Understanding and Assessing Climate Change: Preparing for Nebraska's Future

2024 Climate Change Impact Assessment Report

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Understanding and Assessing Climate Change: Preparing for Nebraska’s Future was produced by a multi-disciplinary team from the University of Nebraska–Lincoln, the University of Nebraska Medical Center, Creighton University, the Nebraska Indian Community College, the USGS Nebraska Cooperative Fish and Wildlife Research Unit, and Pale Blue Dot, LLC. This report, authorized by the Nebraska Legislature through Legislative Bill (LB) 1255, contributes to the scientific foundation for understanding climate-related vulnerability in Nebraska and is intended to support decision-making and inform State policies, plans, and programs to promote action and build resilience to climate impacts.

Note: This report and additional supporting resources will be available to the public on the Nebraska State Climate Office website at https://nsco.unl.edu.

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Lead authors are experts in fields related to their chapter (see Appendix A: About the Authors for brief author biographies). The chapters focus on assessing climate and its impacts, management options, and resilience strategies based on the available scientific science. Lead authors are responsible for the content and serve as their respective chapters' primary point of contact.

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As required by LB1255, the University of Nebraska–Lincoln Institute of Agriculture and Natural Resources contracted with third-party, science-based organizations to identify and recommend science-based, prescriptive measures for the State of Nebraska to take regarding the climate hazards, impacts, and risks identified in this report.

Pale Blue Dot

Pale Blue Dot, located in Minnesota, is a sustainability, climate action, carbon management, and renewable energy consultancy firm established in 2014. Their mission is to support the transition to a low-carbon economy through an array of sustainability assessment, consultancy, and planning services, as well as through education that increases awareness and enhances public dialogue.

Pale Blue Dot has extensive climate, carbon, and renewable energy planning experience from the scale of individual sites to community-wide efforts. They have completed over 60 relevant community planning efforts, including sustainability plans, climate vulnerability studies, vulnerable population assessments, climate action and adaptation plans, renewable energy potential studies and master plans, heat island mitigation plans, and tree canopy and green infrastructure carbon sequestration master plans.

About their Name

It all started with the words of Carl Sagan. After seeing the 1990 photo, known as the Pale Blue Dot, taken by the Voyager I spacecraft, Sagan penned his thoughts, both poignant and profound, which capture the essence of our seemingly vast and indestructible planet for us. In his memorable and moving words, Sagan tells us that while we may feel omnipotent and universally superior, in the cosmic scheme of things, we are but "a mote of dust suspended in a sunbeam." These words, though, also give us hope and remind us how, even though our planet may be small and lost among the billions of other galaxies, it is still our home, our "pale blue dot."

Sagan's words continue to inspire those at Pale Blue Dot each day. They recognize that our planet is both immensely fragile and infinitely precious. They work to provide effective and practical ways for each of us to make a meaningful positive impact on our precious world. Carl Sagan called us all to "preserve and cherish that pale blue dot," and they believe, through the efforts of us all, we can do just that.

Emmons & Olivier Resources, Inc.

Emmons & Olivier Resources Inc. (EOR), headquartered in Minnesota, is a water resource engineering and environmental consulting firm established in 1997. EOR is a leader in stormwater management and watershed planning, passionate about protecting waters, restoring healthy ecosystems, and enhancing communities' unique sense of place. Their multidisciplinary engineers, scientists, and landscape architects share a common purpose for providing alternative and sustainable approaches to resource management that provide long-term, holistic solutions.

Acknowledgments

The authors would like to acknowledge Nebraska State Senator Eliot Bostar and U.S. Congressman (and former Nebraska State Senator) Mike Flood for their bipartisan support in introducing Nebraska Legislative Bill 1255, which authorized and provided funding for this report.

We also acknowledge the following individuals from the University of Nebraska–Lincoln (UNL) Institute of Agriculture and Natural Resources (IANR) for their support in the preparation of this report: Dr. Michael Boehm, Vice Chancellor IANR; Dr. Derek McLean, Agricultural Research Division Dean; Dr. Tala Awada, Agricultural Research Division Associate Dean; and Dr. Larkin Powell, Director of the School of Natural Resources.

Thank you to UNL's IANR Agricultural Research Division, the Office of Research and Innovation, the College of Engineering, the Departments of Agronomy & Horticulture and Agricultural Economics, and the Daugherty Water for Food Global Institute for their financial assistance in providing the supplemental funding needed to complete this report.

To the advisory panel, contributing authors, reviewers, and other experts who provided input into the report in various capacities, we express our gratitude for your time and contributions. However, the lead authors assume full responsibility for their chapters.

We thank the following communications experts at UNL for their time and advice in developing key messages, managing press activities, editing, and graphic design: Leslie Reed, Public Affairs Director, Office of University Communication & Marketing; Cara Pesek, Communications Director, IANR Office of Vice President/Vice Chancellor; Emily Case-Buskirk, Communications Specialist, National Drought Mitigation Center; and Abbey Snyder, Web and Graphics Designer, IANR Media.

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Finally, we extend our heartfelt thanks to the many Nebraska citizens who have expressed the importance of this work. Your unwavering commitment to creating a sustainable future for Nebraska inspires and reinforces our collective efforts.

Executive Summary

Jerome Okojokwu-Idu, Deborah Bathke, and Eric Hunt*

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Nebraska stands at the crossroads of experiencing and addressing the challenges climate change brings. Tackling the far-reaching impacts of climate change on agriculture, water resources, energy systems, ecosystems, and vulnerable populations requires collaboration, knowledge sharing, and coordinated strategies. Leveraging the deep environmental knowledge held by Indigenous communities, mobilizing the power of faith-based organizations, and drawing upon the experience of localized adaptation initiatives are key to fostering resilience and advancing fair and just solutions. This report provides a comprehensive analysis of critical insights across key sectors, emphasizing the urgency of implementing proactive strategies to mitigate risks, adapt to ongoing changes, and build a sustainable future for all Nebraskans.

Climate

Nebraska's climate has become notably warmer and slightly wetter, with distinct seasonal shifts. This warming has been most pronounced in June, September, and November. Since 2000, every location in Nebraska has experienced at least one record-setting warm month, and many have experienced multiple record-warm months. While annual precipitation trends show a slight increase since the late 19th century, eastern Nebraska faces declining summer precipitation. Variability in moisture has led to record dry and wet months across the state. Warmer winters have reduced snow cover days and decreased heating degree days, altering energy demands and ecosystem dynamics.

Nebraska's future climate will undergo substantial transformations through the 21st century. Statewide annual temperatures are expected to rise by 5°F to 6°F by 2050 and by 7°F to 11.5°F by the end of the century, relative to the 1950 to 2014 historical period. Summer and fall will warm slightly more than winter and spring, leading to more frequent and prolonged heat extremes. Extremely hot days (greater than or equal to 90°F) will multiply two to four times, while extremely warm nights (greater than or equal to 70°F) could increase more than tenfold. Extremely cold days (below 0°F) will diminish significantly, occurring only four to seven days annually by the century's end. Seasonal precipitation patterns will diverge, with winter and spring precipitation projected to increase by 10% to 35%, while summer precipitation may decline by 10% to 20%. Extreme precipitation events, particularly the most intense ones, are expected to rise in frequency and magnitude. Under a high-emission trajectory, parts of Nebraska could face over 50 days annually with temperatures exceeding 100°F by the end of the century.

Water Systems

The impact of climate change on water systems is deeply interconnected with Nebraska's economy, communities, and environment. Changes in precipitation patterns, type, and timing influence water availability, affecting energy, health, and agriculture. Properly managing Nebraska's groundwater is crucial for irrigation and drinking water, making it essential for the state's ability to cope with climate change.

However, climate change is expected to complicate water issues in Nebraska, impacting both the amount and quality of ground and surface water. These changes will have far-reaching implications for the state's economy, communities, and environment. Longer growing seasons and increased evapotranspiration will increase the demand for irrigation, putting more pressure on water resources.

Groundwater levels closely follow precipitation trends, making them sensitive to climate change. Intensifying droughts could stress ground and surface water systems, potentially harming the state's agricultural productivity and environmental stability.

Energy

Energy consumption and emissions play a pivotal role in Nebraska's climate future, shaping opportunities for mitigation and adaptation. Energy-related activities, including fossil fuel combustion for electricity, transportation, heating, and fertilizer production, contribute to Nebraska's greenhouse gas emissions. Nebraskans consume energy directly (fuel and electricity) and indirectly (through goods and services), presenting opportunities for efficiency improvements at all levels. Reducing emissions through energy efficiency and fuel switching offers significant financial and environmental benefits, including reduced energy and fertilizer costs. Effective emissions reduction strategies should address residential, commercial, and transportation sectors and policies at local, state, and national levels. Balancing emissions reduction efforts with reliability goals is essential to ensure sustainable transitions.

Ecosystems

Nebraska's ecosystems are undergoing rapid transformations driven by climate change, presenting risks and opportunities. Accelerated shifts in ecosystems impact species distribution and biodiversity, intensifying the loss of species diversity. These changes threaten the resilience of ecological networks, which provide essential services such as pollination, water purification, and carbon storage. Changes to ecosystem services create risks and potential benefits for communities and industries reliant on these systems. Proactive ecosystem management is essential to mitigate risks, preserve biodiversity, and harness opportunities from changing environmental conditions.

Agriculture

Agriculture, a cornerstone of Nebraska's economy, faces escalating challenges from climate change. Shifts in temperature and precipitation trends threaten field crops and rangeland productivity. Key risks include rainfall variability, shifts in rainfall seasonality, more rapid drought development and intensification, rising temperatures, fewer very cold days, and heightened risks of wildfires and hail. These factors could significantly reduce agricultural output if unaddressed. Strategies to maintain productivity include advancements in plant genetics, diversification of crops and cropping systems, and improved soil and water management practices. Effective rangeland management, such as heterogeneity-based approaches and adjusting livestock species and classes, can help mitigate climate-related challenges.

Health

Due to climate change, Nebraskans' health is increasingly at risk, with disparities in vulnerability across populations. Rising temperatures, extreme weather, and shifting environmental conditions contribute to physical and mental health challenges. Vulnerable groups, including senior citizens, children, low-income populations, and those with pre-existing health conditions, face heightened risks of climate change. Proactive efforts to address health risks, such as public health interventions, climate-resilient infrastructure, and community-based programs, can safeguard public well-being and reduce disparities among vulnerable populations.

Communities and the Built Environment

Nebraska's communities and infrastructure are increasingly vulnerable to extreme weather and climate-related events. Urban and rural areas face more frequent and intense extreme events, resulting in prolonged disruptions, widespread impacts, increased costs, and more profound social consequences. Physical infrastructure and social systems are at elevated risk, with implications for long-term safety, equity, and economic stability. Effective responses include land-use planning incorporating climate risk assessments, protecting ecosystems to buffer against extreme events, strengthening infrastructure to enhance resilience, and fostering inclusive dialogue and collaboration across communities and regions.

Indigenous Peoples

Indigenous communities face heightened vulnerabilities to climate change but are also leading in innovative adaptation efforts. Weather and climate events disproportionately affect Indigenous populations, exacerbating existing challenges. Local adaptation initiatives led by Tribal communities exemplify resilience and self-determination in addressing climate impacts. Advancing Indigenous climate adaptation hinges on recognizing sovereignty, upholding rights, and enabling cultural reclamation and innovation. Supporting these efforts is essential to fostering equitable and effective climate resilience strategies.

Climate Justice and Equity

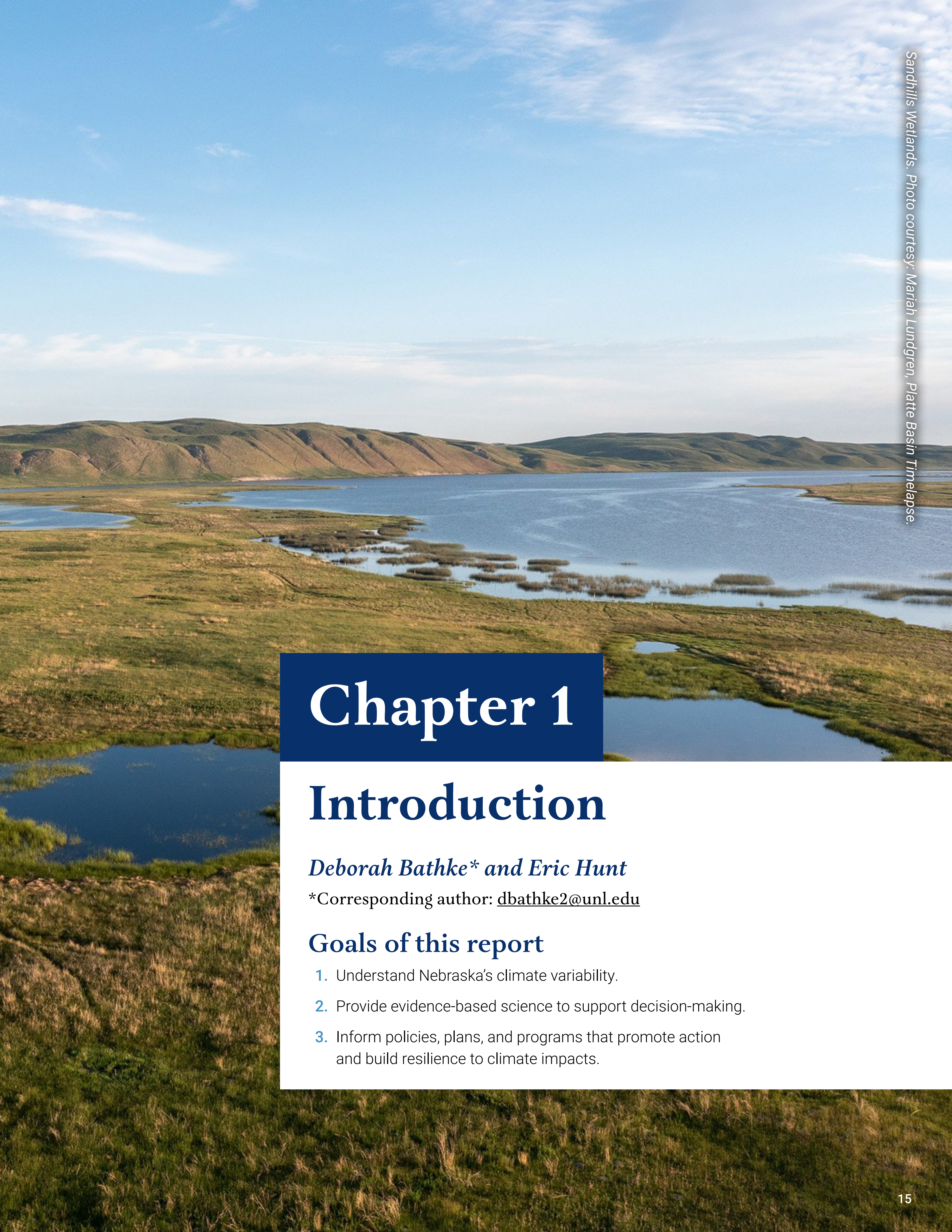
Climate change exacerbates social inequalities, disproportionately impacting vulnerable populations in Nebraska. Low-income individuals and communities of color face higher exposure to climate risks, including extreme weather and environmental degradation. Without targeted policy interventions in housing, workplace protections, and energy, climate-related impacts will likely deepen social inequities. Ensuring equitable participation in climate planning and action is essential to address ongoing changes and reduce future risks. Meaningful engagement and resource allocation for marginalized communities are critical to achieving climate justice.

The Response of the Faith Community

Faith communities have a unique opportunity to contribute to climate action, though their potential remains untapped. Religious leaders in Nebraska have not widely integrated climate issues into their teachings, advocacy, or institutional practices. Political affiliations often overshadow religious imperatives on climate action. Programs such as the federal Inflation Reduction Act and Nebraska's ONE RED Non-Residential Solar Program offer financial pathways for faith-based organizations to implement greenhouse gas emissions reduction projects. Religion can inspire societal action by aligning climate advocacy with moral and spiritual values, unlocking a powerful avenue for addressing climate change.

Nebraskans' Perceptions of Climate Change

Public perceptions in Nebraska are pivotal in shaping the state's response to climate change. Most Nebraskans agree that climate change is happening and acknowledge that human activities play a role. However, political views heavily influence these perceptions, creating a spectrum of opinions about the urgency and nature of climate action. Younger Nebraskans are more likely to view climate change as human-caused and to support proactive measures to address it. Local experiences, such as extreme weather events, further shape perceptions, underscoring the importance of connecting broader climate trends to tangible, community-level impacts. This highlights the need for inclusive communication strategies that bridge generational and political divides while encouraging collective action to manage and mitigate climate risks.



Sandhills Wetlands. Photo courtesy: Mariah Lundgren, Platte Basin Timelapse.

Chapter 1

Introduction

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Goals of this report

1. Understand Nebraska's climate variability.
2. Provide evidence-based science to support decision-making.
3. Inform policies, plans, and programs that promote action and build resilience to climate impacts.

About this report

Background

The Institute of Agriculture and Natural Resources (IANR) commissioned the first edition, **Understanding and Assessing Climate Change: Implications for Nebraska** (Bathke et al., 2014), to evaluate and summarize the existing scientific literature on our changing climate. Scientists from IANR's School of Natural Resources and the Department of Earth and Atmospheric Sciences produced a timely and seminal reference for state and local policymakers, government agency leaders, private industry, and citizens of the state of Nebraska. This report was notable in being the first state-level climate change report for Nebraska and among the first in the central United States.

The 2014 report was based on the findings of the Intergovernmental Panel on Climate Change (IPCC, 2014) and the Third National Climate Assessment (Melillo et al., 2014). Scientists interpreted findings from these reports to highlight observed and projected changes in temperature and precipitation for Nebraska. Additionally, subject-matter experts prepared commentaries to address the implications of these changes on sectors of importance to Nebraska. This report also included explanations related to understanding the causes of climate change, how scientists separate natural and human influences on climate, projecting future climate with global climate models, and achieving scientific consensus.

In 2022, the Nebraska Legislature passed LB1255 (2022), introduced by Senators Bostar and Flood, which authorized and distributed funding to UNL IANR to develop an update to the 2014 report. As specified in LB1255, UNL contracted with a third-party, science-based organization to identify and recommend specific prescriptive measures to be taken by the State of Nebraska relating to this report. Working with our state legislative contacts, the IANR and UNL liaisons, and the advisory panel report, we identified Pale Blue Dot, a firm in Maplewood, Minnesota. Pale Blue Dot has provided climate and sustainability planning and consulting services to nearly 150 communities and organizations across the United States, including the City of Omaha.

