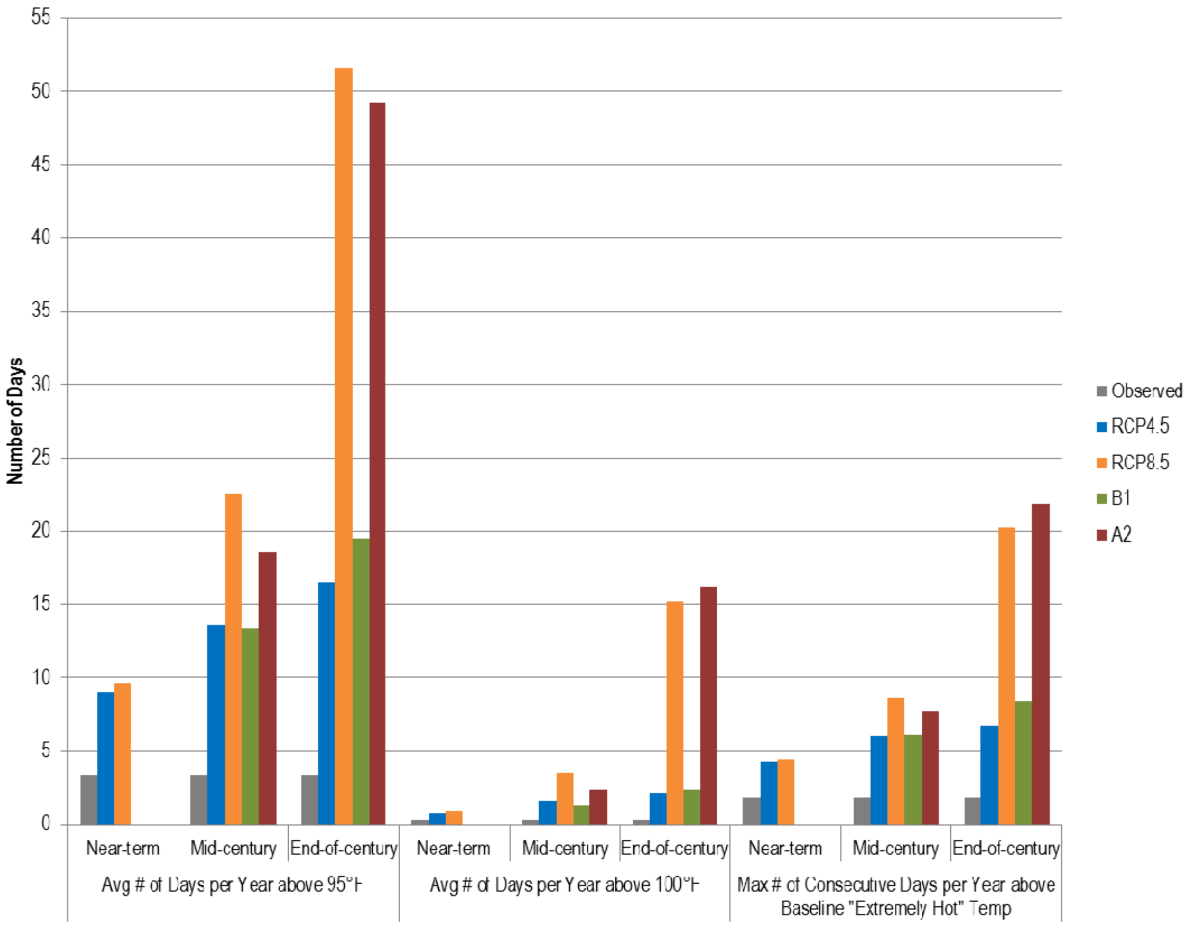
**NA is data that is not available in the CMIP climate data processing tool*

Future Conditions. Climate projections suggest Philadelphia may experience more days of extreme heat, though the magnitude of the projected increase varies across scenarios. Figure 2 shows the number of days for each scenario and time period. By the end of the century, the projections suggest Philadelphia may experience 17 to 52 days above 95°F and 2 to 16 days above 100°F, depending on the scenario.

[5] Based on observations from Philadelphia International Airport and Philadelphia Northeast Airport.

[6] The CMIP climate data processing tool is not equipped to provide average annual days exceeding threshold for "very cold" and "extremely cold" days.

Figure 2 – Projected Temperature Extremes in Philadelphia



Furthermore, these hot temperatures may persist for longer durations. The maximum number of consecutive "extremely hot" days per year is projected to more than double from the baseline, increasing to 6 to 9 days per year by mid-century and 7 to 22 days per year by the end of the century. Additionally, the highest average temperature sustained for seven days is projected to increase to within a range of 97 to 102°F by the end of the century.

Not all extreme temperature variables show notable changes. For example, there is not a marked increase in the average number of days per year at or above 105°F and 110°F, as reaching such a threshold in extreme temperatures is not expected.

The temperature associated with the extreme cold days is projected to warm. The coldest temperature of the year is projected to increase to 8.6 to 9.1°F in the near-term, 8.6 to 13.1°F by mid-century, and 10.1 to 17.5°F by the end of the century. A decrease in the number of days per year below freezing is also projected, with an estimate of 72 to 73 days below freezing per year in the near-term, 54 to 70 days by mid-century, and 33 to 60 days by the end of the century.

2.1 Precipitation Extremes

Increased precipitation will likely increase runoff, potentially flooding roads, tunnels, eroding bridge foundation supports, and carrying infectious pathogens, increasing the risk of water-borne diseases. These events may require additional pumping and crew deployments during and after the storm. (PACIA, 2009)

This section considers the magnitude of observed and future precipitation from storms. It does not consider additional meteorological factors that may affect City infrastructure and services during a storm, such as wind and temperature. In the SEPTA study of data from March 1994 to April 2012, ICF found that disruptions along the Manayunk/Norristown line occurred for 47% of the days when precipitation was greater than 1.4 inches per day, 60% of the days when snowfall was greater than 7.5 inches, and 100% of the days when snowfall was greater than 11.5 inches (ICF, 2013). Flooding along Philadelphia's tidal rivers is as likely to occur from an extreme precipitation event as from storm surge during a coastal storm (CCSP, 2009).

Past and Present Precipitation and Related Hydrologic Extremes. Philadelphia experiences intense precipitation due to strong thunderstorms,[7] tropical storms, hurricanes, Nor'easters, and winter snowstorms. In a given year, there is approximately an 18 percent chance that Philadelphia will be hit by a tropical storm or hurricane between June and November (COP, 2012). Recent storms that have impacted the city include Hurricane Sandy in October 2013, Tropical Storm Lee in September 2011, Hurricane Irene in August 2011, Hurricane Jeanne in September 2004, and Hurricane Isabel in September 2003. A number of major snowstorms have occurred recently, with four of the 10 biggest snowstorms of record hitting Philadelphia occurring during the past decade (2003-2013). During drafting of this report, Philadelphia experienced a Nor'easter that brought the fourth snowstorm with six inches or more in one winter; this represents a first in 130 years of recorded Philadelphia weather history.

Historical statistics of extreme precipitation are shown in Table 3. These statistics were calculated using the CMIP climate data processing tool for observed data from 1961 to 1999. A "very heavy" precipitation day (representing the 95th percentile) gets more than about 0.9 inches of precipitation and occurs about 11 days per year, while an "extremely heavy" precipitation day (representing the 99th percentile) occurs twice per year and is a day with more than approximately 1.6 inches of precipitation. These values are lower than the averages produced for the SEPTA study for 1994 to 2012, where "very heavy" precipitation is about 1.4 inches/day and "extremely heavy" precipitation is 2.5 inches/day (ICF, 2013). This suggests that the CMIP climate data processing tool may underestimate extreme events, either because the averaging of precipitation across the Philadelphia region (as done with the CMIP climate data processing tool over a geographic area of 225 square miles) dampens the extreme precipitation measurements at a given location or because the intensity of storms has increased over the past decade. The Philadelphia Water Department reports that since 2004 there has been an increase in the intensity and frequency of storm events resulting in significant flooding in several areas of the city.

