Executive Summary

The Climate Change Impact Assessment provides a summary of the best available science on the potential impacts of climate change to people, places, and resources in Delaware. The purpose of the Climate Change Impact Assessment is to increase Delaware's resiliency to climate change by understanding and communicating the current and future impacts of climate change. Delaware's Climate Change Impact Assessment will provide a strong scientific foundation for the development of the state's mitigation and adaptation planning and strategies.

Methodology and Sources

The Climate Change Impact Assessment was developed through the collaborative efforts of the Delaware Department of Natural Resources and Environmental Control (DNREC) and a community of scientists and practitioners from Delaware's state agencies and universities. DNREC's Division of Energy and Climate took the lead role in developing the Assessment, including researching and drafting the sector assessment chapters, coordinating review and editing, and assembling the final document. Information sources include: peer-reviewed scientific literature; national and regional climate assessments; and interviews with technical and subject experts, including scientists and practitioners from Delaware's academic and government institutions.

The chapter on climate trends (Chapter 2) includes an analysis of Delaware's climate trends conducted by the Delaware State Climatologist Dr. Daniel J. Leathers (University of Delaware). This analysis utilized historic temperature and precipitation data from weather stations throughout Delaware.

To develop future climate scenarios for Delaware, the Division of Energy and Climate contracted with Dr. Katharine Hayhoe (ATMOS Research & Consulting). Dr. Hayhoe developed climate projections that provide average, seasonal, and extreme temperature and precipitation projections for the state of Delaware through the year 2100 (Chapter 4). The Assessment includes both a summary of the findings and detailed graphs of 165 climate indicators developed through this analysis. Graphs and technical information can be found in the Appendix.

The potential impacts related to sea level rise were drawn largely from the findings of the Sea Level Rise Vulnerability Assessment by Delaware Coastal Programs (completed in 2012). In addition, other sources of information were referenced to describe potential impacts of sea level rise, including recent reports by the National Oceanic and Atmospheric Administration and the U.S. Climate Change Science Program.

The eleven members of the Climate Change Impact Assessment Steering Committee guided the development of the Assessment, providing content expertise, peer review, and editorial oversight. In addition, more than 50 subject experts were interviewed and consulted for review of draft text. These contributors are listed in the Acknowledgments.

Findings

The Climate Change Impact Assessment is organized in two main sections: 1) Climate, and 2) Resources. The findings include:

- Historic climate trends in Delaware (temperature and precipitation)
- Future climate projections for Delaware (temperature and precipitation)
- Potential impacts of climate change (including temperature, precipitation, and sea level rise) to Delaware's resources in five sectors: public health, water resources, ecosystems and wildlife, agriculture, and infrastructure

Historic Climate Trends

Temperature:

- Annual and seasonal temperatures have increased by approximately 2˚F over the past century. An analysis of Delaware statewide mean annual and seasonal temperatures indicates a modest warming trend in temperatures during the period 1895 through 2012 annually and for all seasons.
- Delaware has experienced an upward trend of 0.2°F per decade for mean annual, winter, spring, and summer season temperatures. Autumn season temperatures have also seen a significant increase, but at a more modest rate of 0.1°F per decade.
- Nine high-quality National Weather Service Cooperative weather stations across Delaware were analyzed for significant trends in temperature extremes for the period 1895 through 2012 (**Figure 1**). Only a few significant trends were identified from these stations, including a decrease in the number of days with temperatures below 32°F and 20°F and an increase in the length of the growing season.
- Heating degree-days showed a significant downward trend annually, and for the spring and autumn seasons. Cooling degree-days showed significant upward trends only annually and during the summer season, mirroring the temperature increases annually and during the summer.

Precipitation:

- Delaware's historic climate shows highly variable precipitation patterns. Analysis of data shows a modest increase in autumn precipitation of 2.7 inches over the past century.
- No significant trends in annual precipitation are indicated. Only the autumn season (September-October-November) evidenced an upward trend in seasonal precipitation, with an increase of 0.27 inches per decade.
- Delaware's precipitation patterns are highly variable (both large inter-annual and intra-annual variability). Although Delaware's average annual precipitation is approximately 45 inches, statewide annual values have varied from as low as 28.29 inches in 1930 to as high as 62.08 inches in 1948.