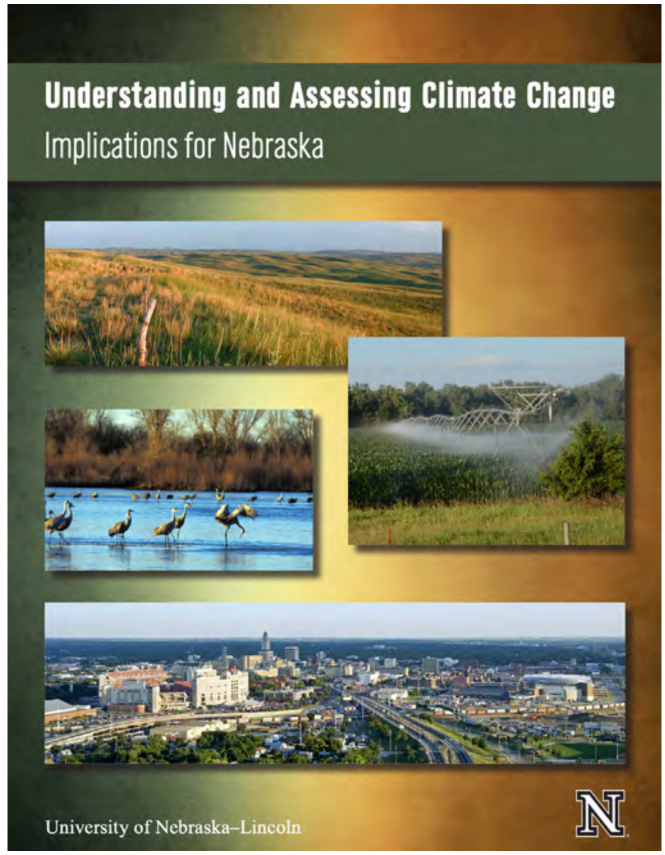


Figure 1.1. Understanding and Assessing Climate Change: Implications for Nebraska (Bathke et al., 2014)

Approach

Our approach for this report included a multidisciplinary team from the University of Nebraska–Lincoln, the University of Nebraska Medical Center, Creighton University, the Nebraska Indian Community College, and the USGS Nebraska Cooperative Fish and Wildlife Research Unit. This team analyzed and synthesized data, peer-reviewed literature, and other information to identify observed changes in Nebraska's climate, evaluate future climate projections, and assess the impacts of climate change on key sectors in Nebraska. An advisory panel, consisting mainly of UNL center directors, guided the activities of the writing team. University and federal government experts and our advisory panel reviewed the report.

For this second edition, our key objective remains the same as its predecessor—describing recent trends in Nebraska's climate and interpreting the model-based projections of future climate. We delve more deeply into the effects of climate change by summarizing the latest science on sector impacts, identifying gaps in knowledge, and highlighting management, adaptation, and policy options. While these options can have benefits, they can burden others. We include new chapters on climate justice, equity, and Indigenous communities to ensure that future actions consider the trade-offs and societal impacts. Finally, we include an assessment of survey data and information about Nebraskans' beliefs and attitudes. Like the 2014 report, many analyses in this assessment are based on published scientific literature, including the most recent NCA and IPCC reports (Box 1.1). This update also includes original data analyses, downscaled model output, and survey data to provide specific information for Nebraska. We have omitted in-depth information related to the causes of climate change. Reputable climate scientists worldwide continue to be in near unanimous agreement (greater than 99%) that human influences have warmed the atmosphere, oceans, and land. Furthermore, the speed of the changing climate exceeds what can be attributed to natural variability (Lynas et al., 2021). The most recent IPCC (Chen et al., 2021) states the following:

> **Since systematic scientific assessments began in the 1970s, the influence of human activity on the warming of the climate system has evolved from theory to established fact.**

Preparing for Nebraska's future must include climate change mitigation, adaptation, and resilience (Box 1.2). The future climate depends on the choices that we, as a society, make today. Without mitigation actions, the risks of intensifying extreme weather and harmful climate impacts will continue to grow and lead to more damage and economic losses to the state (USGCRP, 2023). Statewide climate planning efforts through the Nebraska Department of Environment

Box 1.1. The National Climate Assessment and the Intergovernmental Panel on Climate Change

National and international groups regularly assess the state of the science of climate change. These include the following:

The National Climate Assessment (NCA) is the federal government's report on climate change impacts, risks, and responses (USGCRP, 2023). Congressionally mandated under the U.S. Global Change Research Program, NCA reports are due to Congress and the president "not less frequently than every four years." These reports integrate scientific information from multiple sources and sectors to highlight key findings and significant knowledge gaps related to the climate's current status, observed changes, and projected future trends. NCA reports are used by national, state, and local governments, citizens, communities, and businesses to create climate resilience and sustainability plans. The most recent assessment, NCA5, released in November 2023, can be found at https://nca2023.globalchange.gov.

The Intergovernmental Panel on Climate Change (IPCC) is a global scientific body created by the United Nations to assess the science of climate change drivers, impacts, and future risks and how adaptation and mitigation measures can reduce those risks (IPCC, 2024). For the assessment reports, thousands of experts from 195 member nations assess and summarize the scientific papers published yearly. These reports aim to provide policymakers at all levels with the scientific information needed to develop climate policies. It does not create or enforce policy but is the key source of authoritative knowledge on the causes and effects of climate change and helps inform international climate change negotiations and agreements. The most recent IPCC reports can be found at https://www.ipcc.ch/about.

Stiefel Prairie. Photo courtesy: Michael Farrell, Platte Basin Timelapse.

and Energy (NDEE) focus on implementing mitigation actions that target climate change (NDEE, 2024b). By also highlighting strategies to build resilience, reduce vulnerability through adaptation, and reflect on policy options, this report will supplement the NDEE efforts. While this report provides a scientific basis to help us understand and assess climate change in Nebraska, time and resource constraints made it impossible to include all relevant topics, sectors of the state's economy, and the assessment of specific local vulnerabilities. Other climate planning efforts address mitigation efforts, local vulnerabilities, and other sectors of Nebraska's economy (e.g., City of Lincoln, 2021; City of Omaha, 2024).

Guide to this report

Intended audience

This report synthesizes scientific information and evaluates the state of the science on climate change to inform a broad audience of decision-makers across the state of Nebraska. These decision-makers include state, local, and Tribal governments, city planners, public health officials, natural resource managers, utility providers, business owners, agricultural producers, community organizers, educators, students, the media, and concerned individuals who need to make decisions about the climate impacts they are facing. Hopefully, this report will lead to increased awareness and the initiation of actions that will enable Nebraskans to prepare for and adapt to future changes in our climate.

This assessment relies on the expert judgment of the report authors, advisory panel, and reviewers to determine what topics were included in each chapter, to describe what we know and where uncertainties remain, and to communicate the risks, responses, and opportunities associated with climate change. We view this assessment as a living document that will evolve as new knowledge becomes available. Any amendments or additions will be available on the Nebraska State Climate Office website at https://nsco.unl.edu.

Structure and format

Components of this report include the following:

Key messages related to this report are summarized at the beginning of each chapter and in the Executive Summary that precedes Chapter 1. Key messages, identified by chapter authors, convey the main idea or points that the author wants readers to understand and remember.

Physical science chapters: Chapter 2, "Climate Change Contexts," discusses global and national climate change and how those changes relate to what we see in Nebraska. Chapter 3, "Observed Changes in Nebraska's Climate," and Chapter 4, "Projections of Nebraska's Future Climate," assess how Nebraska's temperature, precipitation, and extreme events have changed in the past and are projected to change in the future.

Focused topic chapters: Chapters 5 through 14 summarize current and future risks related to climate change and discuss what options reduce those risks for selected sectors of Nebraska. This report builds on the range of topics covered in the 2014 report by adding three new chapters: Indigenous Peoples (Chapter 11), Climate Justice and Equity (Chapter 12), and Nebraskans' beliefs and attitudes toward climate change (Chapters 13 and 14).

Information boxes contain examples, expand ideas, or highlight important information from the main text.

Confidence and likelihood: As with national and international assessments (Box 1.1), chapter authors use specific terms to communicate information about scientific confidence and certainty associated with important findings, observations, and projections (Box 1.2).

Next steps include activities planned for 2025 to increase the report's accessibility and promote public engagement and outreach around climate resilience (Chapter 15).

Supplemental report: Prepared by paleBluedot and Emmons & Olivier Resources, Inc., the supplemental report includes opportunities for mitigation, adaptation, and resilience climate risk assessments to help individuals, communities, and the State of Nebraska increase climate resiliency. It also includes a risk assessment and a summary of the impacts of each focused topic.

Appendices: The appendices contain supplementary materials that describe the authors' qualifications

(Appendix A), technical data or survey instruments that support chapter findings (Appendix B), and a complete list of the plans and documents reviewed in the supplemental report (Appendix C).

References: A complete list of the works cited throughout this report.

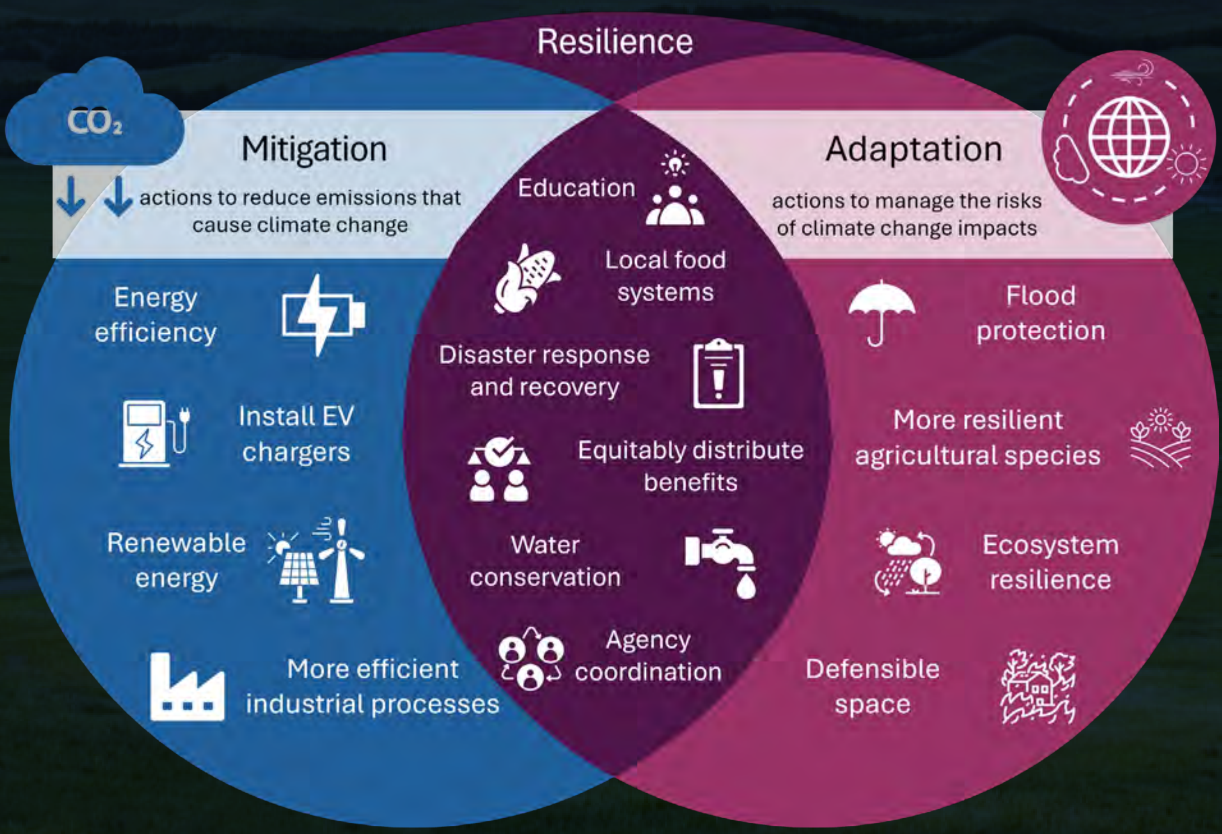
Box 1.2. Mitigation, adaptation, and resilience

Climate change is not only a threat to future generations; it is here and now. The planet is warming faster than predicted, and we are seeing the impacts of human-caused warming. Tackling current effects and preparing for future impacts requires three related strategies.

Mitigation: **Efforts to reduce or prevent the flow of heat-trapping greenhouse gases into the atmosphere either by reducing sources of these gases or enhancing the "sinks" that capture and store these gases. Mitigation aims to limit the rate and magnitude of future climate change.**

Adaptation: **Actions that prepare for or adjust to climate change's current or expected impacts. Adaptation goals include reducing the risks from the harmful effects of climate change and making the most of any potential benefits or opportunities.**

Resilience: **Coping and managing the impacts of climate change while preventing them from worsening.**

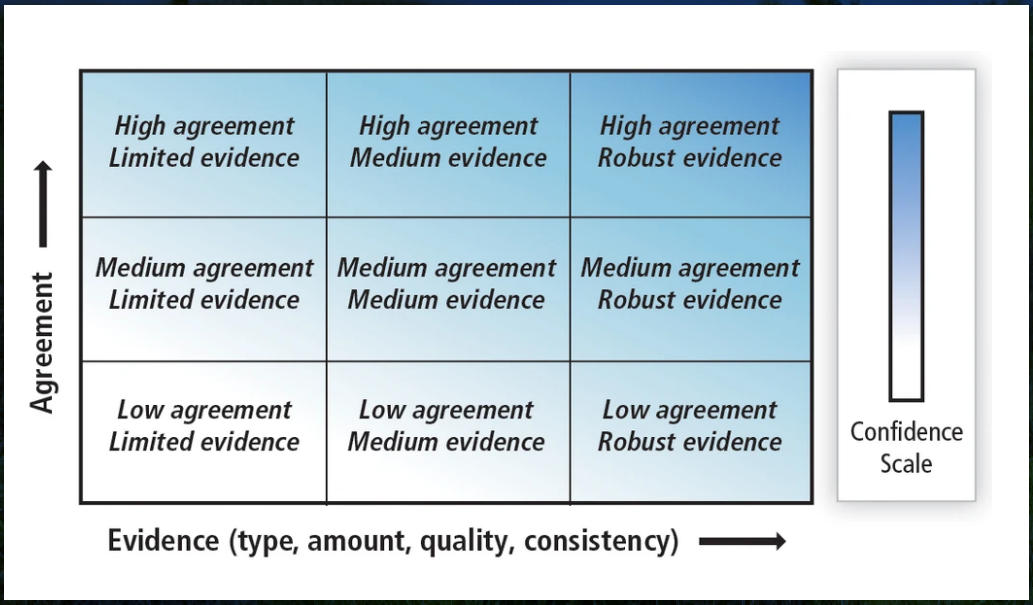


Venn diagram showing the relationship between climate mitigation, adaptation, and resilience. Some actions support either mitigation or adaptation goals, while a subset can address both. After Rabinowitz et al. (2023).

Gunderson Ranch. Photo courtesy: Michael Forsberg, Platte Basin Timelapse.

Box 1.3. Confidence and likelihood

Confidence refers to the degree of certainty researchers have in a result's accuracy and reliability. It is built upon factors such as the amount, quality, strength, and consistency of evidence that supports a finding, the robustness of the methods to detect, evaluate, attribute, and interpret climate trends, and the degree of agreement across scientific information sources (Figure 1.2).



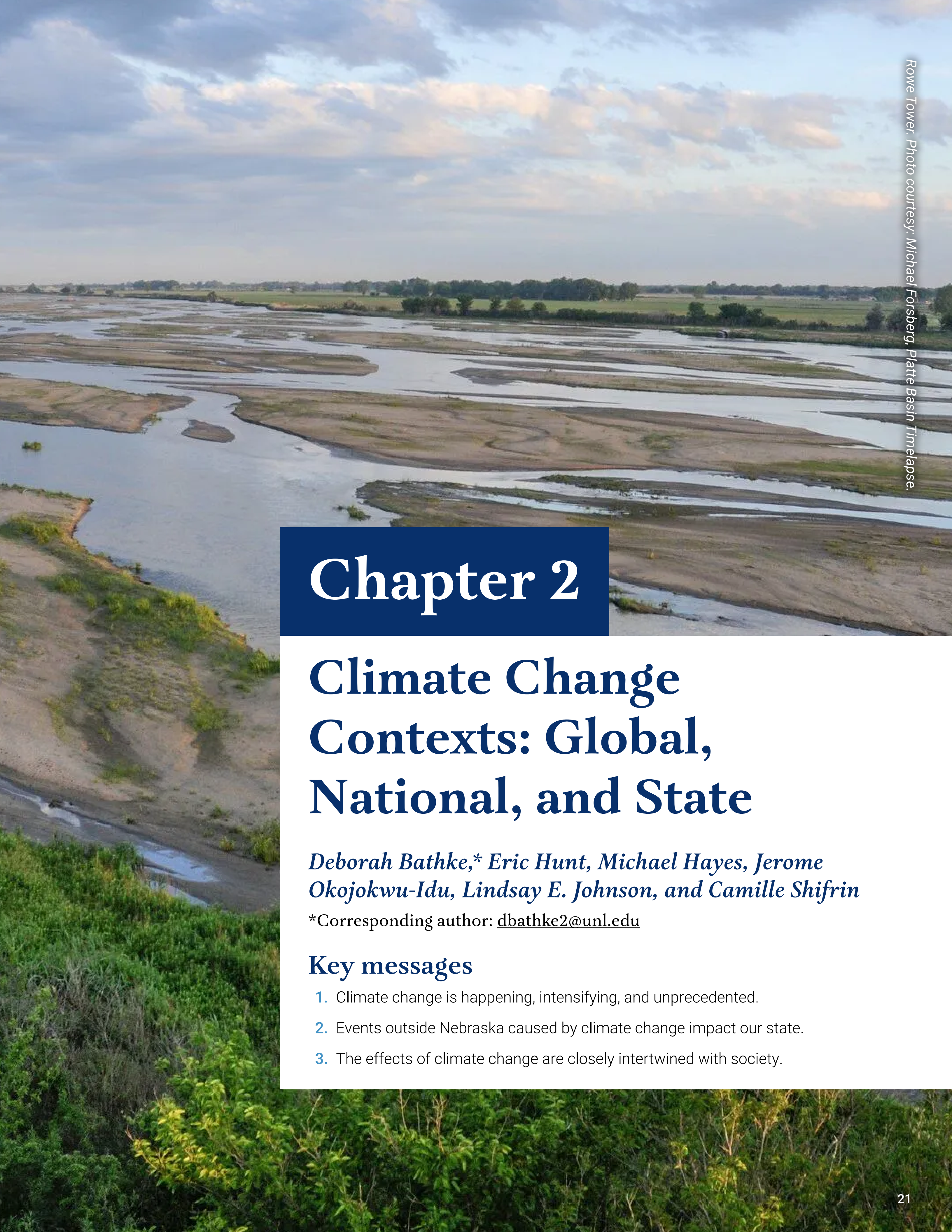
A depiction of evidence and agreement statements and their relationship to confidence. Confidence increases toward the top-right corner as suggested by the increasing strength of shading. Generally, evidence is most robust when there are multiple, consistent independent lines of high-quality evidence. (Source: Mastrandrea et al., 2010)

The **likelihood** of a finding is based on a statistical analysis of observed or projected results or the authors' expert judgment based on their assessment of scientific information across varying sources (Table 1.1).

TERM	LIKELIHOOD OF OUTCOME
Virtually certain	99%–100% probability
Very likely	90%–100% probability
Likely	66%–100% probability
About as unlikely as not	33%–66% probability
Unlikely	0%–33% probability
Very unlikely	1%–10% probability

Likelihood scale
(Source: Mastrandrea et al., 2010)

Saline Wetlands. Photo courtesy: Ethan Freese, Platte Basin Timelapse.



Rowe Tower. Photo courtesy: Michael Forsberg, Platte Basin Timelapse.

Chapter 2

Climate Change Contexts: Global, National, and State

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Key messages

1. Climate change is happening, intensifying, and unprecedented.
2. Events outside Nebraska caused by climate change impact our state.
3. The effects of climate change are closely intertwined with society.