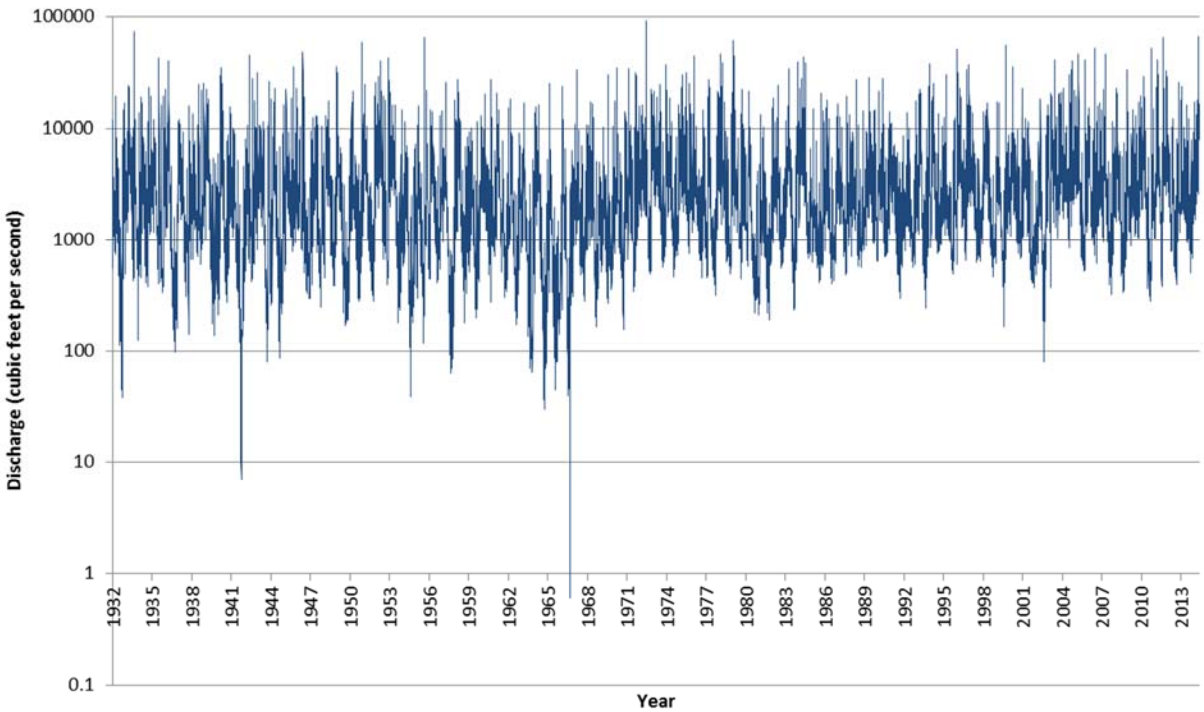
Table 3 – Extreme Precipitation in Philadelphia (1961-1999)

Variable	"Extremely heavy" daily precipitation	Average Annual Days Exceeding Threshold	"Very heavy" daily precipitation	Average Annual Days Exceeding Threshold
Precipitation	1.6 in.	2	0.9 in.	11

[7] We are referring here to thunderstorms not tied to tropical storms or hurricanes.

Increased precipitation generally leads to increased runoff and discharge into the Schuylkill and other tributaries. Figure 3 shows the daily mean discharge rates for the Schuylkill River just upstream from the Fairmount Dam.[8]

Figure 3 – Daily Mean Observed Discharge on the Schuylkill River

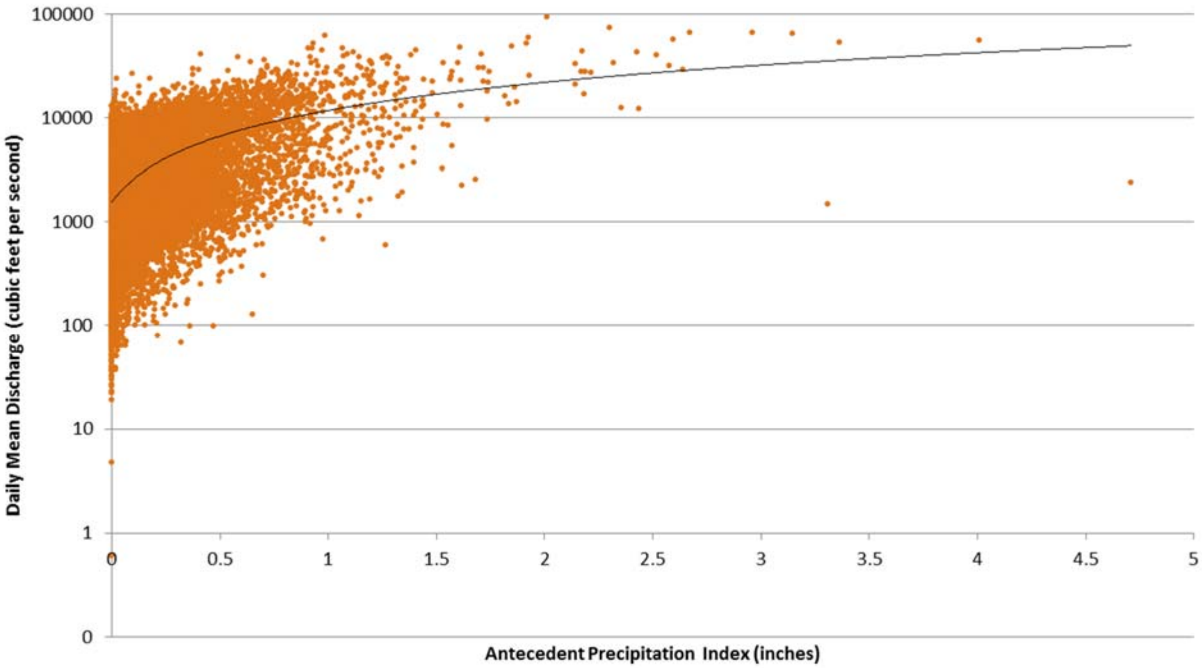


Data from USGS 01474500 Schuylkill River at Philadelphia, PA.

Figure 4 shows a correlation between precipitation and discharge. Four different observation stations were used as inputs to compute an antecedent precipitation index. The index was computed as an average of the following: precipitation at Conshohocken on Day X, precipitation at Reading Spaatz Field on Day X and Day X-1, average of precipitation at Palm 3 (near Pennsburg) on Day X and Day X-1, average of precipitation at Tamaqua on Day X-1 and Day X-2. This approach accounts roughly for the time that it takes for runoff to travel from the place where the precipitation falls to the Schuylkill discharge monitoring station. Figure 4 illustrates that the relationship between precipitation and discharge using a logarithmic vertical axis. Even with this simple statistical model, a relationship between extreme discharge and extreme precipitation can be seen.

[8] These data were obtained from USGS National Water Information System.

Figure 4 – Correlation of Antecedent Precipitation Index and Daily Mean Discharge (1949-present)



Discharge Data from USGS 01474500 Schuylkill River at Philadelphia, PA; Precipitation Data from NCDC Conshohocken - GHCND:USC00361737, Reading Spaatz Field - GHCND:USW00014712, Palm 3 SE, PA US - GHCND:USC00366681, Tamaqua - GHCND:USC00368758

Future Conditions. Philadelphia is projected to experience a few more "heavy" and "extremely heavy" precipitation events per year across all scenarios and time periods. By the end of the century, the average number of "very heavy" precipitation events is projected to increase by about 2 to 4 event days; while the "extremely heavy" precipitation events may increase by about 2 event days per year. However, these extreme precipitation events are not projected to become notably more intense.

The amounts of precipitation during "very heavy" and "extremely heavy" daily events are projected to remain relatively constant over the coming century, but because the number of total days with precipitation events may increase (as suggested by an increase in annual and seasonal total precipitation, while the percentiles of extreme daily events remain constant), the frequency of events exceeding the 95th and 99th percentiles may also increase.

Similarly, the amount of precipitation during maximum 3-day precipitation events per season is projected to increase. Winter months are projected to experience the heaviest increase in precipitation during these events, with many scenarios suggesting more than a 60 percent increase.

It is difficult to suggest at what future time period the increase in winter precipitation will shift from snow accumulations to rainfall/sleet due to the additional factors that affect this shift (i.e., the air temperatures at varying atmospheric heights).

3. Drought

Drought conditions reduce water availability challenging the city to meet water demand, compromise the quantity and quality of drinking water, affect air quality, and increase incidence of illness and disease. (CDC, 2010)

Drought is complex, and the scientific community uses many varied definitions. For example, drought can be defined as dry weather patterns that persist in a given area or as a period of low water supply in response to prolonged periods of dry weather (NOAA, 2014). For purposes of this report, short-term drought is considered to last one to three months and medium-term drought is considered to last three to six months.