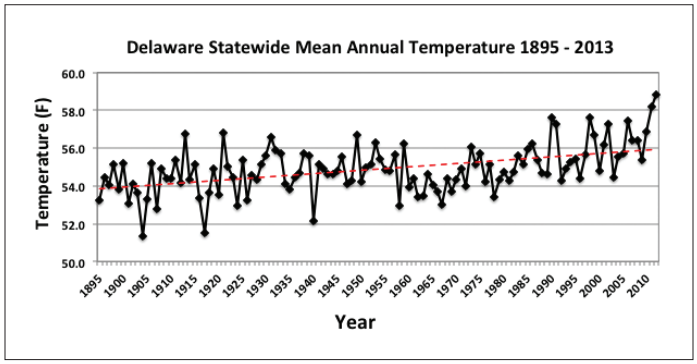

Figure 1. Statewide mean annual temperature for Delaware, 1895-2013. Source: Leathers (2013).

Future Climate Projections

The future climate of Delaware depends on the decisions we make today and in the years to come. To understand the impact of our choices on future climate, we analyzed possible changes in temperature and precipitation that can be expected for the State of Delaware in the near future and over the coming century under two possible future scenarios. The ***lower scenario*** represents a future in which people shift to clean energy sources in the coming decades, reducing emissions of carbon dioxide (CO_2) and other greenhouse (heat-trapping) gases that are causing climate to change so quickly. The ***higher scenario*** represents a future in which people continue to depend heavily on fossil fuels, and emissions of greenhouse gases continues to grow.

Average annual and seasonal temperatures are expected to increase over the coming century.

- By 2020-2039, temperature increases of 1.5 to 2.5°F are projected, regardless of scenario (**Figure 2**).
- By mid-century or 2040-2059, temperature increases under the lower scenario range from 2.5 to 4°F and around 4.5°F for the higher scenario.
- By end of century or 2080-2099, projected temperature changes are nearly twice as great under the higher versus lower scenario: 8 to 9.5°F compared to 3.5 to 5.5°F.
- Slightly greater temperature increases are projected for spring and summer as compared to winter and fall.

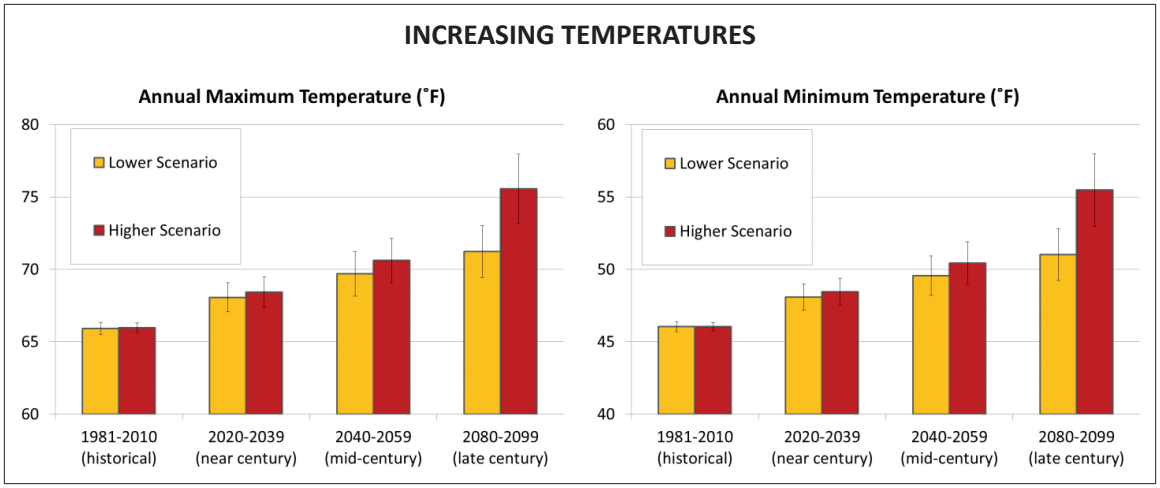

Figure 2. Annual maximum (daytime) and minimum (nighttime) temperatures are projected to increase. (Note difference in temperatures in y-axis.) Changes are average for the State of Delaware, based on individual projections for 14 weather stations. Source: Hayhoe et al. (2013).

- The growing season is also projected to lengthen, with slightly greater changes in the date of last spring frost as compared to first fall frost.

Temperature extremes are also projected to change. The greatest changes are seen in the number of days above a given high temperature or below a given cold temperature threshold. By mid-century, changes under the higher scenario are much greater than changes under the lower scenario.