Introduction

Nebraska, where east meets west and north meets south, boasts unique landscapes and diverse ecosystems (Chapter 7). Nearly 80,000 miles of scenic rivers and the underlying High Plains Aquifer provide our state with abundant water resources (Chapter 5). Additionally, Nebraska ranks in the top five in the U.S. regarding wind resources (X. Yang et al., 2024) due to the generally flat terrain and location relative to the Rocky Mountains and the seasonal jet stream. With over 200 days of sunshine annually, Nebraska ranks thirteenth in the nation for solar potential (NDEE, 2024c). These natural resources are vital to our state's economy and way of life, supporting agricultural production (Chapter 8), industrial development, mineral extraction, power generation (Chapter 6), recreation, and tourism. Protecting and managing these resources is an integral part of our state's culture and is essential to long-term economic sustainability.

Nebraska transitions between humid conditions in the eastern part of the state and semi-arid conditions in the west. Characteristics include warm, humid summers and cold winters (Chapter 3). The state's continental position, located far from the moderating effects of the ocean, means that we experience large swings in the weather from day to day and season to season. Weather and climate-related hazards include severe thunderstorms, tornadoes, hail, flooding rains, droughts, heat waves, and blizzards. Personal observations and scientific data show that Nebraska's climate is changing, making it harder to maintain our way of life (IPCC, 2023b; Pytlik Zyllig, 2024; USGCRP, 2023).

Climate change intensifies extreme weather events, impacting crop yields (Chapter 8), displacing communities, damaging infrastructure (Chapter 10), and disrupting tourism. The increased frequency of droughts and the lengthening of the fire season contribute to a higher risk of wildfires. Fire suppression and firefighting efforts increase federal and state budgets, while smoke reduces air quality and impacts human health (Chapter 9). Additionally, climate change drives the spread of invasive species (Chapter 7) and shifts disease patterns from ticks and mosquitoes that carry and spread illness (Chapter 9).

Climate change is happening, intensifying, and unprecedented

Climate change is evident across more than 50 indicators (Figure 2.1), including historical data and observed trends related to its causes or effects. These indicators describe how the environment has changed and help communicate the climate's impacts, risks, and vulnerabilities (EPA, 2024a). This report presents indicators as maps and graphs based on historical observations and measurements. These indicators provide compelling evidence that climate change is increasingly affecting both nature and society.

Temperature

While the Earth's climate has always changed, recent warming (1994 to 2023) has been much faster than the long-term trend (1901 to 2023). Each of the last 10 consecutive years has been the warmest 10 since record-keeping began in 1880 (Blunden & Boyer, 2024). When weather station records are extended with proxy data (such as ice cores, rocks, coral reefs, and tree rings), scientists conclude that the current rate of warming is roughly 10 times faster than the average rate of warming after the last Ice Age (Gulev et al., 2021). Earth's rapid warming has resulted in other large-scale global changes, including reductions in snow and ice, sea level rise, rising ocean heat content, changing rainfall patterns, higher humidity, and shifts in the timing of seasonal events. Many of these climate impacts have been unprecedented for thousands of years (Figure 2.2) (Blunden & Boyer, 2024; Gulev et al., 2021; Marvel et al., 2023).

Human activities have altered the chemistry of the Earth's atmosphere by increasing the emission of greenhouse gases, such as carbon dioxide, methane, and nitrous oxide. As a result, the average global surface temperature has risen by approximately 2°F since the pre-industrial era (Figure 2.3) (Hawkins, n.d.). While a two-degree increase may not seem significant, the Earth's oceans, like a swimming pool on a hot day, can absorb a significant amount of heat with only a

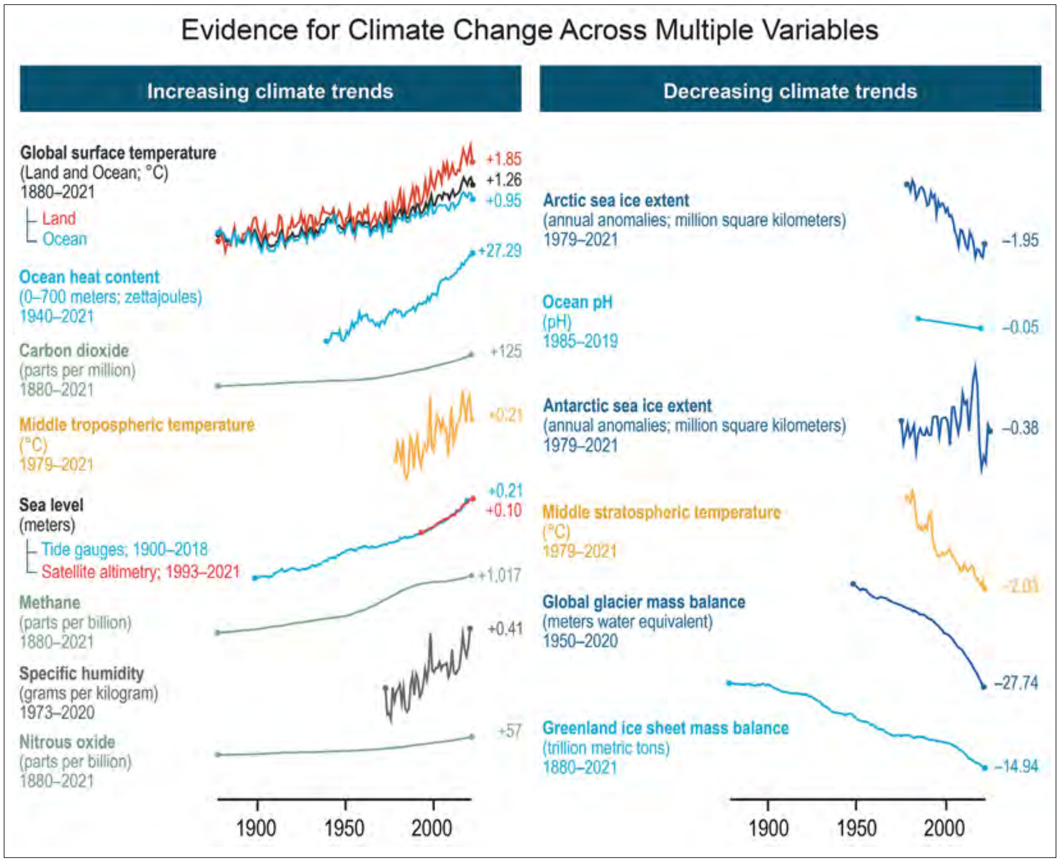


Figure 2.1. Indicators demonstrating evidence of climate change across various aspects of the Earth system between 1880 and 2021. (Source: Marvel et al., 2023)

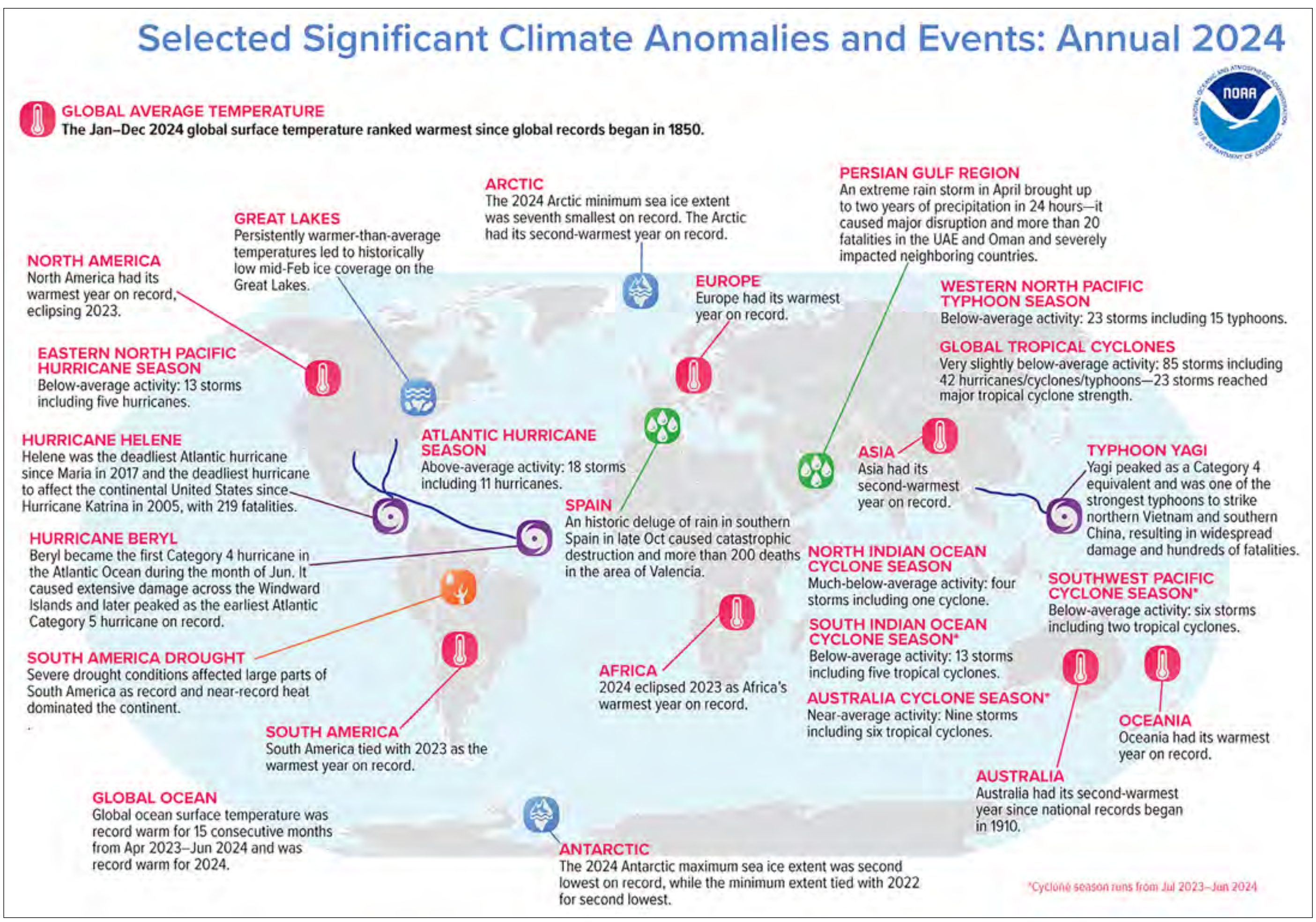


Figure 2.2. Global records set in 2023. (Sources: Blunden & Boyer, 2023; Gulev et al., 2021; Marvel et al., 2023)

small temperature change. Over 90% of the excess heat generated from rising greenhouse gas emissions has been absorbed by the oceans due to their vast volume, estimated at 352 quintillion gallons of water, and high heat-storage capacity. Without this absorption, the Earth would warm much more rapidly, and the impacts of climate change would be even more severe. However, the oceans have a limited capacity to absorb carbon dioxide; as the ocean temperatures rise, their ability to absorb carbon dioxide decreases (Gruber et al., 2023).

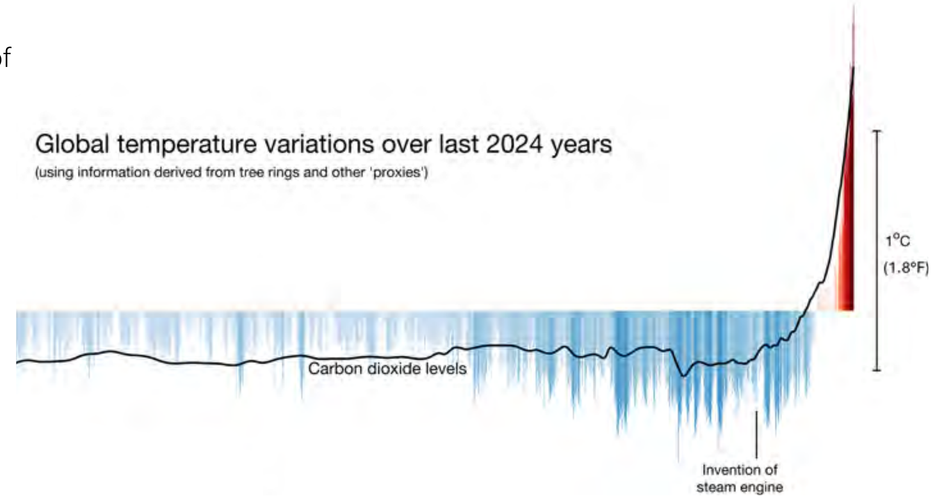


Figure 2.3. Global temperature anomalies over the last 2,024 years, using proxy data in combination with instrumentation. (Adapted from Hawkins, n.d.)

This global average surface temperature increase, referred to as global warming, is not uniform (Figure 2.4). Most regions are experiencing warming, particularly in the higher latitudes over land, while a few areas show isolated cooling (Lindsey & Dahlman, 2025). In the U.S., temperatures have risen more quickly than the global average. Since 1970, temperatures in the contiguous U.S. have increased by 2.5°F; in Alaska, they have risen by 4.2°F (Figure 2.5) (Marvel et al., 2023). Although these increases may seem minor, even small changes in average temperature can significantly impact temperature and precipitation extremes (Box 2.1).

Seasonally, winter is warming nearly twice as fast as summer in many northern states. Temperatures in some areas east of the Rocky Mountains, including parts of Nebraska, have decreased in summer. Studies have linked these regional trends to natural climate variability, irrigation, and aerosol pollution (Marvel et al., 2023). Additionally, the number of frost-free days, or the days between the last occurrence of 32°F in the spring and the first occurrence of 32°F in the fall, has been increasing in the U.S. over the last 40 years (Figure 2.6) (USGCRP, 2023). The length of the frost-free season is an important factor in determining the potential growing season for vegetation, so the increasing length means that the growing season is also increasing.

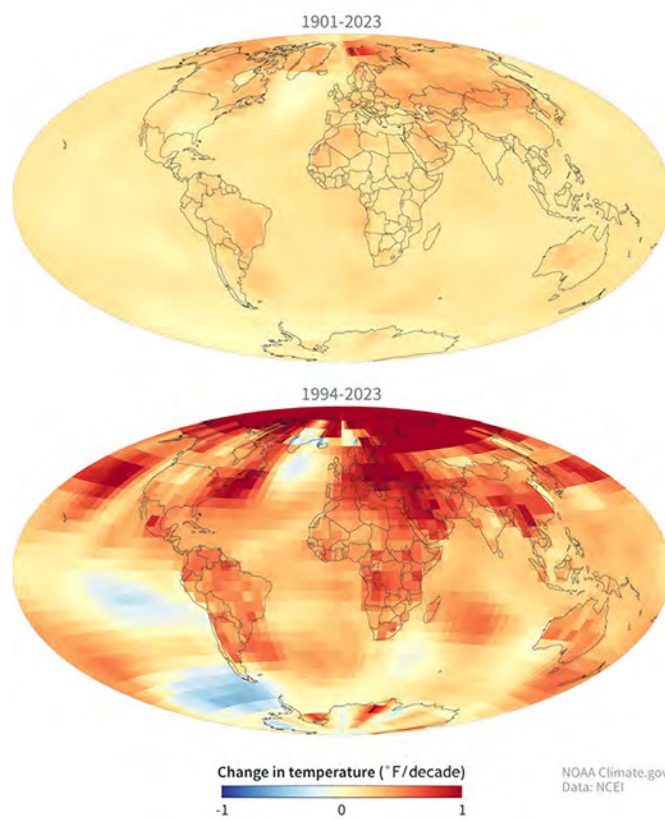


Figure 2.4. Trends in annual surface temperature over the past few decades (1994–2023, bottom) compared to the trend since the start of the 20th century (1901–2023, top). Recent warming is much faster than the longer-term average, with some locations warming 1°F or more per decade. Differences are most dramatic in the Arctic, where the loss of reflective ice and snow amplifies the rate of warming. (Source: Lindsay & Lindsay, 2024)

As temperatures rise, many other changes occur in the climate system. For example, many parts of the water cycle depend on temperature (Figure 2.7) (USGCRP,

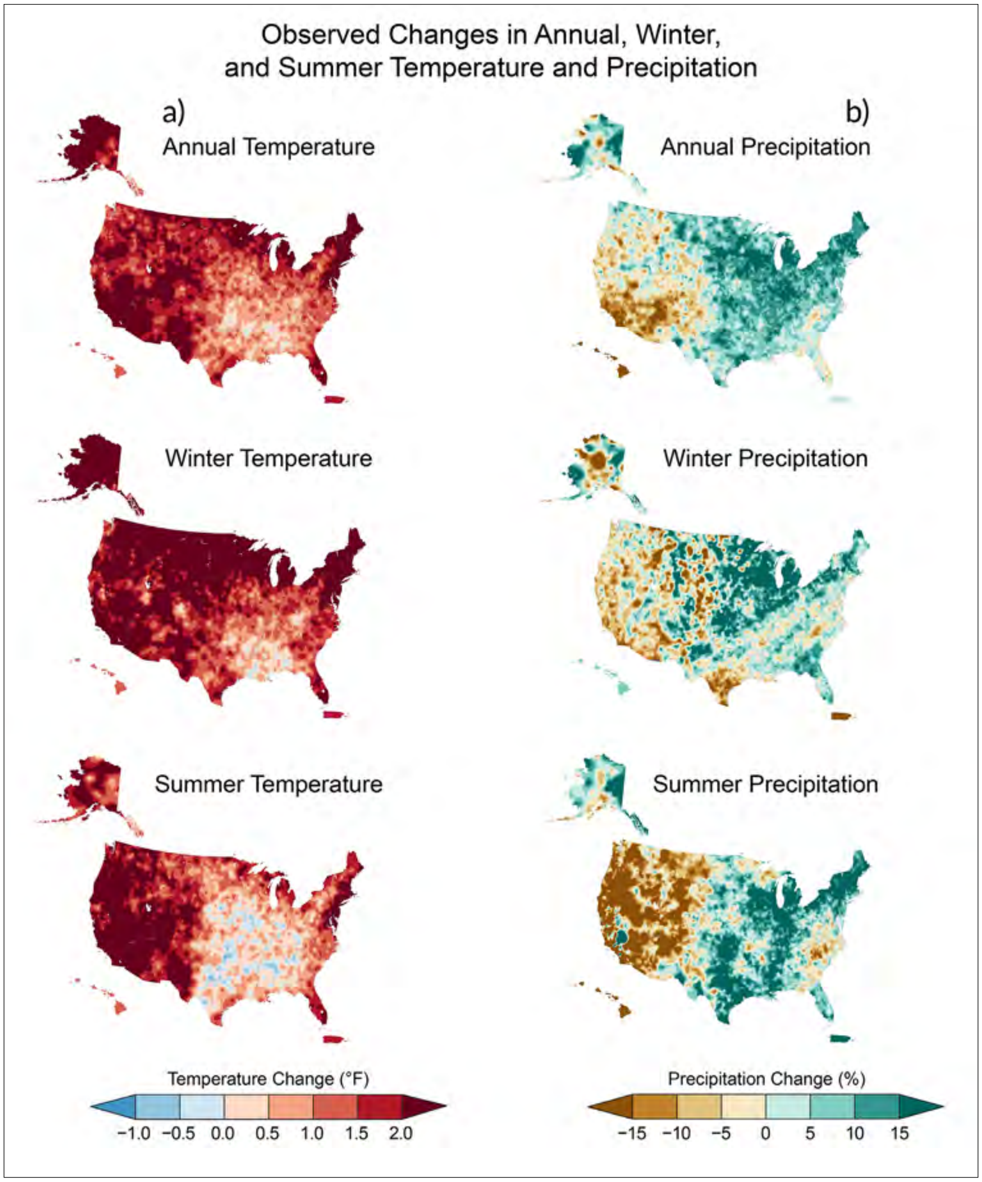


Figure 2.5. Changes shown are the difference between the annual average or seasonal temperatures (left column) and precipitation totals (right column) for the present day (2002–2021) compared to the average for the first half of the last century (1901–1960) for the contiguous United States, Hawaii, and Puerto Rico; and 1925–1960 for Alaska. (Source: Marvel et al., 2023)