Philadelphia is affected both by droughts within the city boundaries and by droughts affecting nearby mountains in the Poconos and Catskills Mountains. These mountains are the headwaters of the Delaware River Watershed. The Philadelphia Water Department's water intake along the lower Delaware River provides drinking water to nearly 1 million people, including 60% of Philadelphia's residents. Droughts in the mountains may affect the quality of water at the lower Delaware River, increasing its salinity. The Philadelphia Water Department has explored climate change issues due to concerns about both salt line movement and water quality changes that that may occur in the Delaware River as a result of the combined impact of potential droughts and projected sea level rise.[9]

Past and Present Conditions. Eastern Pennsylvania is affected by short-term droughts about once every two years but is rarely affected by medium-term drought (PACIA, 2009). The longest drought on record occurred from 1962 to 1965 during an extended period of low precipitation (PACIA, 2009). This drought was so significant that the Philadelphia Water Department uses this period as a benchmark for preventing the intrusion of salinity in the water supply system.

Future Conditions. Climate projections for the state of Pennsylvania suggest varied futures. One study suggests that droughts may increase in frequency in late spring and early fall as a result of decreases in snow cover, increases in extended dry periods, little or only slight changes in summer rainfall, and greater evapotranspiration (PACIA, 2009). However, another study suggests little or no change in short-term drought frequency in the southeast portion of the state, but an increase in short-term drought in the Poconos Mountains (NECIA, 2008). Finally, the USGCRP (2009) suggests under a high emission scenario that short-term droughts could occur every summer in the Catskills Mountains, which potentially could affect water quality in the Delaware River.

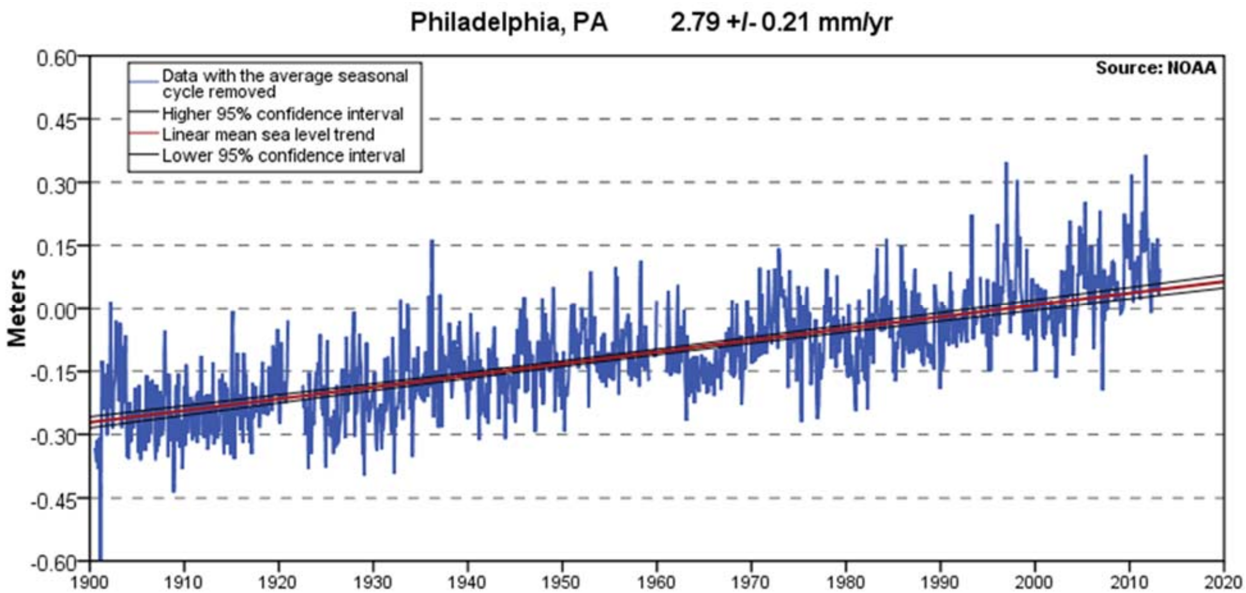
4. Sea Level Rise

Port and harbor facilities may be vulnerable to an increase in severe flooding due to sea-level rise and storm events. In addition, seaboard highways/roads that are currently at or slightly above sea level are vulnerable to flooding (e.g., I-95 corridor in the Philadelphia area). Sea level rise may increase the salinity in the city's water supply, raise groundwater levels potentially flooding some basements, and slow the rate of drainage in some areas after a rain storm. (PACIA, 2009; USCCSP, 2009)

[9] The chloride standard for drinking water 250 parts per million (ppm) or milligrams per liter is sometimes referred to as the salt line (COP, 2012).

Past and Present Conditions. Over the past century, mean global sea level has risen approximately 1.7 mm per year (about 0.07 inches per year) accelerating to a rate of 3.2 mm per year since 1993 (IPCC, 2013).[10] From 1900 to 2006, the tidal gage at Philadelphia suggests a rise of approximately 2.79 mm per year (about 0.11 inches per year), approximately 48% higher than the global rate (see Figure 5). The local linear trend is a combination of global sea-level rise and local vertical land movement, and the Delaware Valley Regional Planning Commission suggests that subsidence plays a local role (DVRPC, 2004). Though the time periods of global rise and local rise are not identical, the discrepancy does suggest Philadelphia has experienced an accelerated rise compared to the global average. Responses to a recent MOS survey suggest that higher tides and a higher water table in recent years has led to more frequent flooding in particularly low-lying areas.

Figure 5 – Mean Sea Level Trend in Philadelphia (NOAA Tides and Current, 2014)



This figure illustrates a mean sea level trend in Philadelphia of 2.79 millimeters/year with a 95% confidence interval of +/- 0.21 mm/yr based on monthly mean sea level data from 1900 to 2006 which is equivalent to a change of 0.92 feet in 100 years (for tidal gauge 8545240 Philadelphia, PA).

Future Conditions. A number of studies suggest global mean sea level may rise within the range of 0.5 to 2.0 meters (20 to 79 inches) by 2100 (IPCC, 2013; Rahmstorf, 2007; Grinsted et al., 2009; Pfeffer et al., 2008; NRC, 2011). This range demonstrates the large uncertainty associated with estimating sea level rise. The contribution of thermal expansion (i.e., ocean water volume expanding as ocean water warms), ice caps, and small glaciers to sea level rise is relatively well-researched, while the impacts of climate change on ice sheets are less understood. The lower end of the range of 0.5 meters is based on the IPCC (2013) analysis.

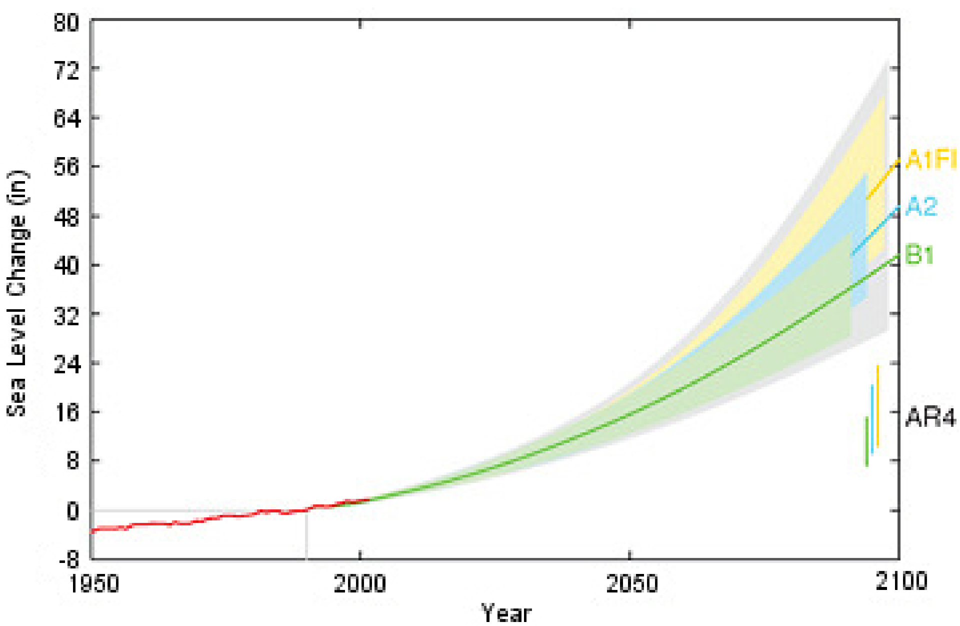
This rise is not expected to occur linearly over this century. Figure 6 shows estimates of sea level rise based on Rahmstorf (2007). Though this is just one of the studies that endeavors to project global sea level rise, it demonstrates a consistent theme that the rise will accelerate towards the second half of the century. By the 2040s, the global mean sea level rise could be approximately 0.4 meters (16 inches) relative to 1990.