- Heat waves are projected to become longer and more frequent, particularly under the higher versus lower scenario and by later compared to earlier time periods.
- The number of very cold days (below 20°F), which historically occurred on average about 20 times per year, is projected to drop to 15 by 2020-2039, to slightly more than 10 days per year by 2040-2059, and to 10 days per year under the lower scenario and only 3 to 4 days per year under the higher scenario by 2080-2099 (**Figure 3**).
- The number of very hot days (over 100°F), which historically occurred less than once each year, is projected to increase to 1 to 3 days per year by 2020-2039, 1.5 to 8 days per year by 2040-2059, and 3 and 10 days per year under the lower and 15 to 30 days per year under the higher scenario by 2080-2099 (**Figure 3**).

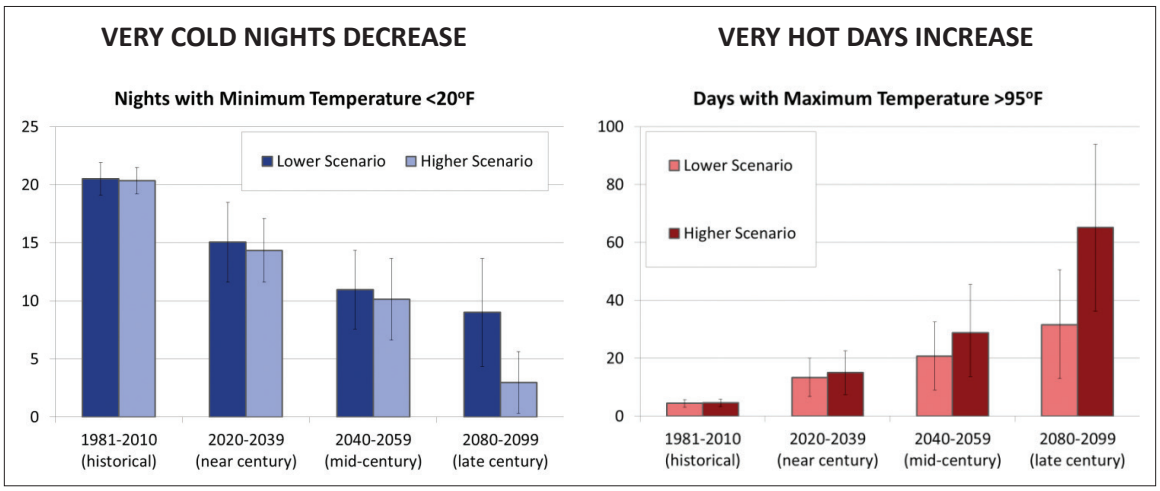

Figure 3. Temperature extremes are projected to change. The greatest changes are seen in the number of days above a given high temperature or below a given cold temperature threshold. Source: Hayhoe et al. (2013).

- Increases in daytime summer heat index (a measure of how hot it feels, based on temperature and humidity) are projected to be larger than increases in maximum temperature alone, due to the nonlinear relationship between heat index, temperature, and humidity.

Average precipitation is projected to increase by an estimated 10 percent by end of century, consistent with projected increases in mid-latitude precipitation in general.

Rainfall extremes are also projected to increase. By end of century, nearly every model simulation shows projected increases in the frequency and amount of heavy precipitation events (**Figure 4**).

Summary of Potential Climate Impacts to Delaware's Resources

The Climate Change Impact Assessment describes potential impacts of climate change to Delaware's resources in five resource areas: public health, water resources, agriculture, ecosystems and wildlife, and infrastructure. The potential impacts relate to the climate projections for Delaware, including increasing annual and seasonal temperatures, increasing temperature extremes, and changes in precipitation patterns, such as more frequent heavy precipitation events. The potential impacts also consider sea level rise, related to the findings of the Delaware Sea Level Rise Vulnerability Assessment. **Table 1** provides a brief summary of the findings of the resource chapters.