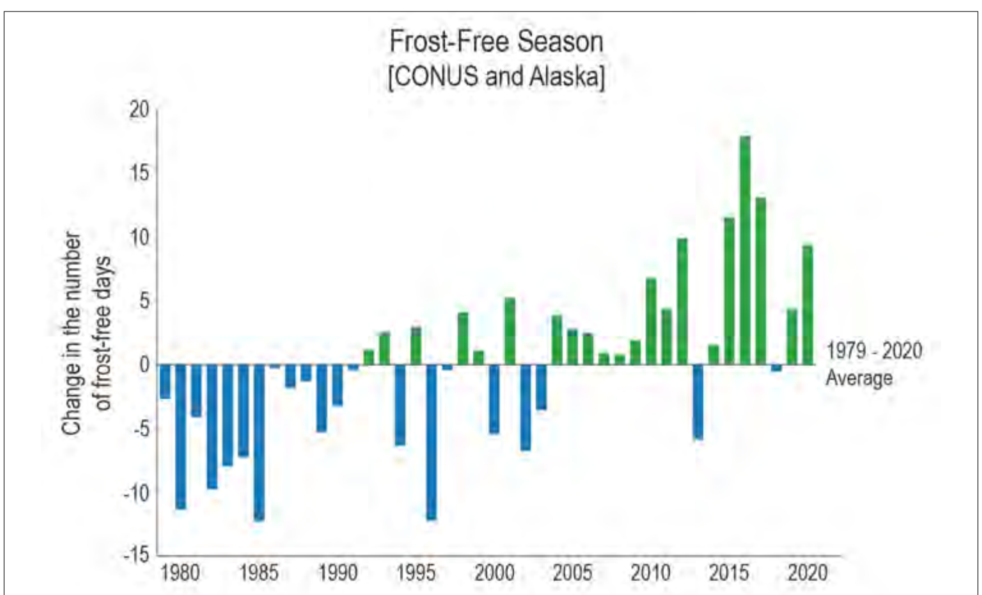
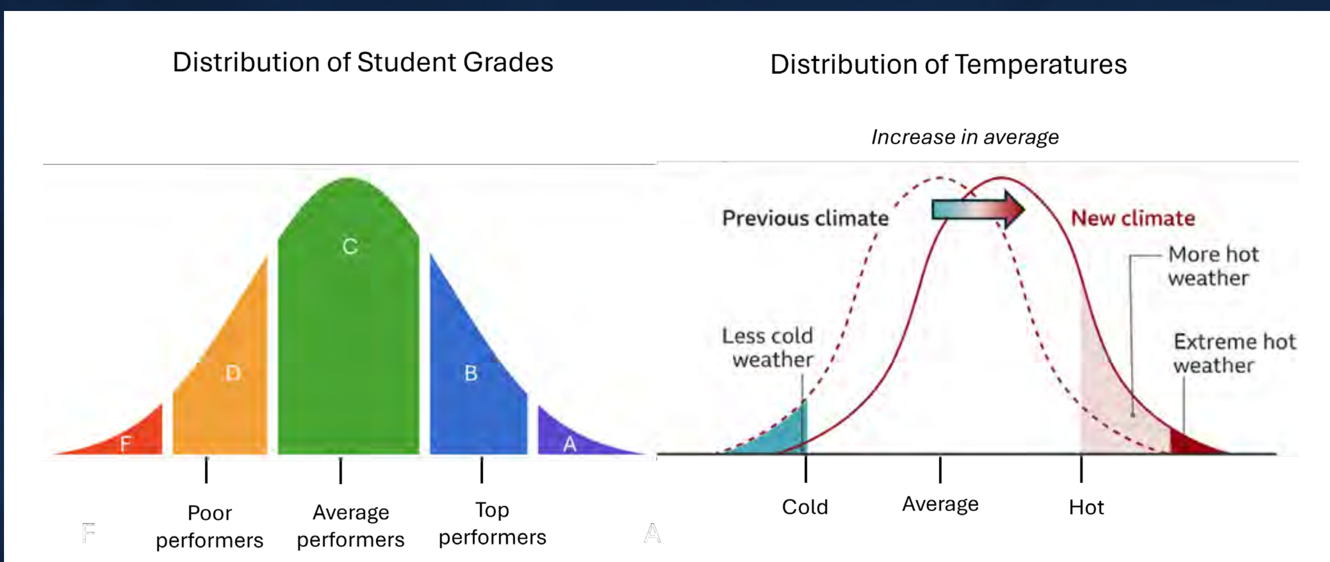


Figure 2.6. The difference between the number of frost-free days each year and the average number from 1979 to 2020 for the contiguous U.S. and Alaska. (Source: USGCRP, 2023)

Box 2.1. How does a small shift in climate affect extreme heat events?

Even small increases in average temperature can make a big difference to heat extremes. For example, high school and college teachers often grade using a bell curve to evaluate students' performance. Within this system, everyone's grade is relative to the rest of the class. Using the figure below, we can see that most students fall in the middle, while the top and poor performers land in the "tails" of the curve. Considering temperature using the same curve, most values fall in the middle, while the coldest and warmest temperatures fall in the tails.

A teacher may want to adjust the curve so failing students can pass. Similarly, shifting the temperature curve to the right, indicating an increase in the average temperature, could result in more hot and extremely hot temperatures.



The effect of extreme heat on climate. (Adapted from EPA, 2016)

Photo courtesy: Adobe Stock.

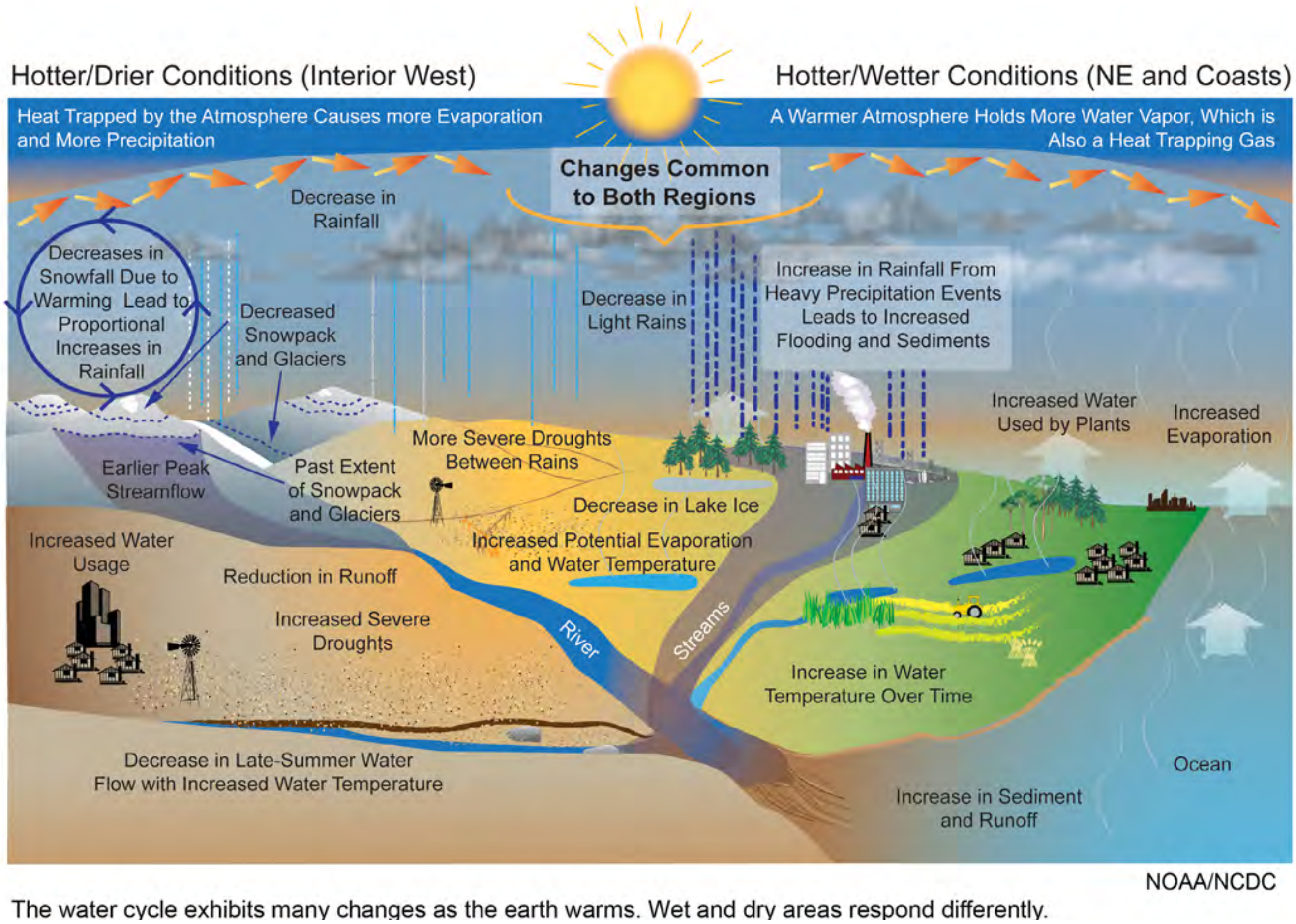


Figure 2.7. Changes to the water cycle caused by a warming planet. (Source: USGCRP, 2009)

2009), affecting the timing and amount of rain and snow. From 1901 to 2023, the average global yearly rainfall has increased, and the rate of increase has become faster since the 1980s (Figure 2.8). Monitoring these changes is important because they can disrupt many natural processes. Sparse weather station networks, poor data, and short record lengths, combined with the highly variable nature of precipitation across space and time, make it difficult to understand changes, particularly on a global scale. For instance, 76 nations and territories are represented by fewer than five weather stations (Jaffrés, 2019). In the U.S., which has the highest density of stations worldwide, each station represents roughly 400 square miles (NASA, n.d.).

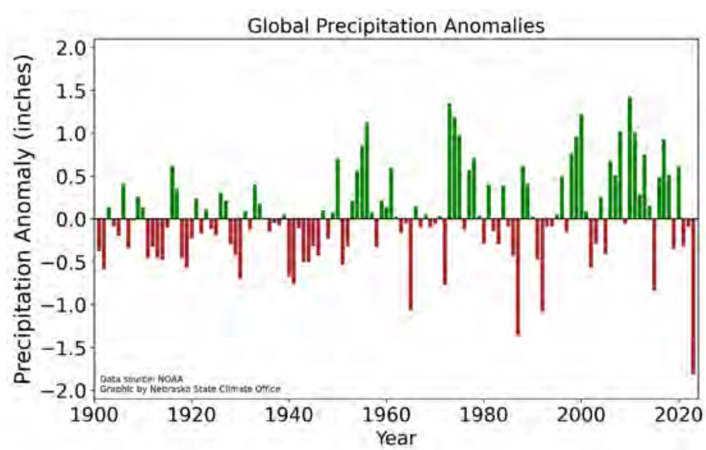


Figure 2.8. Annual global precipitation anomalies, 1901–2021. This graph uses the 1901–2000 average as a baseline to depict change. (Source: NOAA, 2022)

Rain and snow

Annual average precipitation has also increased in the U.S., differing across seasons and regions (Easterling et al., 2017; Marvel et al., 2023). Much of the eastern half of the U.S. is getting wetter, while parts of the Southwest are getting drier (Figure 2.5b). While the Northeast and Midwest have seen wetter conditions in all seasons, other areas, such as the Southeast, have seen a shift in the timing of precipitation. Across the northern Great Plains, precipitation shows drying in the region's western part in winter and summer.

Snow cover is declining globally as temperatures warm (Blau et al., 2024). In the Northern Hemisphere, satellite records show that the largest declines are in the spring (Easterling et al., 2017). These declines are partly due to warmer temperatures shortening snow time on the ground, reflecting an earlier spring snowmelt. River basins across the U.S. are experiencing rapid declines in snow in response to human-caused warming (Figure 2.9). The largest declines are in the Southwest and Northeast. Snow loss in the larger Mississippi basin, of which Nebraska is a part, has been estimated at 5% to 6% per decade since 1980 (Gottlieb & Mankin, 2024; Kelly, 2024). As snow melts, it releases water into rivers, streams, and reservoirs, infiltrates soil, and recharges groundwater. Changes in the amount of snow or the timing of melt can lead to water shortages and increased drought risks, threatening the water supply of the ecosystems and hundreds of millions of people.

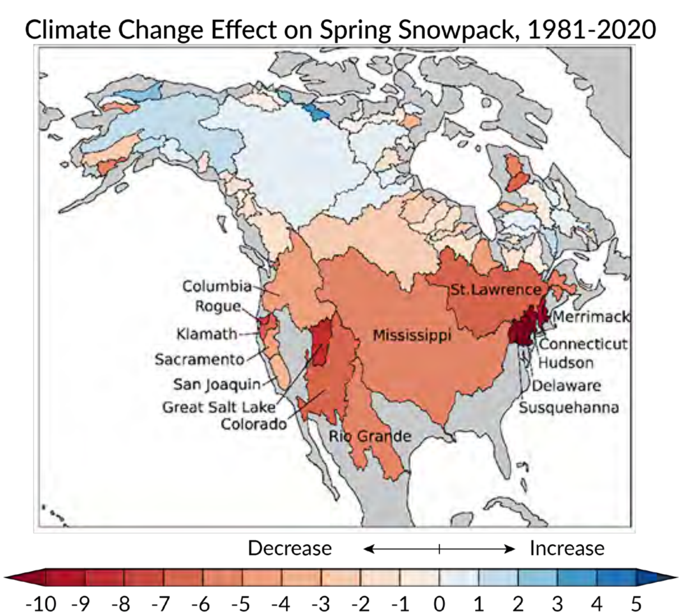


Figure 2.9. Climate change effects on spring snowpack, 1981–2020. (Source: Kelly, 2024)

Extreme weather and climate events

Extreme events are rare occurrences of severe weather conditions such as heat waves, heavy rainfall, drought, and severe thunderstorms. Due to their infrequent nature and historical data constraints, detecting and attributing trends to climate change can be challenging. Projecting future changes is also challenging because, due to their coarse resolution, climate models struggle to adequately represent the small-scale physical processes that drive these changes in extreme events. Despite this, many new developments have been made since the release of Nebraska's last climate assessment report (Bathke et al., 2014) that provide evidence of change and the influence of human-induced warming on these events (Seneviratne et al., 2021).

Extreme heat and cold

Globally, the frequency and intensity of extreme heat have increased, and those of extreme cold have decreased since 1950 (Sheridan & Lee, 2018; Seneviratne et al., 2021). In the western U.S., the risk of hot days where the temperature is at or above 95°F has increased (Figure 2.10). Warm nights where the temperature does not drop below 70°F have increased nearly everywhere except for the northern Plains; here in Nebraska, they have remained nearly constant. The number of cold days where the temperature is at or below 32°F has decreased everywhere except in the Southeast, where the number of days below freezing is already relatively small (Marvel et al., 2023).

Heavy precipitation and flooding

The frequency and intensity of heavy precipitation events have likely increased (66% to 100% probability) globally in places with good observational coverage, though significant regional and seasonal variations exist (Seneviratne et al., 2021). Since the 1950s, heavy precipitation events have become more frequent and intense across much of the country (Figure 2.11) (Marvel et al., 2023). In the northern Plains, a 24% increase in extreme precipitation days (defined as the top 1% of heaviest precipitation events) has occurred. These changes have contributed to increasing trends in large flood frequency (Figure 2.12) (Stevens et al., 2023).

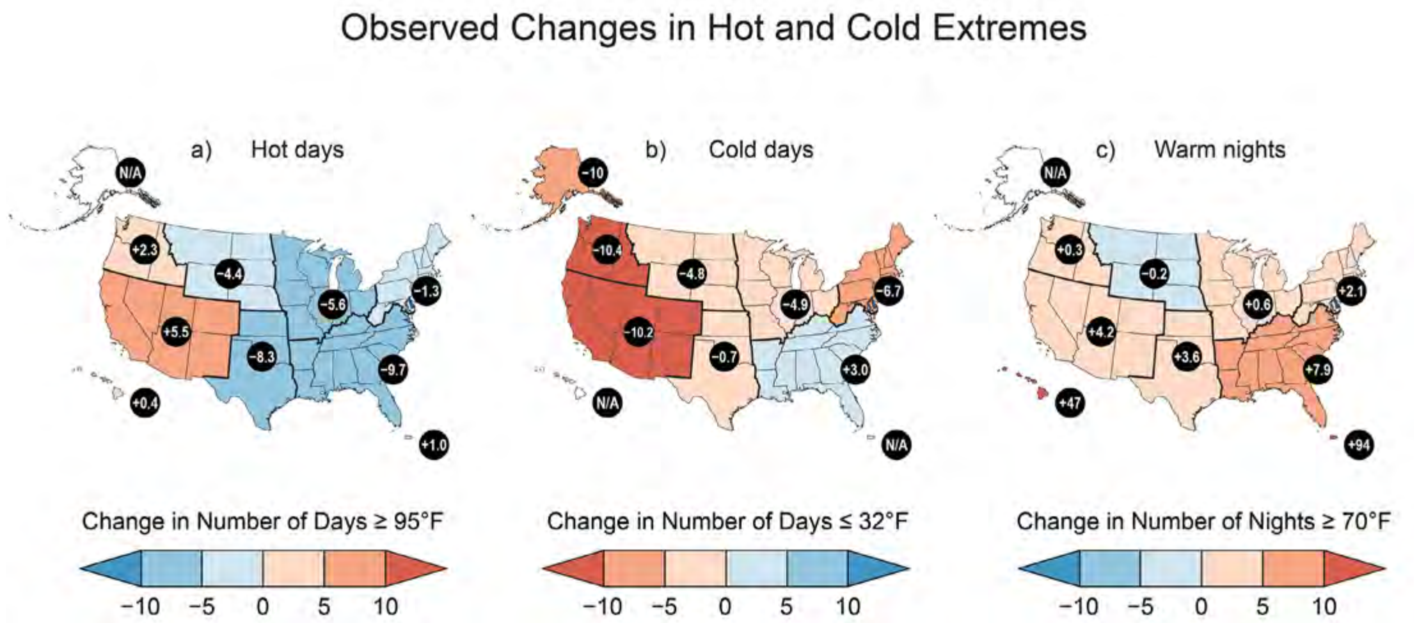


Figure 2.10. Over much of the country, the risk of warm nights has increased, while the risk of cold days has decreased. The risk of hot days has also increased across the western U.S. This figure shows the observed change in the number of (a) hot days (at or above 95°F), (b) cold days (at or below 32°F), and (c) warm nights (at or above 70°F) over the period of 2002–2021, relative to 1901–1960 (1951–1980 for Alaska and Hawai'i and 1956–1980 for Puerto Rico). (Source: Marvel et al., 2023)