As noted, sea level rise in Philadelphia may differ locally due to factors such as changes in land elevation (subsidence), salinity, ocean circulation, sedimentation, and erosion. Assuming the difference between mean sea level rise for Philadelphia and the global mean sea level rise continues to be approximately 1.09

[10] Since 1993, the use of satellite observations of sea level rise has increased the accuracy of sea level measurements.

mm (0.043 inches) per year, local mean sea level rise could be roughly 0.5 meters (20 inches) higher by the 2040s, relative to the 1986 to 2005 average. By the end of the century, local mean sea level rise could be between 0.4 and at least 1.1 meters (16 to 43 inches) above the 1986 to 2005 average, assuming a global mean sea level rise between approximately 0.3 and 1 meters (12 to 39 inches), as described in the IPCC AR5 scenarios. The upper end of this set of scenarios does not represent a maximum upper bound. It does not include some of the modeling results that are cited in the AR5 report that estimate a global mean sea level increase of up to 2 meters (79 inches). The National Climate Assessment includes a scenario of 2 meters of global sea level rise by 2100. Therefore, for decisions in Philadelphia for which there is high aversion to risk, a scenario of 2 meters should be considered.

Figure 6 – Projection of Global Mean Sea Level Rise from 1990 to 2100 (NRC, 2011)



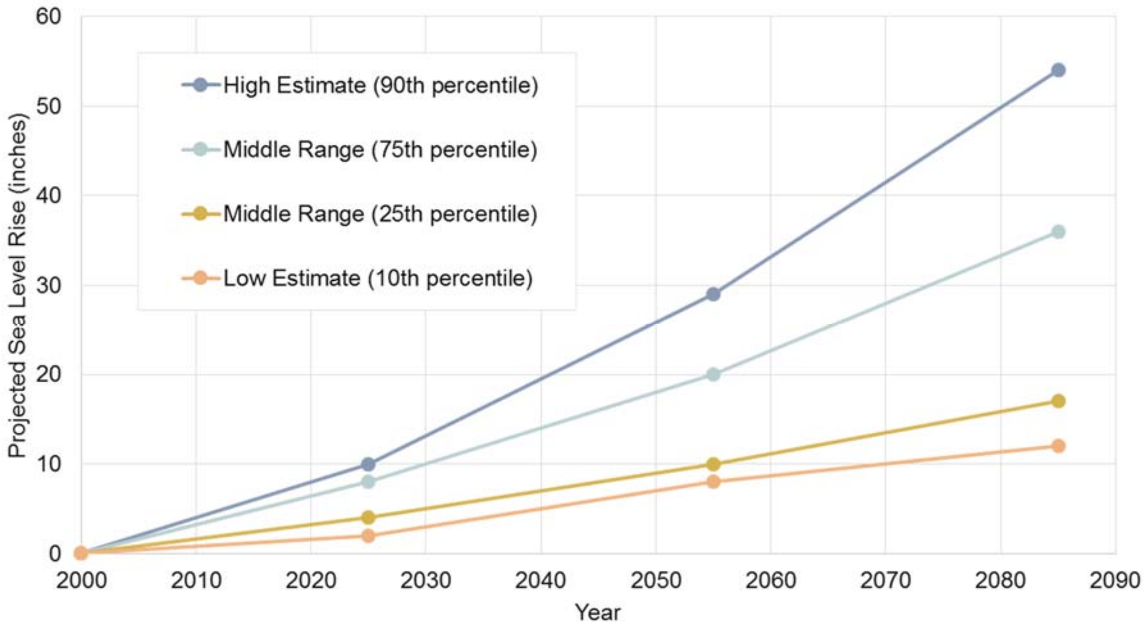
Where 60 inches is approximately 1.5 m; and 40 inches is approximately 1 m; and observations of global sea level rise are provided by the red line; relative to 1990

These sea level rise scenarios would increase coastal flooding and have some impact on water quality. Pennsylvania's Climate Impact Assessment suggests that chloride in the Delaware River in the vicinity of Philadelphia increases about 3-6 parts per million for every 0.1 m (4 inches) of sea level rise (COP, 2012). This suggests there may be significant increases in chloride levels by the end of this century.

The Climate & Urban Systems Partnership (CUSP) has created projections for SLR in Philadelphia. The projections estimate that sea level will rise in Philadelphia somewhere between 30 and 137 cm (12 to 54 inches) by the 2080s, with a middle range of 43 to 91 cm (17 to 36 inches).[11] Figure 7 shows the range of SLR projections from CUSP.

[11] To see the full projections from CUSP, see http://www.cuspproject.org/climate-science/projections.

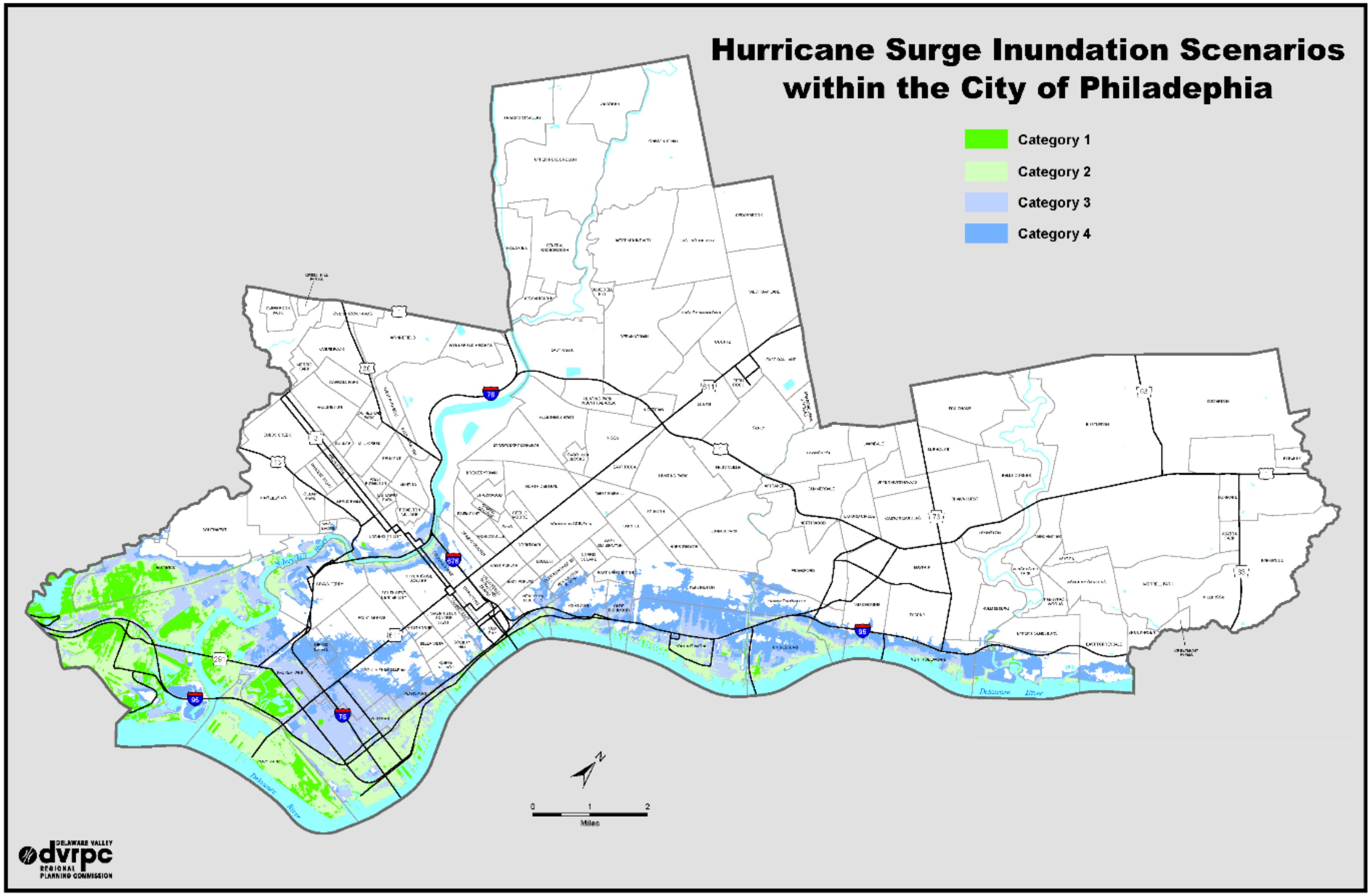
Figure 7 – CUSP Sea Level Rise Projections[12]



Sea level rise is one factor that will increase storm surge due to hurricanes (e.g., Woodruff, 2013). DVRPC created scenarios of storm surge for various categories of hurricanes using the SLOSH (Sea, Lake, and Overland Surges from Hurricanes) model. The model, developed by the National Weather Service, estimates storm surge heights resulting from historical, hypothetical, or predicted hurricanes by taking into account various hurricane parameters. Result from the model are shown in Figure 8. The figure depicts inundation from Category 1 – 4 storms, resulting from a worst-case combination of landfall location, forward speed of the storm, and direction of the storm for each hurricane category.