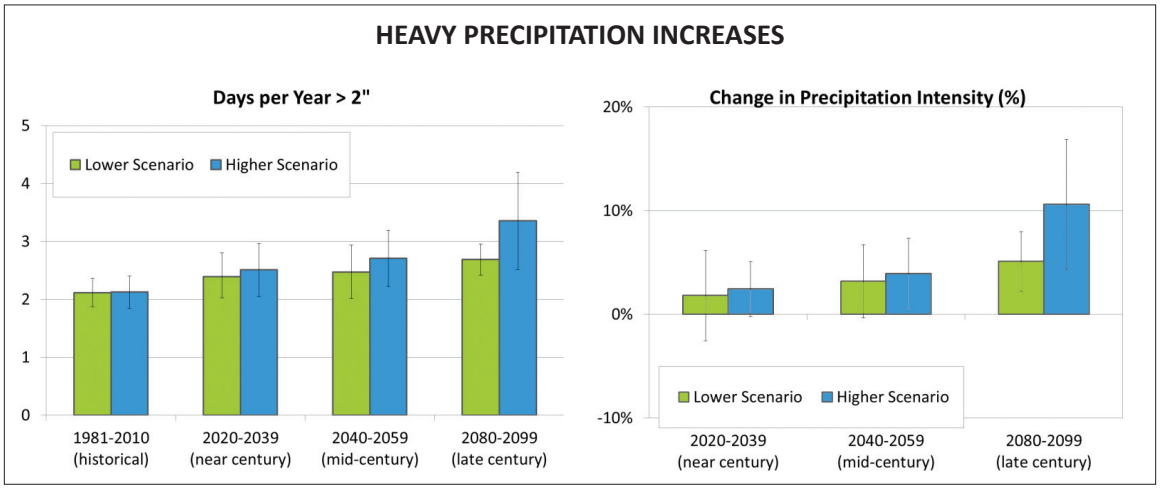

Figure 4. Rainfall extremes are also projected to increase. By end of century, nearly every model simulation shows projected increases in the frequency and amount of heavy precipitation events. Source: Hayhoe et al. (2013).

Table 1. Summary of potential climate impacts by resource in Delaware

Public Health	
Increasing temperatures	*Changes in precipitation: Increasing extreme rain*
Increasing temperatures have direct and **serious impacts on human health,** particularly for vulnerable populations: elderly or very young people, those with underlying health conditions such as asthma or heart disease, and socially isolated individuals with limited access to air conditioning or health care. Increasing temperatures may worsen air quality, exacerbating conditions that produce ground-level ozone.	Flooding may stress the capacity of **stormwater and wastewater** outfalls, causing water to back up and transporting polluted waters to upland areas. Increasing precipitation and sea level rise may lead to failure of septic drain fields as groundwater levels rise. Increasing precipitation and temperatures may lead to conditions that increase exposure to allergens, as well as to pathogenic diseases.

Water Resources			
Increasing temperatures	*Changes in precipitation: Increasing dry days*	*Changes in precipitation: Increasing extreme rain*	*Sea level rise*
Water supply and demand will be affected by rising temperatures and longer periods of dry days, especially in summer months.	**Salinity** increases upstream in coastal rivers and streams during periods of drought, when freshwater inflow decreases. This effect may be magnified with increasing frequency and duration of seasonal droughts, and may be further exacerbated with sea level rise.	**Sewer and stormwater systems** will be increasingly strained to manage peak flows that may exceed their design specifications. Increased flooding associated with extreme rain events may result in structural or operational damage to **dams, levees, impoundments, and drainage ditches**.	**Salinity** in tidal reaches of rivers and streams may be affected by climate change impacts. Sea level rise could increase the tidal influence and salinity levels upriver, although increased precipitation could offset the increasing salinity with additional freshwater inflow.

Agriculture			
Increasing temperatures	*Changes in precipitation: Increasing dry days*	*Changes in precipitation: Increasing extreme rain*	*Sea level rise*
Heat stress resulting from extreme heat days or sustained heat waves can have significant impacts for **poultry and other livestock**. Hotter summers lead to greater heat stress on animal health and reduced feed and growth efficiency, and may require increased **energy usage** for ventilation and cooling in livestock barns and poultry houses. A longer growing season and warmer winter temperatures may provide some benefits for crop production. However, warmer winter temperatures may result in **increased competition from weed species and insect pests**.	Rising temperatures and increased frequency of drought may lead to **crop losses, reduced yields**, impaired pollination and seed development, and higher infrastructure and energy costs to meet irrigation needs. Heat, drought, and extreme weather may affect the dairy industry by reducing **forage supply and quality**, which accounts for more than half of the feed requirements for dairy cows.	Extreme rain events can affect infrastructure and systems that are critical to agriculture. Flooding can impair transportation of crops or livestock to markets or processing facilities, prevent deliveries of feed, or damage processing facilities for poultry and other livestock. Rain events of increasing frequency and intensity will have significant impacts at **critical periods in crop production**, such as delayed planting or post-planting washouts and increases in disease pressure.	Sea level rise may affect soil and groundwater quality in coastal regions and along tidal reaches of streams and rivers.