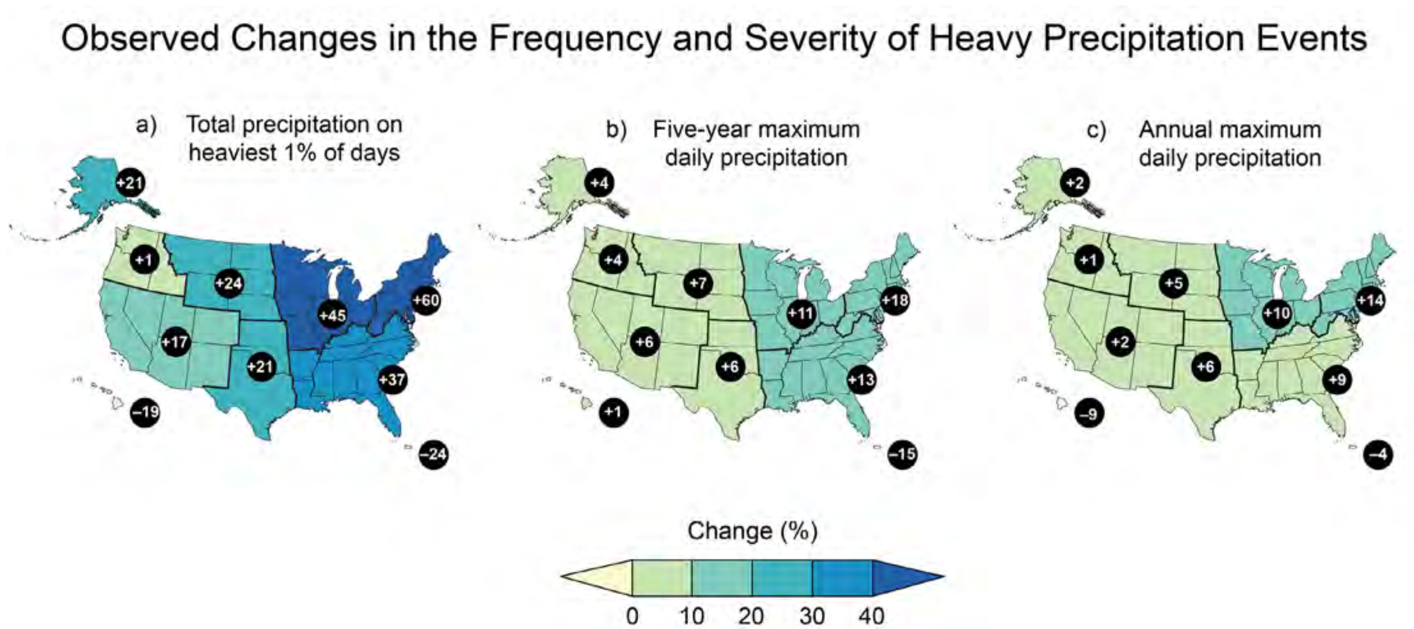


Figure 2.11. The frequency and intensity of heavy precipitation events have increased across much of the U.S., particularly the eastern part of the continental U.S., with implications for flood risk and infrastructure planning. Maps show observed changes in three measures of extreme precipitation: (a) total precipitation falling on the heaviest 1% of days, (b) daily maximum precipitation in a five-year period, and (c) the annual heaviest daily precipitation amount over 1958–2021. Numbers in black circles depict changes in percentage at the regional level. (Source: Marvel et al., 2023)

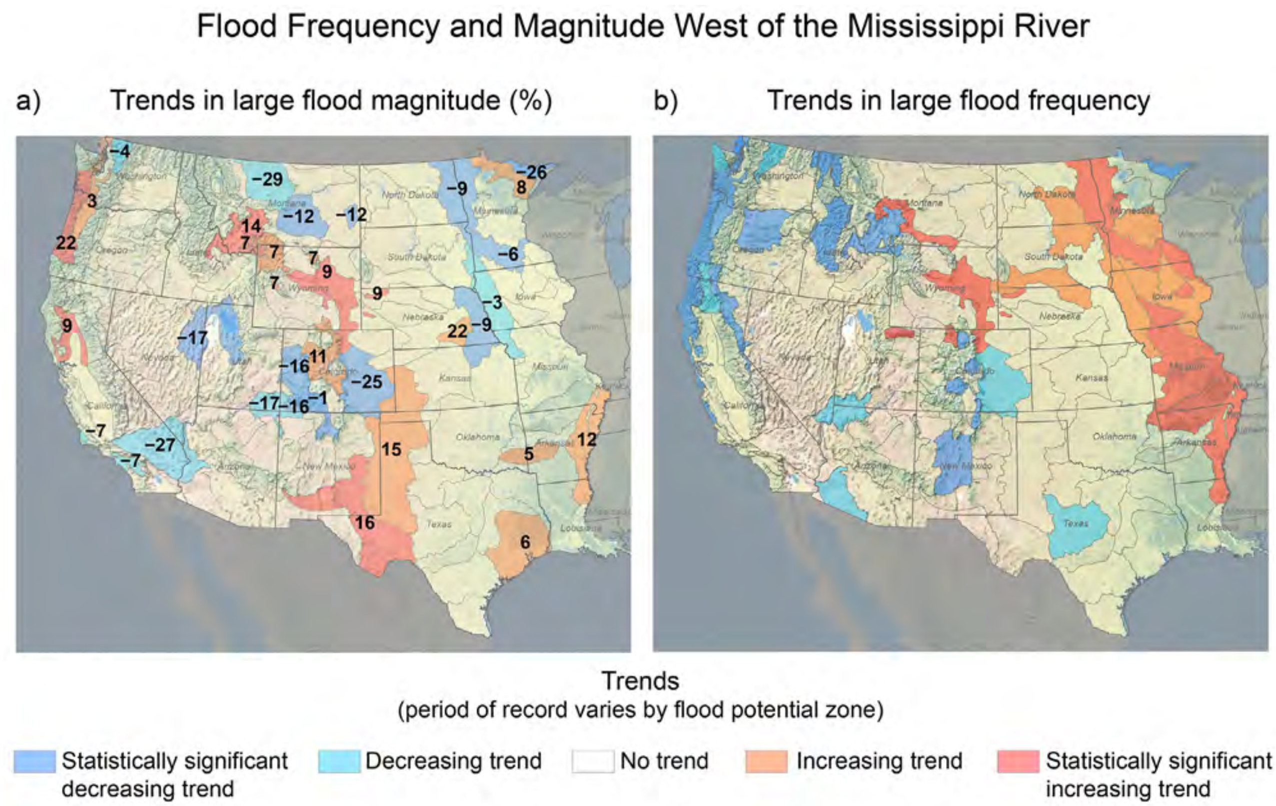


Figure 2.12. Trends in the (a) magnitude and (b) frequency of large floods in the western U.S. within 117 flood potential zones. Shading in warm colors (reds) represents increasing trends, and shading in cool colors (blues) represents decreasing trends. Darker shades indicate where trends are statistically significant. The (a) percentage of change in annual flood magnitudes is indicated by black numbering. Trends in magnitudes vary by the available record length (most commonly from the early 1900s through 2020), while (b) trends in frequency are from 1945 to about 2020. (Source: Stevens et al., 2023)

Drought

Drought is a complex phenomenon that is difficult to define. It looks different based on where and when it occurs, how long it lasts, and whom it affects. Scientists have identified more than 150 definitions of drought (Wilhite & Glantz, 1985), and dozens of indicators exist to measure its severity (Svoboda & Fuchs, 2016). Some drought indicators consider water availability as measured by precipitation, streamflow, groundwater, reservoir levels, soil moisture, and other variables. Other indicators consider factors that represent demand, such as temperature and evapotranspiration. Despite this complexity, scientists can detect some trends in drought events. Global-scale trends indicate that drought has increased on all continents. These increases generally result from increased atmospheric demand caused by high temperatures rather than decreases in precipitation (Seneviratne et al., 2021). The rapid onset and intensification of drought, also known as flash drought, is likely to increase across much of the globe (Christian et al., 2023). The Standardized Precipitation Evapotranspiration Index (SPEI) shows that since the early 20th century, the eastern half of the U.S. has generally experienced wetter conditions. In comparison, portions of the West have experienced drier conditions (Figure 2.13) (Stevens et al., 2023). The SPEI determines drought severity through a combination of precipitation and evapotranspiration, making it suitable for studies of the effect of climate change on drought severity (Nwayor & Robeson, 2024).

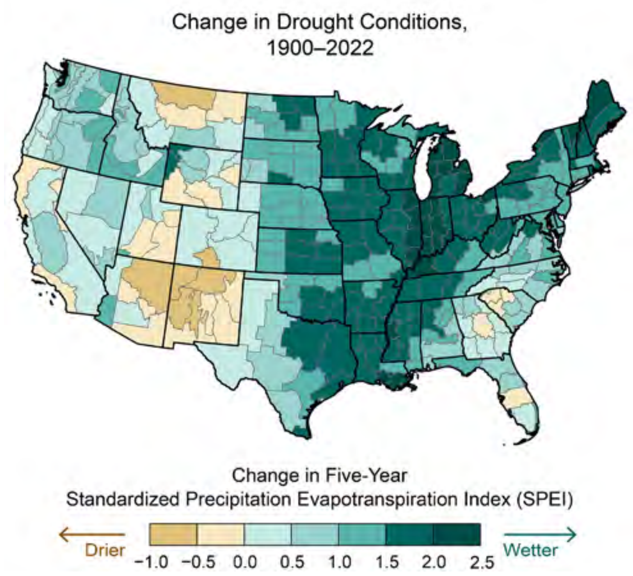


Figure 2.13. This map shows the total change in drought conditions across the contiguous United States, based on the long-term average rate of change in the five-year Standardized Precipitation Evapotranspiration Index (SPEI) from 1900 to 2022. As defined by NOAA, data are displayed for small regions called climate divisions. The 45 teal-shaded areas represent wetter conditions, and brown areas represent drier conditions. (Source: Stevens et al., 2023)

Wildfire

Fueled by higher temperatures and drier conditions, wildfires are becoming more extreme and burning for more prolonged periods across the globe in response to climate change (Jones et al., 2022). Hotter temperatures dry out the landscape, making it more prone to fires. As wildfires burn, they release billions of tons of carbon dioxide into the atmosphere, cause billions of dollars in property damage, displace thousands of people from their homes, threaten ecosystems, and release air pollution across continents (MacCarthy et al., 2023).

The annual average number of acres burned in the U.S. has increased since the mid-1980s (Figure 2.14a). An increase in the wildland-urban interface—where development meets or mixes with natural areas—has increased rapidly since 1990. Together, these changes show that many areas across the U.S. have experienced an increased risk of loss of life and property damage from wildfires (Figure 2.14b) (Stevens et al., 2023).

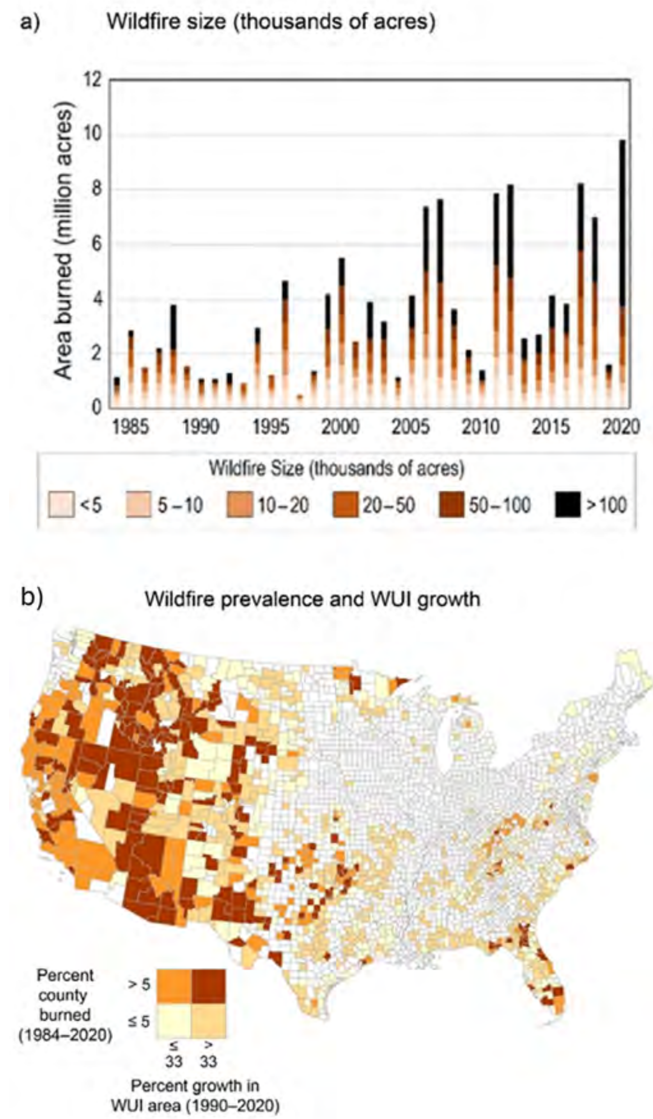


Figure 2.14. The (a) chart shows the number of acres burned between 1984 and 2020 for the contiguous U.S. The different shades within each bar indicate the proportional contribution of different fire size classes to the total for that year. The (b) map portrays U.S. counties where wildland-urban interface (WUI) growth and wildfires are most prevalent. Counties are categorized by their level of WUI growth between 1990 and 2020 and areas burned between 1984 are 2020. Counties are not categorized where wildfires do not meet the minimum size requirements for monitoring trends in burn severity mapping or where percent growth in WUI area is less than zero. (Source: Stevens et al., 2023)

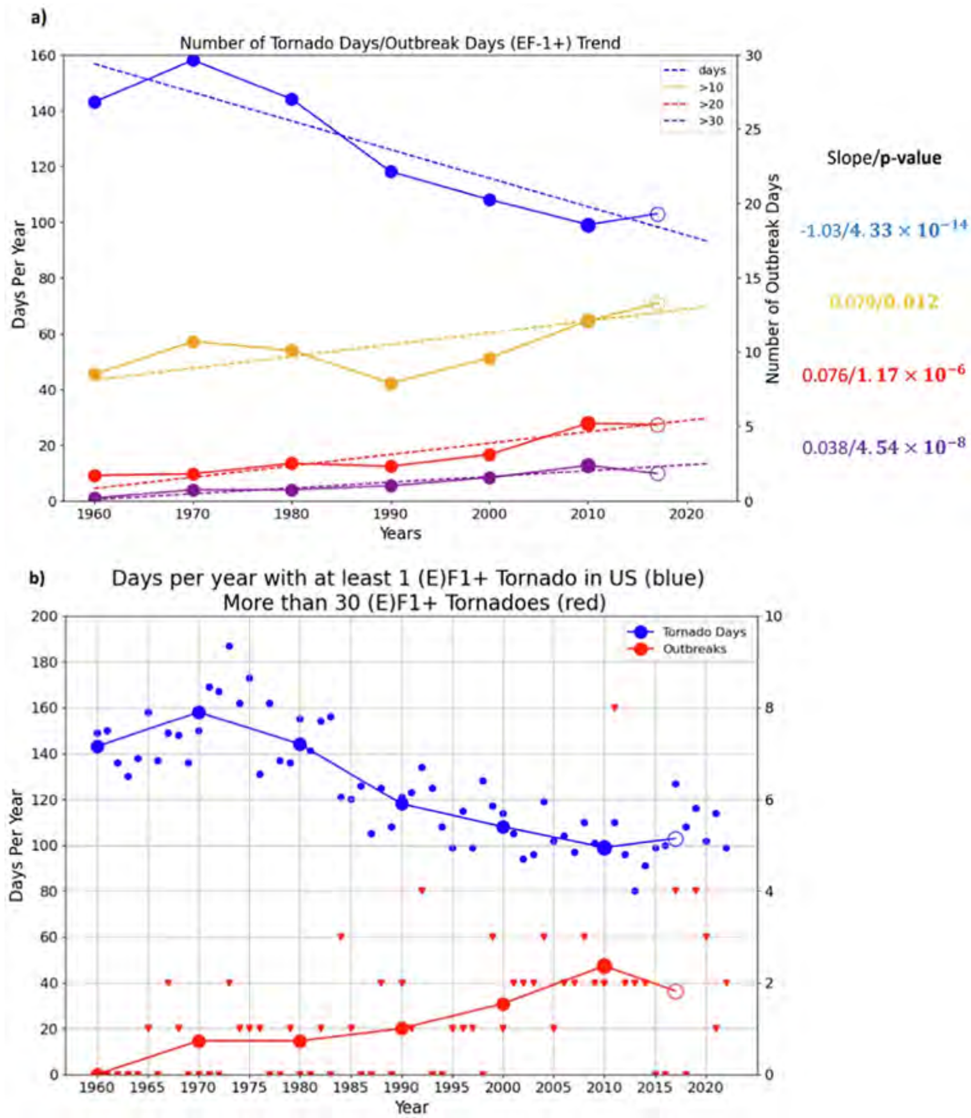


Figure 2.15. Linear trends (a) (dashed lines) of tornado days and of tornado outbreak days with >10, >20, and >30 (E)F-1+ tornadoes with corresponding slopes/p-values. The (b) number of days per year with at least one (E) F-1+ tornado (small circles) and >30 (E)F-1+ tornadoes (small triangles)1. Large circles and solid lines are decadal means centered on the decade (e.g., 1965–1975 for 1970). The open circles represent the final decadal mean taken in 2017 (i.e., 2012–2022). (Source: Graber et al., 2024, http://creativecommons.org/licenses/by/4.0)

Tornadoes and hail

Changes in small-scale, short-lived weather events, such as thunderstorms, tornadoes, and hail, are challenging to assess and have greater uncertainty than other aspects of the environment like larger-scale temperature changes (Taszarek et al., 2021). On a global scale, scientists have low confidence (limited agreement or evidence in research findings) in observed trends in tornadoes and hail due to inadequate observation networks and inconsistencies in observational practices (Seneviratne et al., 2021).

In the U.S., recent research suggests that the average annual number of tornadoes has remained relatively constant since 1950 (Coleman et al., 2024; Guo & Bluestein, 2016). Other research indicates that while tornadoes are occurring less frequently, the number of tornadoes occurring in outbreaks is increasing (Figure 2.15) (Gensini & Brooks, 2018; Graber et al., 2024). A recent example is the April 26, 2024, outbreak in Nebraska and Iowa, which saw 25 tornadoes (NOAA NWS, 2024). Data also show a change in the seasonality of tornadoes, with fewer warm-season (March to

August) tornadoes in the Great Plains. Nebraska has lost about one tornado day per decade over the period 1960–2022 (Moore, 2018; Coleman et al., 2024; Graber et al., 2024). Meanwhile, tornadoes in parts of the Midwest and Southeast are showing increasing trends, particularly in the cool season, suggesting an eastward shift in "Tornado Alley" (Figure 2.16) (Gensini & Brooks, 2018; Graber et al., 2024).

Thunderstorms are associated with other important hazards, including hail and lightning. As with tornadoes, identifying trends for these hazards is challenging due to observer biases, the limited length of the record, and changes in the observing systems (Stevens et al., 2023). However, days with environmental conditions favorable for producing large hail—greater than two inches in diameter or about the size of a pool ball—have become more frequent over the central and eastern parts of the U.S. (Figure 2.17) (B. Tang et al., 2019).