[12] Projections are based on a 6-component approach that incorporates both local and global factors. The model-based components are from 24 GCMs and two Representative Concentration Pathways. Shown are the low-estimate (10th percentile), middle range (25th percentile to 75th percentile), and high-estimate (90th percentile). Projections are relative to the 2000-2004 base period.

Figure 8 – Hurricane Surge Inundation Scenarios within the City of Philadelphia



Source: Hurricane Surge Inundation areas for category 1 through 4 hurricanes arriving at high mean water. The hurricane surge elevation data used to define these areas was calculated by the National Hurricane Center using the Sea Lake and Overland Surge from Hurricanes (SLOSH) Model. The SLOSH model hurricane surge elevations have an accuracy of +/- 20 percent. The hurricane surge inundation areas depict the inundation that can be expected to result from a worst case combination of hurricane landfall location, forward speed, and direction for each hurricane category.

5. Summary

As described in this report, the best available climate information for Philadelphia suggests warmer and wetter conditions for all seasons. There appears to be a relatively consistent trend of increasing temperature and precipitation over the century for all scenarios and time periods, except one. Heat events and hot days are projected to increase quite substantially by the end of the century; while precipitation events do not show a marked increase in intensity or frequency, except in winter. It is not clear how drought may change, though given the precipitation projections, periods of drought may be less frequent and sustained. Sea level rise is projected to continue and accelerate towards the latter half of the century.

For future work, the City is to consider:

- A robust analysis of past, present, and future drought conditions;
- The identification of important meteorological and hydrological thresholds of concern across city departments (including metrics used to initiate early warning systems);
- An analysis of stream flow data that considers the correlation with precipitation;
- An analysis of past, present, and future wind events; and
- An analysis of storm surge vulnerability.

These activities would help inform City agencies in understanding current vulnerabilities and planning to reduce future vulnerabilities to similar climate hazards in Philadelphia.

6. References

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Table A-1 – Available Processed Climate Projections for use by Philadelphia

Data	PACIA (2009)[13]	NECIA (2008)[14]	SEPTA study	This Report (CMIP Tool)[15]
Treatment and GCMs (scale)	14 GCMS (not all available for extreme analysis) Scale: Pennsylvania	3 GCMs statistically downscaled representing different climate sensitivities; 2 GCMs used for precipitation extremes; 2 GCMs for the hydrologic model, Variable Infiltration Capacity (VIC)	9 GCMs from WCRP CMIP3 that are statistically downscaled	9 GCMs from WCRP CMIP3 that are statistically downscaled 9 GCMs from WCRP CMIP5 that are statistically downscaled (chosen from the 21 GCMs available)
Emission Scenarios	■ Moderately-high (A2) ■ Low (B1)	■ High (A1Fi) ■ Low (B1)	■ Moderately-high (A2) ■ Low (B1)	■ Moderately-high (A2) ■ RCP 4.5 ■ Low (B1) ■ RCP 8.5
Future Time Periods	Baseline 1980-1999 Near-term 2011-2030 Mid-century 2046-2065 End-of-century 2080-2099	Baseline 1961–1990 Near-term 2010–2039 Mid-century 2040–2069 End-of-century 2070–2099	Baseline 1961-2000 Mid-century 2046-2065	Baseline 1961–2000 (CMIP3) 1950-2000 (CMIP5) Near-term 2020-2039 (CMIP5) Mid-century 2045–2065 (CMIP3/CMIP5) End-of-century 2081-2099 (CMIP3/CMIP5)

[13] http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-75375/7000-BK-DEP4252.pdf.com
[14] http://www.northeastclimateimpacts.org/assets/climate-change-in-pennsylvania_impacts-and-solutions.pdf
[15] Developed by ICF for the Department of Transportation Federal Highway Administration

Data	PACIA (2009)[13]	NECIA (2008)[14]	SEPTA study	This Report (CMIP Tool)[15]
Projection	■ Seasonal temperatures ■ Annual temperatures ■ Seasonal precipitation ■ Annual precipitation	■ Seasonal temperatures ■ Annual temperatures ■ Seasonal precipitation ■ Annual precipitation	■ Annual temperature ■ Annual precipitation	■ Annual temperature ■ Winter and summer temperatures ■ Annual precipitation ■ Seasonal precipitation
Extremes	■ Max. 5-day precip. total within a year ■ # of days with precip. >10 mm within a year ■ Fraction of annual precip. due to top 5% of precip. events (%) ■ Growing season length ■ Number of frost days ■ Max. number of days per year with the daily max. temp. > 80, 85, 90, 95 and 100ºF	■ Heat index ■ # of days over 90ºF, 100ºF (Philadelphia) ■ Precip. intensity (number of precipitation days each year ÷ total annual precipitation) ■ # of days per year with >2 inches of rain ■ Max. amount of precipitation to fall during a 5-day period ■ Drought16: period each year short-term (1-3 month),medium-term (3-6 month) and longterm (6+ month) droughts ■ Number of snow-covered days per month	■ Change in the frequency of the baseline's 5th and 1st percentile of maximum temperature ■ Change in the frequency of the baseline's 5th and 1st percentile of precipitation events	■ 95th and 99th percentile of hot days ■ Average number of days per year above 95, 100, 105, 110ºF (and maximum number of consecutive days) (also provided by season) ■ 95th and 99th percentile of cold days ■ Average number of days below freezing ■ 95th and 99th percentile of daily precipitation (and the average number of these events per year) ■ Largest 3-day precipitation amount for each season *(see Appendix for full-list)*
Uncertainty and Data Limitations	■ Range of projections across GCMs is provided ■ Box-whisker plots for all variables, not able to locate just a table of numbers (will need to pull from figures) ■ Recommended to use GCM results for the state as a whole but not for particular places or sub-regions of PA (avg. horizontal resolution of the models varies btwn about 1.5° and 4.5°)	■ Range of projections across emission scenarios and models is provided ■ Methodology used to downscaled data is considered out-dated compared to current techniques ■ Based on 2 to 3 GCMS, depending on climate model (climate sensitivities may be appropriate for temperature ranges across GCMs, but may not be for capturing precipitation spread across models) ■ Not clear if this information has been produced in its entirety for Philadelphia ■ In the past, we have obtained through the NECIA climate data portal[17] but access to this data appears limited.	■ Range of projections across emission scenarios and models is provided ■ Relies on only 1 grid cell	■ Range of projections across emission scenarios and models is provided ■ Presents CMIP3 and CMIP5 projections ■ Relies on 4 grid cells

[16] Drought is defined as occurring when monthly soil moisture is more than 10 percent below the long-term mean (relative to historical simulations). (NECIA, 2008)
[17] http://www.northeastclimatedata.org/welcome_home.php?userID=38

Appendix B. DOT CMIP Tool Projections

B.1 Methodology of the projections developed by the DOT CMIP Data Processing Tool

For the U.S. Department of Transportation (DOT), ICF created a tool, US DOT CMIP Climate Data Processing Tool, which post-processes statistically downscaled data of the World Climate Research Programme's (WCRP) Coupled Model Intercomparison Project (CMIP). The WCRP CMIP is used to inform the IPCC findings in their climate change assessment reports into a series of policy- and planning-relevant climate variables.[18] The raw data from the downscaled CMIP3 and CMIP5 Climate and Hydrology Projections website contain daily maximum temperature, minimum temperature, and precipitation values for each climate model. This website also provides observed daily maximum temperature, minimum temperature, and precipitation values for the same grid locations.[19] The DOT CMIP Climate Data Processing Tool converts that raw data into projected changes in 45 temperature variables and 13 precipitation variables.[20]

For this effort, we downloaded statistically downscaled data:

- **For CMIP3 climate projections**: We considered a low emission scenario (B1) and a moderately-high emission scenario (A2). The 9 climate models (aka the *climate model ensemble*) include: cccma_cgcm3_1, cnrm_cm3, gfdl_cm2_0, gfdl_cm2_1, ipsl_cm4, miroc3_2_medres, miub_echo_g , mpi_echam5, and mri_cgcm2_3_2a. For climate model and scenario, we downloaded data for four grid cells[21] around Philadelphia to provide changes in future conditions under mid-century (2045-2065) and end-of-century periods (2081-2099) for the B1 and A2 scenarios relative to baseline conditions (1961-2000).[22]

- **For CMIP5 climate projections**: We considered a low emission scenario (RCP4.5) similar to the CMIP3 B1 scenario and a moderately-high emission scenario (RCP8.5) similar to the CMIP3 A2 scenario. The 9 climate models were selected to closely resemble those available for the CMIP3 data projections, and included: CCMA CanESM2, CNRM-CM5, GFDL-CM3, GFDL-ESM2M, IPSL-CM5A-MR, Miroc5, CCSM4, Mpi-esm-mr, and Mri-cgcm3. For each climate model and scenario, we downloaded data for four grid cells around Philadelphia to provide changes in future conditions for near-term (2020-2039), mid-century (2045-2065) and end-of-century periods (2081-2099) for the RCP4.5 and RCP8.5 scenarios relative to baseline conditions (1950-2000).

For each climate model ensemble (i.e., CMIP3 and CMIP5 models), emission scenario, and time period, the CMIP Tool averages the future change across the climate models. As we are unable to attach a probability of one emission scenario over another, all emission scenarios are considered equally likely. Thus, when considering the results presented in the report and Appendix B.2, the range of plausible future conditions across the scenarios for a given time period should be considered. In general, this range grows with future time reflecting the divergence of the future pathways in emissions.

[18] Additional information can be found at: http://www.wcrp-climate.org/index.php/wgcm-cmip/about-cmip
[19] The observed data come from gridded observed meteorological data. The website cites the source of the observed data as: Maurer, E.P., A.W. Wood, J.C. Adam, D.P. Lettenmaier, and B. Nijssen, 2002, A Long-Term Hydrologically-Based Data Set of Land Surface Fluxes and States for the Conterminous United States, J. Climate 15(22), 3237-3251.
[20] See technical notes on the CMIP Climate Data Processing Tool for description of the methodology used in developing each variable.
[21] Four grid cells covering the Philadelphia region were chosen for a robust average (opposed to just using one model grid cell). This may reduce the extreme weather conditions that might be suggested if using a single grid cell.
[22] We were constrained by availability of CMIP3 statistically downscaled data which does not provide near-term results.

In addition to the range across emission scenarios, there is uncertainty associated with the projections produced across the climate models (assuming a given emission scenario). For example, climate models may vary in their treatment of the scientific algorithms embedded in the models (e.g., how clouds are represented or how particles scatter incoming sunlight). Because of this, it is best to work with a collection of results across climate models. It is difficult and not always accurate to ‘cherry pick’ one climate model to use over another. This is particularly true for modeling precipitation which tends to show large variability across climate models.

With that in mind, the results provided in Appendix B.2 show the projections across emission scenarios averaged across the climate model ensemble as well as the range across the models for each ensemble average. This provides some sense of the climate model uncertainty (range across the models) and emission scenario uncertainty (range across the scenarios).

B.2 Results of the DOT CMIP Data Processing Tool

Table B.2.1 presents the projections produced by the CMIP Climate Data Processing Tool. The WCRP CMIP3 climate model ensemble average is presented for the B1 and A2 emission scenarios for mid-century and end-of-century periods. The WCRP CMIP5 climate model ensemble average is presented for the RCP4.5 and RCP8.5 emission scenarios for near-term, mid-century, and end-of-century periods. In parenthesis, the 95% confidence interval across the range of climate models is provided. Within the available resources, we were not able to provide a statistical analysis to isolate those futures that are statistically different from today. Instead, we simply highlight those futures that suggest a 10 percent or 20 percent change from today's conditions. The ensemble projections that suggest at least a 10 percent change from observations are identified by bold font; those that suggest at least a 20 percent change from observations are identified by bold, italic font.

Table B.2.1 – CMIP Temperature and Precipitation Projections

	Ob-served*	Near-term		Mid-Century				End-of-Century			
		RCP4.5	RCP8.5	B1	A2	RCP4.5	RCP8.5	B1	A2	RCP4.5	RCP8.5
Annual Temperature Averages											
Average Annual Mean Temperature (°F)	54.4	57.3 (56.7 to 57.9)	57.6 (56.9 to 58.2)	58.1 (57.6 to 58.7)	59.1 (58.4 to 59.9)	58.8 (58.0 to 59.5)	**60.2 (59.3 to 61.0)**	59.5 (58.8 to 60.2)	**63.1 (62.0 to 64.1)**	59.4 (58.5 to 60.4)	**63.7 (62.5 to 64.9)**
Average Annual Maximum Temperature (°F)	64.0	66.8 (66.2 to 67.4)	67.1 (66.4 to 67.8)	67.8 (67.3 to 68.4)	68.8 (68.0 to 69.6)	68.3 (67.5 to 69.1)	69.7 (68.8 to 70.6)	69.2 (68.4 to 69.9)	**72.8 (71.7 to 74.0)**	69.0 (68.0 to 70.0)	**73.3 (72.1 to 74.5)**
Average Annual Minimum Temperature (°F)	44.9	47.8 (47.2 to 48.4)	48.1 (47.5 to 48.7)	48.5 (48.0 to 49.0)	**49.5 (48.8 to 50.1)**	49.2 (48.6 to 49.9)	**50.6 (49.9 to 51.4)**	**49.8 (49.1 to 50.5)**	**53.3 (52.3 to 54.3)**	**49.9 (49.0 to 50.8)**	**54.1 (53.0 to 55.3)**
Hottest Temperature of the Year (°F)	96.6	99.8 (98.8 to 100.7)	100.0 (99.1 to 100.9)	101.0 (100.0 to 102.0)	101.9 (100.3 to 103.5)	101.3 (100.2 to 102.3)	103.0 (101.7 to 104.3)	102.2 (101.3 to 103.1)	**107.0 (104.3 to 109.6)**	102.0 (101.0 to 103.1)	**107.3 (106.0 to 108.6)**
Annual Extreme Heat											
"Very Hot" Day Temperature (Very Hot defined as 95th Percentile Temp) (°F)	90.2	93.4 (92.6 to 94.1)	93.7 (92.9 to 94.4)	94.4 (93.6 to 95.3)	95.6 (94.3 to 96.8)	94.6 (93.8 to 95.5)	83.0 (64.5 to 101.6)	95.8 (94.9 to 96.6)	**100.3 (97.8 to 102.7)**	95.2 (94.2 to 96.2)	**100.1 (98.6 to 101.6)**
"Extremely Hot" Day Temperature (Extremely Hot defined as 99th Percentile Temp) (°F)	94.7	98.0 (97.1 to 98.8)	98.1 (97.3 to 99.0)	99.2 (98.2 to 100.1)	100.0 (98.6 to 101.5)	99.2 (98.3 to 100.2)	86.8 (66.8 to 106.8)	100.3 (99.3 to 101.4)	**105.6 (102.2 to 109.0)**	100.0 (98.9 to 101.0)	**105.0 (103.2 to 106.9)**