Table 1. ***continued***

Ecosystems and Wildlife			
Increasing temperatures	*Changes in precipitation: increasing dry days*	*Changes in precipitation: Increasing extreme rain*	*Sea level rise*
Many of Delaware's **wildlife species** will face changes in habitat quality, timing and availability of food sources, abundance of pests and diseases, and other stressors related to changes in temperature and precipitation. Increased temperatures and more frequent droughts will stress **freshwater habitats**, including streams, rivers, and ponds. Higher water temperatures are likely to increase the incidence of harmful algal blooms, which affect the availability of oxygen and light for aquatic species. Extreme decreases in oxygen levels may lead to more frequent fish kills.	Increasing dry days combined with increased air temperatures may lead to higher evapotranspiration and **decreased soil moisture**. These factors are likely to contribute to plant stress, resulting in decreased productivity and greater susceptibility to pests and diseases.	Tidal flooding is likely to increase from both sea level rise and potential increases in heavy rain events. **Tidal wetlands** will be affected by greater storm surges, scouring of tidal creeks and channels, and greater swings in salinity.	**Coastal ecosystems** are already vulnerable to coastal storms; the combined effects of sea level rise and extreme rain events may lead to increased erosion and loss of beach habitat.

Infrastructure			
Increasing temperatures	*Changes in precipitation: Increasing dry days*	*Changes in precipitation: Increasing extreme rain*	*Sea level rise*
Under heat wave conditions, peak **demands for electricity** in summer months increase dramatically and vulnerability to power outages can affect wide regions. Increased heat can accelerate **deterioration of infrastructure**, such as heat stress in structural supports and exposure of pavement to high heat. Buckling or rutting of asphalt may occur on roads or runways. These impacts may require increased maintenance and more frequent monitoring to prevent damage and ensure public safety.	Drought conditions tend to push the salt line up the Delaware River; this increased salinity can affect the **availability and function of cooling water** needed for power generation and other industrial uses.	With potential increases in precipitation falling in more intense storm events, the higher volume and velocity of surface runoff can result in rapid erosion and scouring. This can undermine **structural supports for roads, bridges, culverts, and other drainage structures**. Flooding **impacts to road and rail lines** also affect energy production, particularly for coal-fired power generation that relies on coal transport by rail. Changes in the timing of spring thaw and shifts in seasonal flows and water levels could increase flooding, particularly in urban areas of northern Delaware, where a high percentage of impervious surface area already contributes to severe stormwater runoff problems.	Sea level rise is likely to **affect roads and bridges** throughout the state. In Sussex and Kent Counties, many beach communities may be affected by sea level rise cutting off their primary access roads and evacuation routes. In New Castle County, Delaware City and portions of State Route 9 are also vulnerable to severe flooding from sea level rise. The Port of Wilmington is a major facility that could be significantly affected; an estimated 60 percent of the Port's main facilities could be inundated by 3 feet of sea level rise.

Conclusions

Delaware's climate is changing. Increasing temperatures, shifts in precipitation patterns, and rising sea level are already being experienced across the state. Future climate changes are expected to affect Delaware and the surrounding region by increasing average, seasonal, and extreme temperatures; average precipitation; the frequency of heavy precipitation events; and the total amount of rainfall that falls in the wettest periods of the year.

For all temperature-related indices, there is a significant difference between the changes expected under higher versus lower scenarios by end of century. For many of the changes, this difference begins to emerge by mid-century. In addition, analyses of sea level rise highlight the potential impacts to a wide range of resources, particularly in a low-lying state with extensive ocean and bay shoreline, tidal rivers, and valuable ecosystems.

The projections described here underline the value in preparing to adapt to the changes that cannot be avoided. Changes that likely cannot be avoided would include most changes in precipitation and, at minimum, the temperature-related changes projected to occur over the next few decades, and under the lower scenarios. However, immediate and committed action to reduce emissions may keep temperatures at or below those projected under the lower scenario. Thus, the larger temperature impacts projected under the higher scenarios can be avoided by concerted mitigation efforts.

Delaware faces potential impacts from changes in temperature, precipitation, and sea level rise. State officials, local governments, residents, and businesses must prepare for changing climate conditions that will affect communities and economic sectors throughout Delaware.

The Climate Change Impact Assessment will be a valuable resource for practitioners who make important planning and policy decisions that affect people, communities, and resources across the state. The data and analyses included in this Assessment are a foundation for understanding how climate affects all sectors in Delaware, and will provide a starting point for addressing climate impacts through mitigation and adaptation efforts.