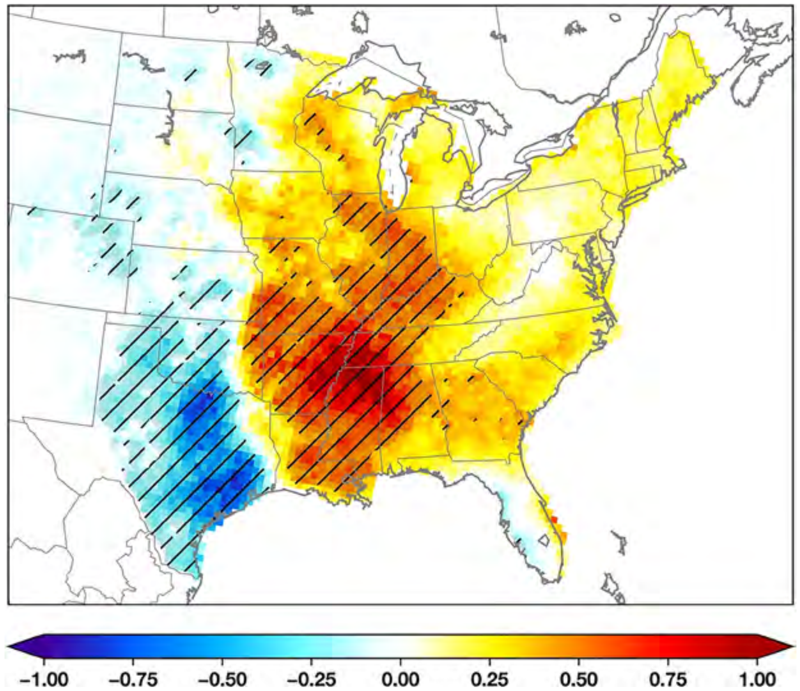


Figure 2.16. Tornado environment frequency trends. Warm colors indicate increasing trends in tornado frequency based on the analysis of the Significant Tornado Parameter, an index that relates environmental conditions to tornado occurrence. (Source: Gensini and Brooks, 2018, http://creativecommons.org/licenses/by/4.0)

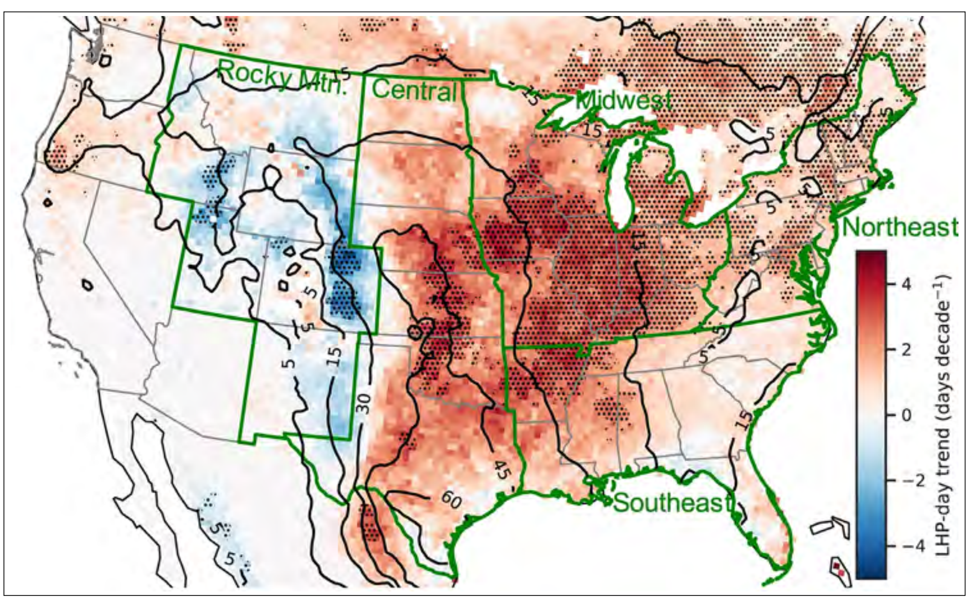


Figure 2.17. Hail environment frequency trends for hail greater than 2 inches. Shading represents trends in the number of days, with warm colors indicating increasing trends in hail frequency based on the analysis of the Large Hail Parameter. This index relates environmental conditions to hail size. (Source: Tang et al., 2019, http://creativecommons.org/licenses/by/4.0)

Summary of observed changes across the U.S.

Table 2.1 summarizes the observed changes in climate across the U.S. and the corresponding confidence level as indicated in the Fifth National Climate Assessment (Box 1.3). Confidence levels are based on the amount of evidence and the level of consensus (Marvel et al., 2023).

Table 2.1. Observed changes in the U.S. climate and the associated confidence level.

Note: Confidence levels align with those indicated in the Fifth National Climate Assessment (Box 1.3), reflecting the amount of evidence and level of consensus. (Marvel et al., 2023)

OBSERVED CHANGE	CONFIDENCE
Observed warming over the continental United States and Alaska is higher than the global average.	High confidence
Heat waves have become more common and severe in the West since the 1980s.	High confidence
Drought risk has been increasing in the Southwest over the past century.	Very high confidence
Rainfall has become more extreme in recent decades, especially to the east of the Rockies.	Very high confidence
Hurricanes have been intensifying more rapidly since the 1980s, causing heavier rainfall and higher storm surges.	Very high confidence
Over the past few decades, more frequent and extensive wildfires have been burning in the West.	Very high confidence
Tornado outbreaks have become more frequent, tornado power has increased, tornado activity is increasing in the fall, and Tornado Alley has shifted eastward.	Low confidence, but evidence is increasing.
Changes in extreme events are driven by human-caused climate change	Increasing confidence

Events outside Nebraska caused by climate change impact our state

Earth is a complex, interconnected system, meaning changes in faraway regions affect the U.S. and Nebraska. Direct climate impacts refer to the immediate and observable effects of climate changes, like rising temperatures, increased precipitation, or more extreme weather events. In contrast, indirect climate impacts are the cascading effects that occur because of these direct changes. They often affect ecosystems, food chains, and human societies in more complex ways, potentially even exceeding the severity of the initial direct impact. Examples are highlighted in Case Study 1, "Warming in the Arctic Causes Heat Waves and Cold Snaps in Nebraska," and Case Study 2, "Warming and Cooling in the Tropics Affects Nebraska's Temperature and Precipitation," which demonstrate how changes in the Arctic and tropics cause direct impacts to Nebraska's weather and climate by altering atmospheric circulation.

Figure 2.18. The cascading impacts of climate change. (Adapted from Youmshajekian & Fragapane, 2024)

The effects of climate change are complex and interconnected with society

The interconnectedness of the Earth's climate system with society can lead to cascading effects. Changes in one area can significantly impact others and impact national security, water availability, human health, economic stability, and migration patterns. Outcomes can be unpredictable and significantly disrupt the social systems we rely on, leading to a cascade of issues across different sectors of society (Figure 2.18). The most vulnerable populations often experience the harshest consequences (Chapter 12). Three case studies demonstrate how initial direct climate impacts lead to indirect impacts that affect society and ecosystems in complex ways. Each relates to Nebraska. Case Study 3 discusses how climate change threatens national security. Case Study 4 highlights the cascading and surprising effects of hurricanes. Finally, Case Study 5 features wildfires in Nebraska.

Case studies

Case Study 1: Warming in the Arctic causes heat waves and cold snaps in Nebraska

A jet stream is a narrow band of strong winds in the upper atmosphere. Located between four and eight miles above the Earth's surface, they can reach more than 275 miles per hour. Jet streams exist in both the Northern and Southern hemispheres and are formed at the boundaries between warm air near the equator and cold air at the poles. The jet stream's location and seasonal movement drive weather patterns, shift storm tracks, and cause temperature extremes. For example, when the jet stream dips southward, it brings cold Arctic air into lower latitudes, causing winter cold snaps. When it moves northward, warm air from the tropics may flow into regions that typically experience cooler weather.

Research suggests climate change influences the behavior of jet streams (Francis & Vavrus, 2015). As the Arctic warms up to four times faster than the global average (Rantanen et al., 2022), temperature differences between the cold polar regions and warmer air to the south break down, leading to a weaker and more wavy jet stream (Figure 2.19). This can result in extreme weather events like the prolonged heat wave over North America in August 2023 (Figure 2.20) (Doermann, 2023). This heat wave shattered high-temperature records across the central U.S., affected millions of people, burned crops to a crisp, killed hundreds of cattle in Nebraska and Kansas, and strained utility providers, including record energy usage in Lincoln (Bernt, 2023;

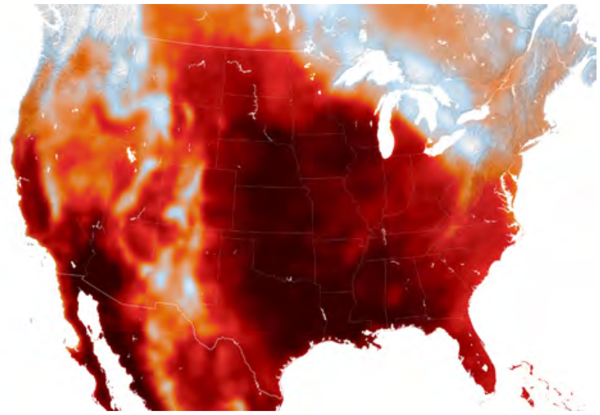


Figure 2.20. Air temperatures at 6.5 feet above the ground at approximately 3:00 p.m. Central Daylight Time on August 23, 2023. Image produced by combining satellite observations with temperatures predicted by a version of the Goddard Earth Observing System (GEOS) model. The darkest reds indicate areas where temperatures exceeded 104°F. (Source: Doermann, 2023, NASA Earth Observatory image by Lauren Dauphin, using GEOS-5 data from the Global Modeling and Assimilation Office at NASA GSFC)

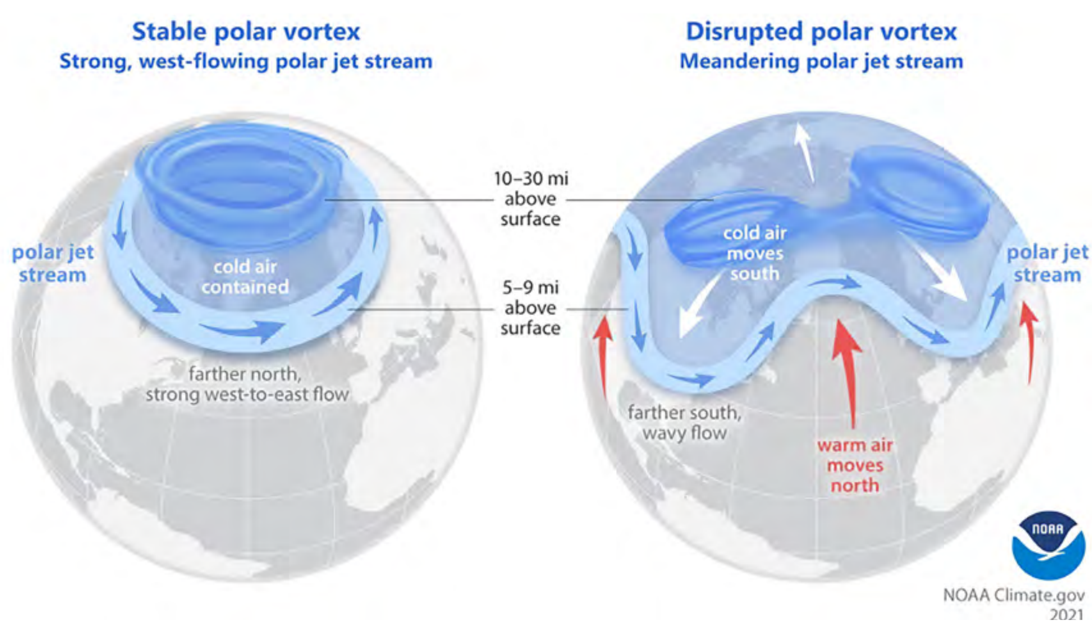


Figure 2.19. When the Arctic warms, the jet stream weakens and becomes more wavy, allowing cold Arctic air to move to the south and warm tropical air to move to the north. (Source: Lindsey, 2021)

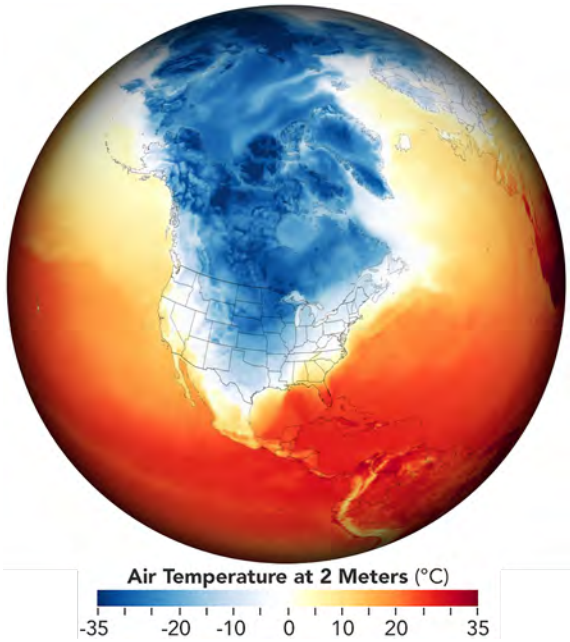


Figure 2.21. Record cold in mid-February 2021. (Source: NOAA NWS, 2021)

Hunt, 2023; NOAA NCEI, 2023; USDA FSA, 2023). In winter, a slower, wavier jet stream can cause severe winter weather outbreaks, such as the February 2021 Arctic Blast (Figure 2.21), which brought snow, ice, and extremely cold temperatures to the central U.S. Frigid Arctic air spilled southward over the U.S. as far as the Gulf Coast. Temperatures as much as 50°F below average strained the power grid and froze pipelines, leading millions to lose power for days, killing nearly 300 people, and costing an estimated $27.2 billion. That week, cities in Nebraska, including Lincoln (-31°F), Valentine (-33°F), North Platte (-29°F), and Broken Bow (-33°F), set daily record low temperatures. The lowest temperature reported in the state was Imperial at -39°F, while the warmest was -13 °F in Elgin. The brutally cold temperatures, dangerous wind chills, and heavy snow created hardship for livestock and impacted residents as rolling blackouts were implemented in response to increased power demand (Beach, 2024a; Diaz, 2021; NSCO, 2021; NOAA NWS, 2021).

Case Study 2: Warming and cooling in the tropics affects Nebraska's temperature and precipitation.

Changes in sea surface temperatures in the tropical Pacific Ocean have far-reaching impacts on regional temperature and precipitation because they can change atmospheric circulation. The El Niño–Southern Oscillation (ENSO) is a natural climate phenomenon that occurs when the ocean and atmosphere work together to cause fluctuations in the global climate. ENSO consists of three phases: El Niño (warm phase), La Niña (cool phase), and ENSO-neutral. During an ENSO event, the surface temperature of the tropical Pacific Ocean warms (or cools) by 1.8°F to 5.4°F compared to normal phases, then swings back and forth every two to seven years on average. They vary in intensity and duration, impacting global circulation patterns such as the position of the Pacific jet stream, which serves as a large driver of weather across the United States (Figure 2.22).

The ENSO is linked to changes in temperature and precipitation across the globe. In general, ENSO-related temperature and precipitation impacts across

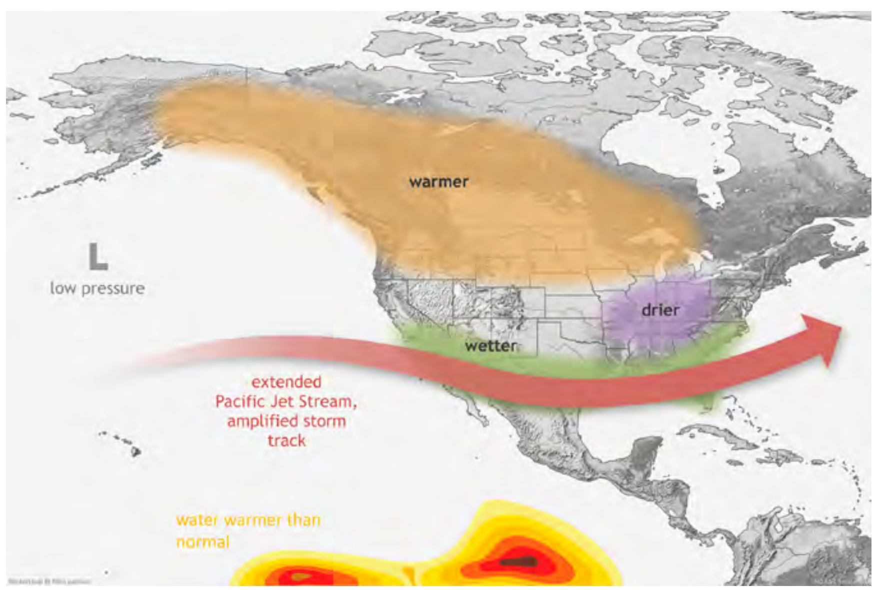


Figure 2.22. The typical impacts of El Niño and La Niña on U.S. winter weather. During El Niño, the jet stream tends to shift southward and steer storms across the southern third of North America. During La Niña, the jet usually shifts toward the poles. (Adapted from Climate.gov, 2016)

the United States are strongest during the cold half of the year (October through March). ENSO events heavily influence temperature and precipitation across the U.S.-affiliated Pacific islands and continental U.S. regions. During El Niño events, when tropical ocean temperatures are warmer than average, winter temperatures in Nebraska are typically warmer, and precipitation is higher than average (Figure 2.23) (NOAA NWS, n.d.). This tendency is stronger in the southern half of the state. During La Niña events, when tropical ocean temperatures are colder than average, winter temperatures in Nebraska are typically cooler, and precipitation is lower than average. (Lee et al., 2023; Zhang et al., 2024). El Niño and La Niña events are not simple mirror images of one another. They exhibit asymmetry in their spatial pattern, seasonal evolution, and duration (Cole et al., 2002). For example, El Niño events tend to be shorter-lived (about 9 to 2 months), while La Niña events can persist for 2 to 3 years.

Scientists have linked multiyear La Niña events to an increased probability of drought events in the Great Plains (Okumura et al., 2017; Zhang et al., 2024). For example, the historic 2012–13 drought (Figure 2.24) followed back-to-back La Niña events (NDMC, 2024; Rippey, 2015). Likewise, the 2022–23 drought followed nearly three consecutive years of La Niña events. Both droughts negatively affected agricultural productivity, leading to the worst and second-worst years in the state's wildfire history (Martens, 2017; Nebraska Farm Bureau, 2023; NFS, 2022; Rippey, 2015).

Other weather and climate events linked to ENSO include heavy rainfall events, the timing and magnitude of tornado season, and the frequency of hail events (Allen et al., 2015; Dommo et al., 2024). These links do not mean particular weather and climate events will occur with every ENSO event. Each event is somewhat different due to the tropical sea surface temperature pattern and strength, the shifting of the jet stream, and random climate variability. In other words, the effect of an ENSO phase on Nebraska is not absolute; instead, it increases the odds of particular weather and climate conditions.