	Ob-served*	Near-term		Mid-Century				End-of-Century			
		RCP4.5	RCP8.5	B1	A2	RCP4.5	RCP8.5	B1	A2	RCP4.5	RCP8.5
Average Number of Days per Year Above Baseline "Very Hot" Temperature (days)	18	*40 (32 to 48)*	*43 (35 to 50)*	*50 (45 to 56)*	*60 (52 to 68)*	*52 (42 to 63)*	*67 (56 to 77)*	*63 (56 to 70)*	*93 (84 to 102)*	*57 (46 to 68)*	*98 (85 to 110)*
Average Number of Days per Year Above Baseline "Extremely Hot" Temperature (days)	4	*14 (10 to 18)*	*15 (10 to 20)*	*20 (16 to 25)*	*28 (20 to 36)*	*21 (14 to 27)*	*32 (24 to 40)*	*30 (24 to 36)*	*63 (50 to 75)*	*25 (17 to 32)*	*65 (51 to 78)*
Average Number of Days per Year above 95°F (days)	3	*9 (7 to 11)*	*10 (7 to 12)*	*13 (10 to 17)*	*19 (12 to 25)*	*14 (10 to 17)*	*23 (17 to 28)*	*19 (15 to 24)*	*49 (37 to 62)*	*17 (12 to 21)*	*52 (40 to 64)*
Average Number of Days per Year above 100°F (days)	0	*1 (0 to 1)*	*1 (0 to 1)*	*1 (0 to 2)*	*2 (0 to 5)*	*2 (1 to 2)*	*4 (2 to 5)*	*2 (1 to 4)*	*16 (6 to 27)*	*2 (1 to 3)*	*15 (8 to 22)*
Average Number of Days per Year above 105°F (days)	0	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	4 (-1 to 10)	0 (0 to 0)	3 (1 to 5)
Average Number of Days per Year above 110°F (days)	0	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	1 (-1 to 3)	0 (0 to 0)	0 (0 to 1)
Maximum Number of Consecutive Days per Year above Baseline "Very Hot" Temperature (days)	6	*11 (9 to 13)*	*11 (9 to 14)*	*14 (11 to 17)*	*18 (14 to 22)*	*14 (11 to 17)*	*21 (15 to 26)*	*19 (14 to 23)*	*42 (31 to 53)*	*17 (13 to 21)*	*43 (31 to 56)*
Maximum Number of Consecutive Days per Year above Baseline "Extremely Hot" Temperature (days)	2	*4 (3 to 5)*	*4 (3 to 5)*	*6 (5 to 7)*	*8 (6 to 10)*	*6 (4 to 8)*	*9 (7 to 11)*	*8 (7 to 10)*	*22 (14 to 30)*	*7 (5 to 8)*	*20 (14 to 27)*
Maximum Number of Consecutive Days per Year above 95°F (days)	2	*4 (3 to 4)*	*4 (3 to 5)*	*5 (4 to 6)*	*6 (4 to 7)*	*5 (4 to 6)*	*7 (6 to 8)*	*6 (5 to 8)*	*16 (10 to 22)*	*5 (4 to 6)*	*16 (11 to 21)*

	Ob-served*	Near-term		Mid-Century				End-of-Century			
		RCP4.5	RCP8.5	B1	A2	RCP4.5	RCP8.5	B1	A2	RCP4.5	RCP8.5
Maximum Number of Consecutive Days per Year above 100°F (days)	0	*1 (0 to 1)*	*1 (0 to 1)*	*1 (0 to 1)*	*1 (0 to 2)*	*1 (1 to 1)*	*2 (1 to 2)*	*1 (1 to 2)*	*6 (2 to 10)*	*1 (1 to 2)*	*5 (3 to 7)*
Maximum Number of Consecutive Days per Year above 105°F (days)	0	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	2 (0 to 4)	0 (0 to 0)	1 (0 to 2)
Maximum Number of Consecutive Days per Year above 110°F (days)	0	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 1)	0 (0 to 0)	0 (0 to 0)
Seasonal Extreme Heat											
Average Summer Temperatures (°F)	84.5	87.1 (86.4 to 87.9)	87.4 (86.7 to 88.1)	88.1 (87.5 to 88.8)	89.2 (88.5 to 90.0)	88.4 (87.5 to 89.3)	90.1 (89.1 to 91.1)	89.5 (88.8 to 90.2)	93.3 (91.9 to 94.7)	89.0 (88.0 to 90.0)	93.7 (92.2 to 95.2)
Highest 4-Day Average Summer Temperature (°F)	93.9	97.0 (96.2 to 97.8)	97.3 (96.5 to 98.1)	98.1 (97.1 to 99.2)	99.0 (97.7 to 100.3)	98.4 (97.4 to 99.4)	100.2 (99.2 to 101.3)	99.5 (98.7 to 100.4)	104.2 (101.4 to 107.0)	99.2 (97.8 to 100.5)	104.2 (102.1 to 106.2)
Highest 7-Day Average Summer Temperature (°F)	92.2	95.1 (94.3 to 95.9)	95.4 (94.6 to 96.2)	96.4 (95.4 to 97.3)	97.3 (96.0 to 98.7)	96.6 (95.6 to 97.5)	98.4 (97.5 to 99.2)	97.8 (96.9 to 98.6)	102.4 (99.6 to 105.2)	96.8 (95.5 to 98.1)	101.7 (99.9 to 103.6)
Number of Days per Season above 95°F											
Winter (days)	0	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)
Spring (days)	0	*0 (0 to 0)*	*0 (0 to 0)*	*0 (0 to 0)*	*0 (0 to 1)*	*0 (0 to 1)*	*0 (0 to 1)*	*0 (0 to 1)*	*2 (1 to 3)*	*1 (0 to 1)*	*2 (1 to 3)*
Summer (days)	3	*8 (6 to 10)*	*9 (6 to 11)*	*12 (9 to 16)*	*16 (10 to 22)*	*12 (9 to 15)*	*20 (16 to 25)*	*17 (13 to 22)*	*41 (31 to 51)*	*15 (11 to 19)*	*44 (34 to 53)*
Fall (days)	0	*1 (0 to 1)*	*1 (0 to 1)*	*1 (1 to 1)*	*2 (1 to 3)*	*1 (0 to 1)*	*2 (1 to 3)*	*2 (1 to 2)*	*6 (4 to 8)*	*1 (1 to 2)*	*6 (4 to 7)*
Number of Days per Season above 100°F											
Winter (days)	0	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)
Spring (days)	0	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 1)	0 (0 to 0)	0 (0 to 1)
Summer (days)	0	*1 (0 to 1)*	*1 (0 to 1)*	*1 (0 to 2)*	*2 (0 to 4)*	*1 (1 to 2)*	*3 (2 to 5)*	*2 (1 to 3)*	*14 (5 to 24)*	*2 (1 to 3)*	*14 (8 to 19)*
Fall (days)	0	*0 (0 to 0)*	*0 (0 to 0)*	0 (0 to 0)	0 (0 to 0)	*0 (0 to 0)*	*0 (0 to 0)*	0 (0 to 0)	1 (0 to 2)	*0 (0 to 0)*	*1 (1 to 2)*
Number of Days per Season above 105°F											

	Ob-served*	Near-term		Mid-Century				End-of-Century			
		RCP4.5	RCP8.5	B1	A2	RCP4.5	RCP8.5	B1	A2	RCP4.5	RCP8.5
Winter (days)	0	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)
Spring (days)	0	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)
Summer (days)	0	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	4 (-1 to 9)	0 (0 to 0)	2 (0 to 4)
Fall (days)	0	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 1)	0 (0 to 0)	0 (0 to 0)
Number of Days per Season above 110°F											
-Winter (days)	0	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)
Spring (days)	0	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)
Summer (days)	0	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	1 (-1 to 3)	0 (0 to 0)	0 (0 to 1)
Fall (days)	0	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)	0 (0 to 0)
Extreme Cold											
Coldest Temperature of the Year (°F)	4.0	*8.6 (7.0 to 10.1)*	*9.1 (7.3 to 11.0)*	*8.6 (7.2 to 10.1)*	*10.1 (8.5 to 11.7)*	*11.3 (9.7 to 13.0)*	*13.1 (11.5 to 14.8)*	*10.1 (8.3 to 11.8)*	*14.6 (12.7 to 16.5)*	*12.2 (10.6 to 13.9)*	*17.5 (15.9 to 19.1)*
"Very Cold" Day Temperature (Very Cold defined as Baseline 5th Percentile Temp) (°F)	17.8	21.3 (20.3 to 22.4)	21.7 (20.5 to 22.9)	*21.8 (21.1 to 22.5)*	*22.9 (22.0 to 23.7)*	*23.4 (22.5 to 24.3)*	*23.4 (20.8 to 26.0)*	*23.1 (22.2 to 23.9)*	*26.9 (25.3 to 28.4)*	*24.1 (22.9 to 25.3)*	*28.1 (26.9 to 29.3)*
"Extremely Cold" Day Temperature (Extremely Cold defined as Baseline 1st Percentile Temp) (°F)	9.0	*13.3 (11.8 to 14.7)*	*14.2 (12.7 to 15.6)*	*13.9 (13.0 to 14.8)*	*15.0 (13.9 to 16.1)*	*15.9 (14.4 to 17.4)*	*17.8 (15.6 to 20.0)*	*15.3 (14.0 to 16.6)*	*19.2 (17.7 to 20.8)*	*16.6 (14.7 to 18.5)*	*21.6 (19.8 to 23.5)*
Average Number of Days per Year Below Freezing (days)	93	73 (70 to 77)	*72 (67 to 76)*	*70 (66 to 74)*	*63 (58 to 67)*	*62 (58 to 67)*	*54 (49 to 59)*	*60 (55 to 66)*	*40 (32 to 48)*	*58 (51 to 64)*	*33 (27 to 39)*
Average Number of Times per Year Temperatures Fluctuate around Freezing (times)	36	36 (35 to 38)	36 (34 to 38)	36 (33 to 39)	34 (31 to 37)	35 (33 to 37)	33 (31 to 35)	*20 (18 to 22)*	*14 (11 to 16)*	34 (32 to 36)	*27 (25 to 30)*
Average Winter Temperatures (°F)	41.9	44.7 (44.0 to 45.3)	45.0 (44.4 to 45.7)	45.7 (45.0 to 46.4)	46.7 (46.0 to 47.4)	*46.6 (45.8 to 47.4)*	47.7 (46.9 to 48.4)	47.0 (46.1 to 47.8)	*50.4 (49.0 to 51.8)*	47.2 (46.0 to 48.3)	*51.0 (49.9 to 52.0)*