In addition to changing regional weather and climate, El Niño events can increase global temperatures as warmer waters in the tropical Pacific Ocean release heat into the atmosphere, increasing global average temperatures. Conversely, the La Niña phase of ENSO usually results in cooler global temperatures. Generally, the warmest year of any decade will be an El Niño year, and the coldest a La Niña one. For example, El Niño contributed to record-breaking global temperatures in 2023 (Blunden & Boyer, 2024). While La Niña tends to cool global temperatures, it is not enough to offset global warming. Evidence suggests that ENSO characteristics are changing, with climate change compounding its impacts (McPhaden et al., 2020). Instrumental and paleoclimate records show that the strength and frequency of high-magnitude strong ENSO events have increased since the 1950s and possibly as far back as 1400 (Lee et al., 2023). In recent La Niña years, global-averaged temperatures have been warmer than El Niño years in earlier decades (Allen et al., 2015). These findings suggest that scientists may need to revisit and revise the frameworks and models used to understand and predict ENSO and its impacts (Yu et al., 2017).

Case Study 3: Climate change risks to national security

The Arctic region provides a vivid example of the interconnection of climate change with society, even in places seemingly far away. Here, temperatures are increasing at a rate more than twice that of the rest of the world, glaciers and ice sheets are melting, and sea levels are rising. This rapidly changing region poses new risks for national security as the Arctic becomes warmer and increasingly navigable due to receding sea ice, adding to the military risks already present (Goodman, 2021). For example, China and Russia are already working together to develop Arctic shipping routes as Russia seeks to deliver more oil and gas to China amid Western sanctions (DOD, 2024a). The Pentagon also reports that China is looking to leverage "changing dynamics in the Arctic to pursue greater influence and access, take advantage of Arctic resources, and play a larger role in regional governance" (DOD, 2024b). China and Russia have also increased their military cooperation with joint exercises in the Arctic in 2022 and 2023. The increasing politicization of the Arctic with climate change introduces significant uncertainties to peace and stability in the region.

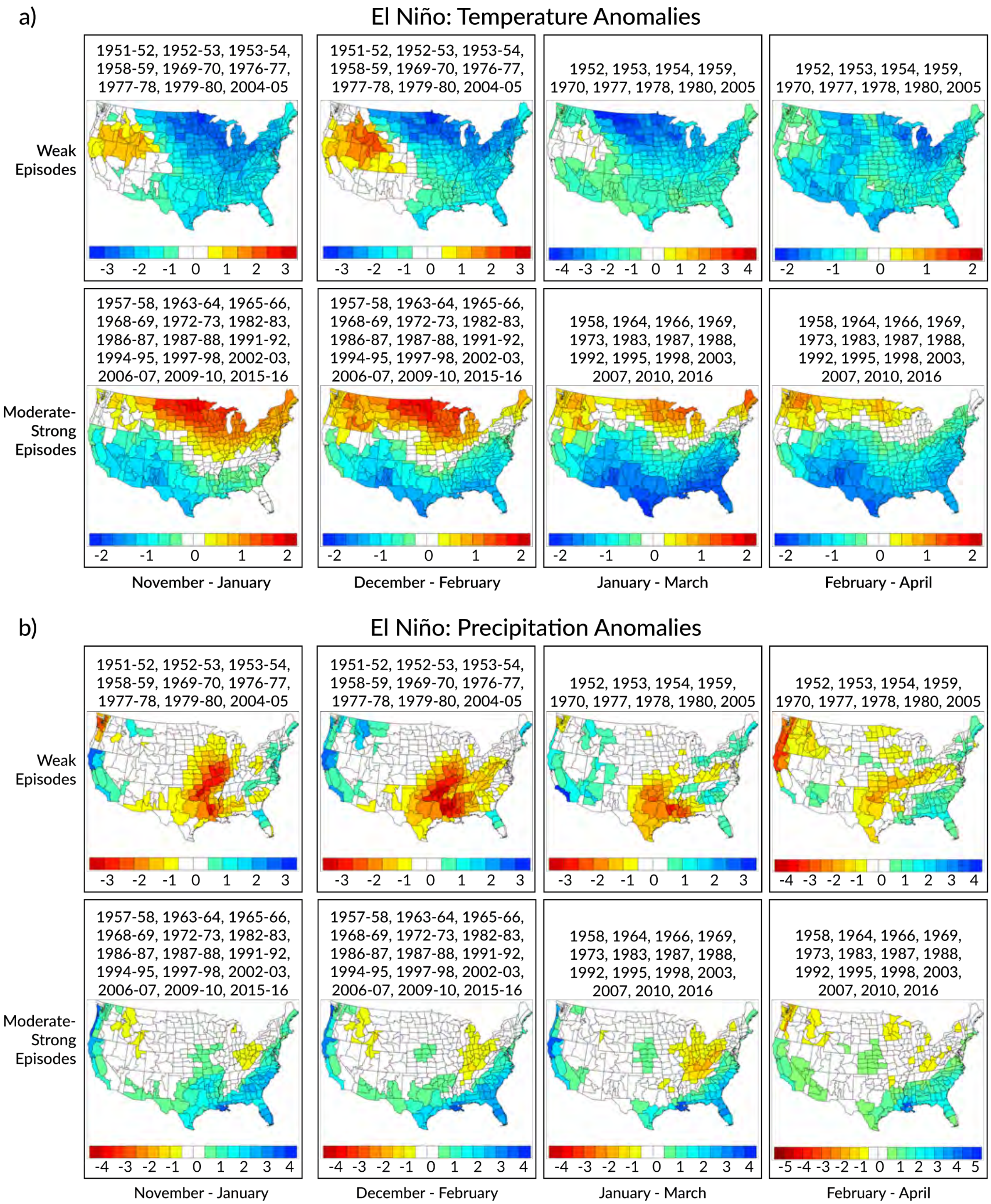


Figure 2.23. The three-month averaged (a) temperature and (b) precipitation anomalies from November through April for weak, moderate, and strong El Niño episodes since 1950. The anomalies are based on the official 1981–2010 normals. These composites are not intended to be a forecast of expected conditions; instead, they use historical data to highlight locations where ENSO can potentially impact temperature and precipitation. (Source: NOAA NWS, n.d., National Weather Service, Newport/Morehead City, NC, Forecast Office)

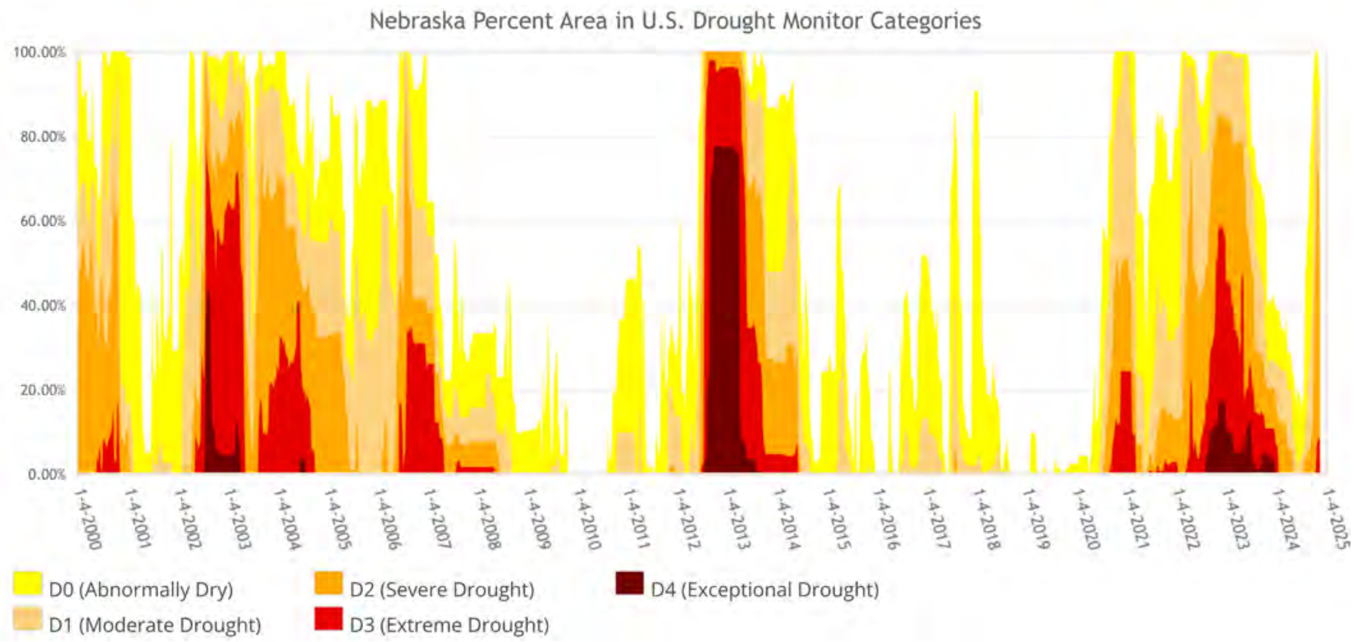


Figure 2.24. U.S. Drought Monitor Time Series. (Source: NDMC, 2024)

U.S. military forces must be prepared to respond in this remote region. Home to Offutt Air Force Base, with over 6,500 active-duty personnel and over 8,500 National Guard and reserve members at units around the state (Military One Source, 2024), Nebraska would likely feel the consequences of increased tensions. Military personnel from Offutt and from National Guard units in the state train in the Arctic to test readiness in the event of an emergency or threat (Bingaman, 2007; Tourtellotte, 2023). Research documents the impacts on the health and well-being of military personnel and their families as well as the economy of surrounding communities, including sectors such as food, housing, retail, transportation, health care, and entertainment (Board on the Health of Select Populations et al., 2013; Gregory, 2008; Kriesel & Gilbreath, 1994).

Responding to climate crises redirects time, attention, and resources away from the military. For example, in the past two years alone, U.S. troops have deployed domestically more than 70 times in response to climate-related hazards, including fighting fires, rescuing citizens from floods, or delivering water (Sikorsky, 2024). The U.S. Department of Defense also noted, "The number of personnel days the National Guard spent on firefighting increased from 14,000 in the fiscal year 2016 to 176,000 days in fiscal 2021. . . . That is more than twelve-fold in just five years" (Garamone, 2023). This demand is almost certain to grow as temperatures rise.

Additionally, climate change directly affects the military's critical infrastructure (DOD, 2024c). In 2019, Offutt Air Force Base was hit by a devastating flood, crippling parts of the base, displacing personnel, and causing millions of dollars in damage (Losey, 2020). This marked the second time in less than 10 years (also in 2011) that flooding threatened base operations (Hasemyer, 2019). While climate change's exact role in the 2019 Nebraska floods is not clear, scientists worldwide agree that the science is clear: climate change is making natural disasters more frequent, stronger, and longer (IPCC, 2023a).

As the U.S. confronts more frequent and intense climate-driven threats at home and abroad, damage and disruptions to military facilities and capabilities have implications for the readiness of our armed forces (NATO, 2023). Attention is diverted away from readiness and preparation for future threats and is instead focused on dealing with urgent crises related to extreme weather and climate events (Garamone, 2023). In addition, military forces will need to operate in more extreme climate conditions, facing demanding operational requirements (NATO, 2023).

Case Study 4: The widespread and long-lasting toll of hurricanes

When a hurricane makes landfall, heavy rainfall, strong winds, storm surge, and flooding cause tremendous damage to coastal communities; trees and powerlines are downed; buildings, roads, and bridges are destroyed; beaches are eroded; and injuries and loss of life occur. Since 1980, 66 hurricanes have impacted the U.S., costing an estimated $1.5 trillion in damages and over 7,000 deaths. Impacts cascade throughout communities, ripple out to a larger geographic area, and linger long after the event (NOAA NCEI, 2024c).

When hurricanes cause transportation systems to collapse—due to port closures, impassable roadways, and flight cancellations— so do supply chains (Kim & Bui, 2019). Floods in North Carolina caused by Hurricane Helene in September 2024 damaged a facility that produces about 60% of the intravenous (IV) fluids in the U.S. (Fortiér, 2024). The company had to stop production, which led to shortages. Hospitals across the country were forced to ration supplies and cancel surgeries. At Nebraska Medicine, doctors used about half of the IV fluid they would typically use, while rural hospitals in Nebraska were forced to cancel surgeries (Parsons, 2024; Ricketts, 2024).

Hurricanes Katrina and Rita in 2005 severely damaged the Gulf of Mexico region, destroying and damaging oil and gas production facilities in the Gulf of Mexico. The hurricanes caused a complete shutdown of oil production and 80% of gas production in the gulf. Repairing the platforms, refineries, and pipelines took weeks to months. The oil and gas industry suffered huge losses, and economic repercussions were felt worldwide (Cruz & Krausmann, 2008). Significant price increases triggered a public outcry over price gouging. In Nebraska, gas prices rose more than 50 cents per gallon the week after Hurricane Katrina; only five states and the District of Columbia had higher prices (Jenkins, 2005).

When Hurricane Katrina made landfall in New Orleans, floodwaters submerged 80% of the city, and catastrophic damage occurred along the Gulf Coast states of Alabama, Mississippi, and Louisiana. As a result, over 1.5 million people were abruptly displaced from their homes (Serraglio & Adaawen, 2023). People fled to every state in the country, including 547 residents who moved to Nebraska (Figure 2.25) (Katrina +10, 2015). About one-third of evacuees did not return to the areas where they were living before the storm. More recently, in the aftermath of Hurricane Maria in 2017, an estimated 130,000 people left the island and U.S. territory of Puerto Rico (Acosta et al., 2020). Nebraska once again received people displaced by the hurricane damage. While data is still being analyzed for September 2024's Hurricane Helene, which left a trail of destruction across Florida, Georgia, the Carolinas, and Tennessee, tens of thousands of people were displaced. They struggled to access food, power, and water (White House, 2004). Sometimes, an inability to recover and rebuild turns a temporary displacement into a permanent move (Serraglio & Adaawen, 2023).

When disasters like Hurricane Helene strike, Nebraskans answer the call for help. In 2024, Nebraskans' hurricane response efforts included military deployments, search and rescue teams, emergency response communications teams, utility restoration crews, food distribution teams, and faculty and student volunteers (10-11 Now, 2024; Gonzalez, 2024a; Jones, 2024.; LES, 2024a; NEMA, 2024; Office of the Governor, 2024).

As the climate warms, Atlantic hurricane activity is changing. Higher ocean temperatures provide more energy for storms, making them stronger. Observations show more hurricane activity, stronger storms, faster intensification, higher rainfall amounts, and bigger storm surges (Gilford et al., 2024; Marvel et al., 2023; Reed & Wehner, 2023; K. Reed et al., 2022). Warmer ocean temperatures fuel stronger winds and heavier rainfall in storms, leading to more destruction when these storms make landfall. Climate change is also raising the sea level (Figure 2.25) by more than eight inches along the Gulf and East Coasts. Combined with stronger and larger storms, it can lead to more catastrophic storm surges. These effects are particularly evident in the Atlantic basin. Research shows that human-caused climate change intensified the maximum wind speeds of roughly 80% of hurricanes between 2019 and 2023, increasing their intensity by an average of 18 miles per hour (Figure 2.26) (Climate Central, 2024; Gilford et al., 2024).

Figure 2.25. Relative sea level change along U.S. coasts, 1960–2021. (Source: Congressional Budget Office, 2024)

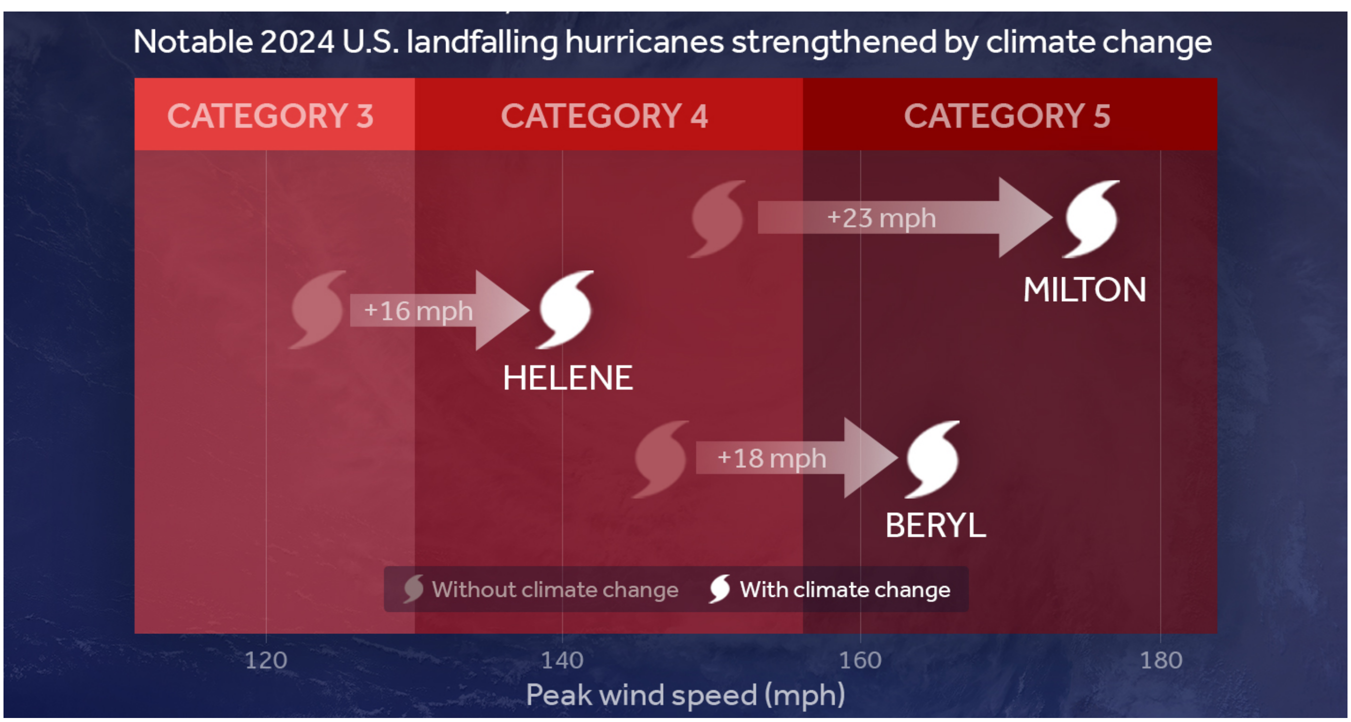


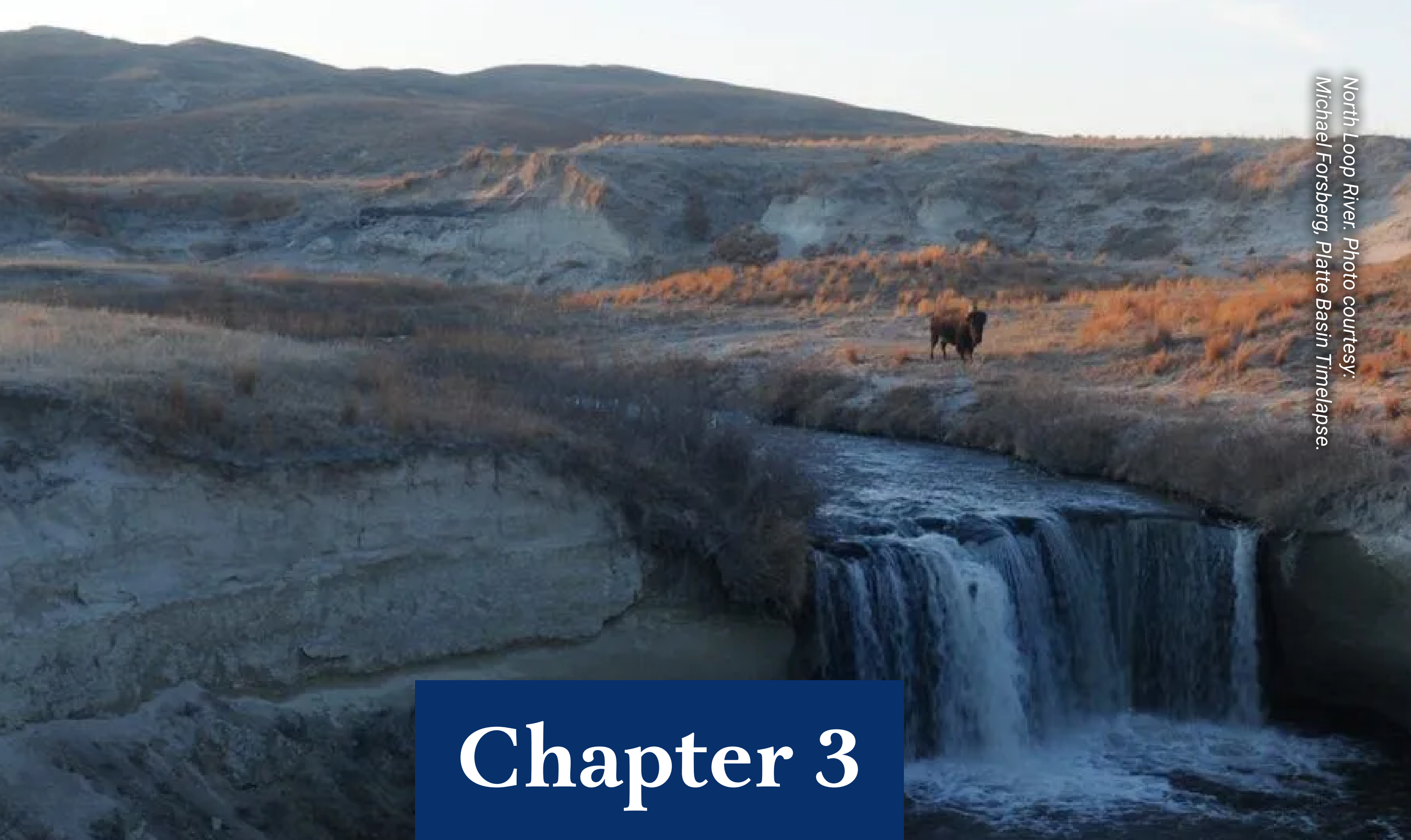
Figure 2.26. Change in peak wind speed and storm category due to climate-change-driven ocean-warming. (Source: Climate Central, 2024, http://creativecommons.org/licenses/by/4.0)

Nebraska National Forest after the October 2022 Bovee Wildfire. Photo courtesy: Marek Uliasz, Adobe Stock.