	Ob-served*	Near-term		Mid-Century				End-of-Century			
		RCP4.5	RCP8.5	B1	A2	RCP4.5	RCP8.5	B1	A2	RCP4.5	RCP8.5
Lowest 4-Day Average Winter Temperatures (oF)	9.5	*13.5 (12.8 to 14.1)*	*14.1 (13.4 to 14.8)*	*14.6 (13.6 to 15.5)*	*15.4 (14.5 to 16.2)*	*15.9 (15.2 to 16.5)*	*17.8 (17.2 to 18.5)*	*15.5 (14.3 to 16.6)*	*19.9 (18.4 to 21.3)*	*16.9 (14.7 to 19.1)*	*22.0 (20.3 to 23.6)*
Lowest 7-Day Average Winter Temperatures (oF)	12.1	*16.1 (14.7 to 17.6)*	*16.6 (15.4 to 17.9)*	*17.2 (16.5 to 17.9)*	*17.6 (16.8 to 18.5)*	*18.4 (17.0 to 19.8)*	*20.1 (18.6 to 21.5)*	*18.0 (17.0 to 18.9)*	*22.1 (20.8 to 23.4)*	*19.1 (17.1 to 21.2)*	*24.0 (22.4 to 25.5)*
Precipitation											
Average Total Annual Precipitation (inches)	44.0	46.5 (45.0 to 48.0)	46.3 (44.7 to 47.8)	46.8 (45.4 to 48.1)	47.0 (44.1 to 49.8)	47.0 (46.1 to 47.9)	48.2 (47.3 to 49.1)	47.1 (45.0 to 49.2)	48.0 (45.1 to 50.8)	48.7 (47.5 to 49.9)	49.5 (47.7 to 51.4)
"Very Heavy" 24-hr Precipitation Amount (defined as 95th percentile precipitation) (inches)	0.9	0.9 (0.9 to 0.9)	0.9 (0.9 to 0.9)	0.8 (0.8 to 0.9)	0.9 (0.8 to 0.9)	0.9 (0.9 to 0.9)	0.8 (0.6 to 1.0)	0.9 (0.8 to 0.9)	0.9 (0.8 to 0.9)	0.9 (0.8 to 0.9)	0.9 (0.9 to .09)
"Extremely Heavy" 24-hr Precipitation Amount (defined as 99th percentile precipitation) (inches)	1.6	1.6 (1.6 to 1.7)	1.6 (1.6 to 1.7)	1.6 (1.6 to 1.7)	1.7 (1.6 to 1.7)	1.6 (1.6 to 1.7)	1.5 (1.0 to 1.9)	1.7 (1.6 to 1.8)	1.7 (1.7 to 1.8)	1.7 (1.6 to 1.7)	1.7 (1.7 to 1.8)
Average Number of Baseline "Very Heavy" Precipitation Events per Year (times)	11.3	13 (12 to 14)	13 (12 to 14)	13 (12 to 14)	13 (12 to 15)	13 (12 to 14)	*14 (13 to 15)*	13 (12 to 15)	*14 (13 to 16)*	*14 (13 to 15)*	*15 (14 to 16)*
Average Number of Baseline "Extremely Heavy" Precipitation Events per Year (times)	2.3	*3 (3 to 3)*	*3 (3 to 3)*	*3 (3 to 4)*	*4 (3 to 4)*	*3 (3 to 4)*	*4 (4 to 4)*	*4 (3 to 4)*	*4 (4 to 5)*	*4 (3 to 4)*	*4 (3 to 5)*
Average Total Seasonal Precipitation											
Winter (inches)	9.9	10.6 (10.2 to 11.1)	10.6 (10.1 to 11.1)	11.0 (10.3 to 11.7)	11.3 (10.4 to 12.2)	10.7 (10.2 to 11.2)	11.5 (10.5 to 12.5)	11.2 (10.2 to 12.3)	*12.1 (11.0 to 13.2)*	11.6 (10.9 to 12.3)	*11.8 (11.0 to 12.5)*
Spring (inches)	11.4	12.0 (11.4 to 12.6)	12.4 (11.8 to 13.1)	12.2 (11.5 to 12.9)	12.3 (11.7 to 12.8)	12.2 (11.6 to 12.8)	12.4 (11.8 to 13.0)	12.4 (11.5 to 13.2)	12.3 (11.3 to 13.4)	12.7 (12.0 to 13.4)	13.1 (12.4 to 13.8)
Summer (inches)	12.2	12.7 (12.0 to 13.4)	12.7 (12.1 to 13.2)	12.9 (12.4 to 13.3)	12.4 (11.5 to 13.3)	12.9 (12.2 to 13.6)	13.1 (12.2 to 14.0)	12.6 (11.8 to 13.3)	12.5 (11.5 to 13.5)	13.2 (12.3 to 14.0)	13.3 (12.4 to 14.1)

	Ob-served*	Near-term		Mid-Century				End-of-Century			
		RCP4.5	RCP8.5	B1	A2	RCP4.5	RCP8.5	B1	A2	RCP4.5	RCP8.5
Fall (inches)	10.5	11.1 (10.1 to 12.0)	10.7 (9.9 to 11.4)	10.8 (10.4 to 11.2)	11.1 (10.2 to 12.0)	11.2 (10.3 to 12.1)	11.2 (10.3 to 12.1)	11.0 (10.4 to 11.6)	11.1 (10.1 to 12.1)	11.3 (10.1 to 12.5)	11.5 (10.7 to 12.3)
Largest 3-Day Precipitation Event per Season											
Winter (inches)	2.0	*3.2 (3.1 to 3.3)*	*3.3 (3.2 to 3.3)*	2.2 (2.0 to 2.3)	2.3 (2.1 to 2.4)	*3.3 (3.1 to 3.4)*	*3.4 (3.3 to 3.6)*	2.3 (2.2 to 2.4)	*2.5 (2.4 to 2.7)*	*3.5 (3.3 to 3.6)*	*3.5 (3.4 to 3.6)*
Spring (inches)	2.2	2.2 (2.1 to 2.4)	2.3 (2.2 to 2.4)	2.4 (2.3 to 2.5)	2.4 (2.2 to 2.5)	2.4 (2.1 to 2.6)	2.4 (2.2 to 2.6)	2.4 (2.3 to 2.5)	2.5 (2.3 to 2.6)	2.4 (2.2 to 2.6)	*2.6 (2.4 to 2.9)*
Summer (inches)	2.8	2.9 (2.7 to 3.1)	2.8 (2.5 to 3.0)	2.8 (2.6 to 3.0)	2.9 (2.6 to 3.1)	2.9 (2.8 to 3.1)	2.9 (2.7 to 3.1)	2.8 (2.7 to 3.0)	2.9 (2.7 to 3.0)	2.9 (2.7 to 3.1)	2.9 (2.7 to 3.1)
Fall (inches)	2.6	2.9 (2.7 to 3.1)	2.8 (2.5 to 3.1)	2.7 (2.5 to 3.0)	2.8 (2.5 to 3.1)	2.8 (2.6 to 3.0)	3.0 (2.8 to 3.1)	2.8 (2.6 to 2.9)	2.8 (2.6 to 2.9)	3.1 (2.9 to 3.3)	3.0 (2.7 to 3.4)

*The observed values shown are for the period 1961-1999. The CMIP5 projections in the U.S. DOT CMIP Climate Data Processing Tool are based on a baseline of 1950-1999, and therefore projected values rely on observed values from that same time period (1950-1999). These observed values are not shown in this table, but do not differ substantially from the 1961-1999 observed values.