As climate change increases the threat from hurricanes, people across the U.S. must change how they perceive and prepare for storms. When storms intensify rapidly, communicating with, preparing for, and evacuating communities in time can be difficult. Additionally, as the climate continues to change and natural disasters grow, insurance companies are increasing the costs of policies, declining to renew policies, or exiting the market altogether (Congressional Budget Office, 2024).

Case Study 5: Nebraska wildfires

We do not have to look outside Nebraska to see how climate events can cascade through society. In 2012, 500,000 acres burned in Nebraska, making it the worst fire season in the state's recorded history (NEMA, 2012). This fire season coincided with the most severe summer drought in the observational record for that region (Hoerling et al., 2014). The hot, dry summer combined with high winds and low humidity led to an abundance of dry fuel in the form of parched cropland, prairies, and ponderosa pine stands. Firefighting included equipment from the Nebraska Army National Guard, mutual aid from more than 100 volunteer fire departments, and the response of hundreds of staff members from almost a dozen state agencies, with costs exceeding $12 million (NEMA, 2012). These fires reduced air quality, burned dozens of structures, destroyed power lines, changed the landscape, strained the resources of private landowners and rural fire departments, and highlighted the need for upgraded firefighting equipment (Stohs-Krause, 2012). Scientists partially attribute the unusually high temperatures (resulting in dry soil moisture) and vegetation accompanying this fire season to anthropogenic climate change (Diffenbaugh & Scherer, 2013). Nebraska's extraordinary 2012 fire season prompted changes in policy, such as the Nebraska Wildfire Control Act (Nebraska Revised Statues, 2013), which increased the capacity of the state, thereby helping to reduce risks and enhancing training and management efforts. In 2022, Nebraska experienced its second-worst fire season in decades, with over 250,000 acres burned (NFS, 2022). Again, the fire season coincided with record-breaking heat, drought conditions, and low soil moisture (Christian et al., 2023). Notably included were the scorching of nearly a quarter of Nebraska's National Forest, the death of a volunteer firefighter, the destruction of the State 4-H Camp and nearby Scott Lookout Tower, the temporary closure of Nebraska Highway 2, and the evacuation of a nearby community (Vaughan, 2022). Studies have found that climate change has increased wildfire season length and frequency and burned areas due to warmer springs, longer summer dry seasons, and drier soils and vegetation (Ostoja et al., 2023; Westerling, 2016). Similarly, increases in climate change–driven fire season frequency, extent, and severity are expected to continue (Leung, 2023).



North Loop River. Photo courtesy: Michael Forsberg, Platte Basin Timelapse.

Chapter 3

Observed Changes in Nebraska's Climate

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Key messages

1. Nebraska is getting warmer and wetter.
2. Over recent decades, June, September, and November have all experienced pronounced warming.
3. Annual precipitation trends have been weakly positive since the late 19th century; however, eastern Nebraska shows negative precipitation trends in summer.
4. Since 2000, all locations in the state have set at least one new monthly record for the warmest average temperature and at least one record dry or record wet month.
5. Warming winter temperatures have led to decreases in days with snow cover and a reduction in the number of heating degree days.

Introduction

This chapter assesses trends in the primary indicators of Nebraska's climate—average temperature and precipitation—for monthly, seasonal, and annual values.

Average climate

Nebraska is a landlocked U.S. state with a continental climate that naturally experiences significant variability. Extremes of temperature and precipitation are not uncommon. While generally considered flat, the state gains over 4000 feet in elevation from east to west. This elevation gradient, combined with decreasing access to moisture from the Gulf of Mexico in western Nebraska, increases precipitation from west to east across the state. This gradient in precipitation is sharper across the state of Nebraska than it is from Omaha to New York. Thirty-year averages and statistics of key climate observations are called climate normal. Climate normals help put the weather into proper context. It is how we judge whether the temperature, rainfall, and other climate conditions are normal for a given location. The current reference period is 1991–2020. This period is updated every 10 years, and new climate normals are calculated. The once-per-decade update also means that climate normals gradually reflect the "new normal" of climate change caused by increasing greenhouse gas emissions.

Temperature

Nebraska has cold winters and warm to hot summers. January is the coldest month on average, and July is the warmest month. Temperatures in the winter tend to be warmer in western Nebraska, where it is sunnier, and downslope winds from the Rockies can elevate temperatures. Temperatures of -20°F or colder occur with more regularity in the northern and western sections of the state. Temperatures in the summer are often warmest in southeast Nebraska, where higher humidity keeps minimum temperatures warmer. Temperatures above 95°F occur statewide but are most frequent in southwest Nebraska. The annual average temperature across the state ranges from the mid 40s in northwest Nebraska to the lower 50s across southeast Nebraska (Figure 3.1).

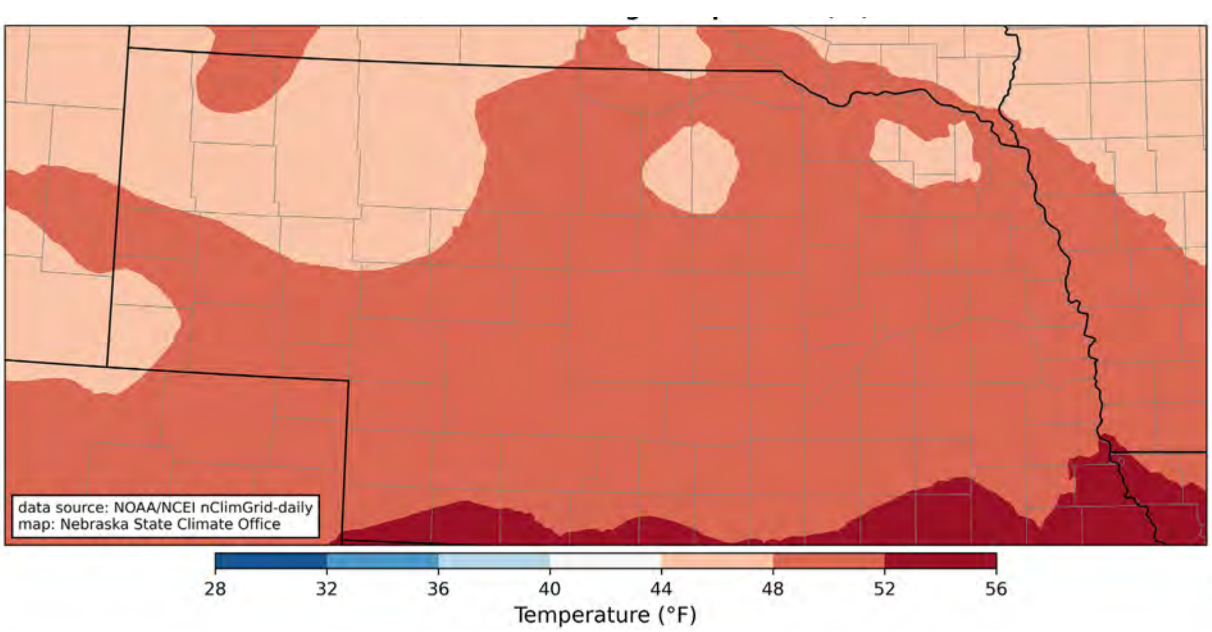


Figure 3.1. Nebraska's annual average temperature from the NCEI 1991–2020 normals. (Source: NOAA NCEI, n.d.)

Precipitation

The annual average precipitation in Nebraska ranges from under 15 inches in the western Panhandle to around 36 inches in the far southeast corner (Figure 3.2). Precipitation falls year-round in the state but peaks in May and June and is lowest in January. Precipitation is also highly variable, with periods of drought and excessive precipitation occurring with some regularity statewide. Some of the annual precipitation falls as snow during the cold season, with a higher percentage occurring as snow in the Panhandle.

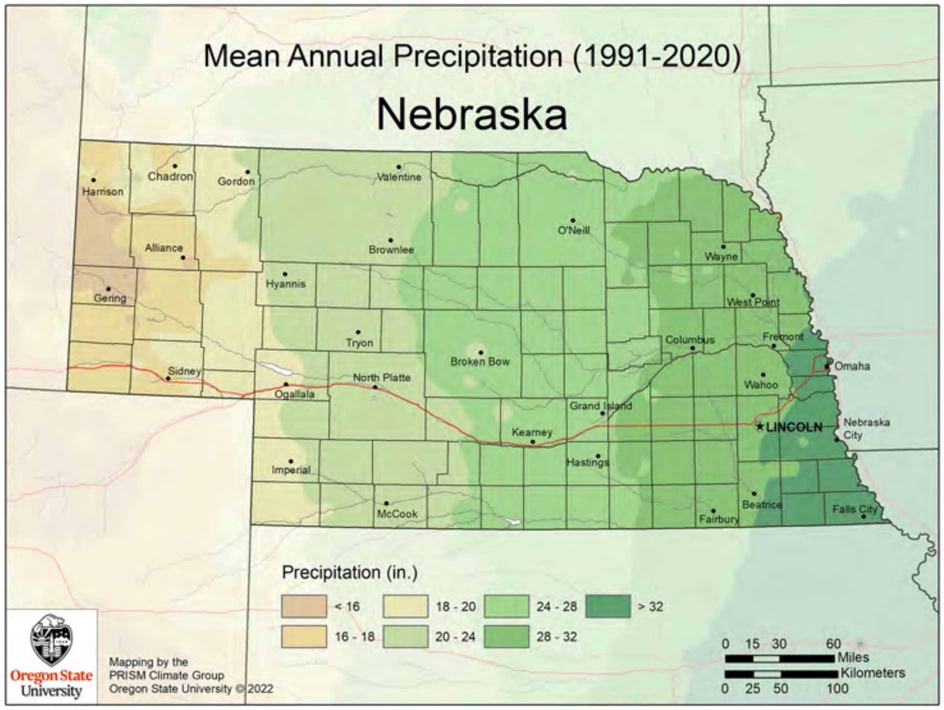


Figure 3.2. Annual average precipitation for the 1991–2020 period. (Source: PRISM Climate Group, 2022)

Data and reference periods

Data used to calculate trends in this report are from NOAA's National Center for Environmental Information and the Applied Climate Information System (ACIS) (Hubbard et al., 2004) unless otherwise specified. The trends discussed in the report are broken into two separate analysis periods for temperature and precipitation: long term (1895–2023) and short term (1980–2023). The former covers the entire observational record. The short term coincides with our satellite period of record. Additionally, each section on seasonal trends contains figures referencing the period from 1895 to 1960 compared to the last thirty years (1994–2023). This follows the practice established in the National Climate Assessment (Marvel et al., 2023).

Climate divisions

Nebraska has a total of eight climate divisions, as assigned by the old U.S. Weather Bureau in the early part of the 20th century. The skipping of the number 4 is a mystery. Figure 3.3 (right) shows the geographic breakdown of the climate divisions. The National Center for Environmental Information determined climate divisions to be areas in the state having common climate characteristics (NOAA NCEI, 2024b).

Figure 3.3. Nebraska's climate divisions as determined by the National Centers for Environmental Information. (Source: NOAA NCEI, 2024b)

Trends

Annual

Annual average temperatures have been increasing at a rate of ~0.016°F per year since 1895, and the rate of temperature increase has doubled since 1980 (Figure 3.4), with a rate of 0.034°F/year. The five-year moving average temperature had periods of below and above average for most of the 20th century. For example, the 1930s and 1950s were consistently above the 20th-century average, and the 1960s and 1970s were generally below it. However, the oscillating periods of below- and above-average temperatures began to end in the early 1980s as temperatures throughout the 1980s and 1990s were generally above the 20th-century average. Since 2000, the five-year moving average has been above the long-term average. Furthermore, four of the top 10 warmest years on record in Nebraska have occurred since 2006, with 2012 being the warmest on record for the state. Only four years since 2000 (2008, 2009, 2018, 2019) have been cooler than the 20th-century average, and no year in the 21st century has been ranked in the top 25 coldest, dating back to 1895.

Precipitation has also increased since the late 19th century at a rate of 0.012 inches/year, a rate that has increased slightly to 0.014 inches/year since 1980 (Figure 3.5). Neither precipitation trend was statistically significant. Like temperatures, precipitation across the state has been highly variable, with distinct wet and dry periods. Precipitation has generally been above historical averages over the past 25 years in Nebraska (Flanagan & Mahmood, 2021), which is reflected in the persistence of the five-year running average being above the 20th-century average so far in the 21st century (Flanagan & Mahmood, 2021). However, during the 21st century, the state has also experienced two extreme drought events (2012 and 2022) that had a sizable impact on the state's water resources, including groundwater. Annual average temperatures in each climate division in the state from 1994 to 2023 were at least 1.0°F warmer compared to the 1895 to 1960 period (Figure 3.6). The biggest increase (1.9°F) was in the Panhandle, and the smallest was in south central Nebraska (1.0°F). The annual average precipitation was higher in each climate division, averaging 1.5 inches higher in north central, south central, east central, and northeast Nebraska (Figure 3.7).

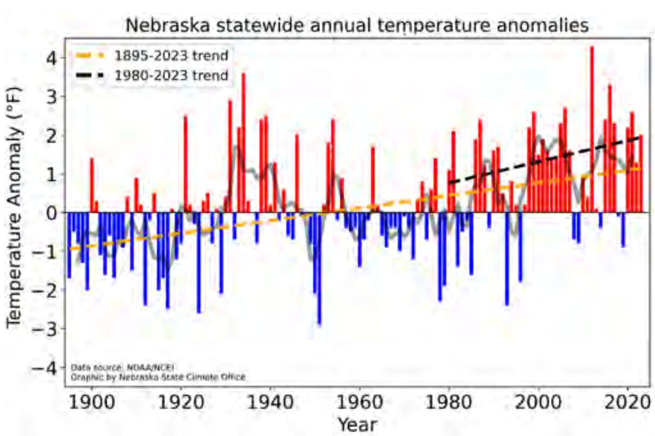


Figure 3.4. Time series of statewide annual temperature anomalies (red for warm, blue for cool) for the period from 1895 to 2023 with respect to the 20th-century average. It also shows temperature trends over the long term (1895–2023, orange dashed line) and the short term (1980–2023, black dashed line). The solid gray line denotes a moving five-year average.

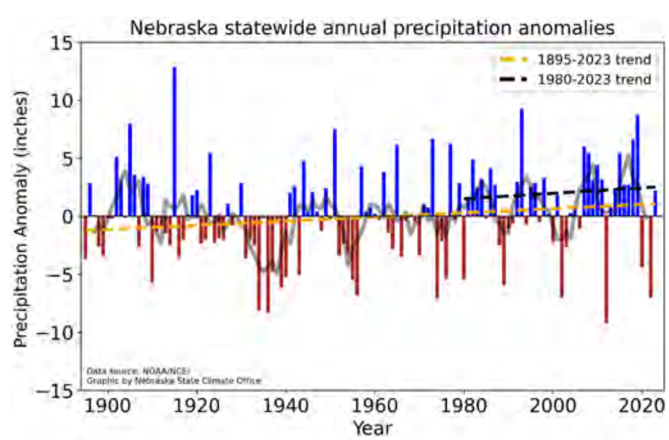


Figure 3.5. Time series of annual precipitation anomalies (blue for wet, brown for dry) for the period from 1895 to 2023 for the 20th-century average. It also shows precipitation trends over the long term (1895–2023, orange dashed line) and the short term (1980–2023, black dashed line). The solid gray line denotes a moving five-year average.

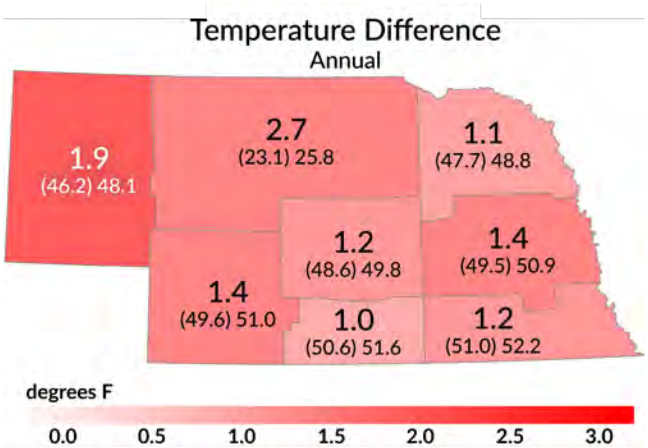


Figure 3.6. Average annual temperature difference from 1994 to 2023 compared to 1895–1960. The number in parentheses in row 2 represents the average temperature from 1895 to 1960, and the number outside of the parentheses represents the temperature from 1994 to 2023.

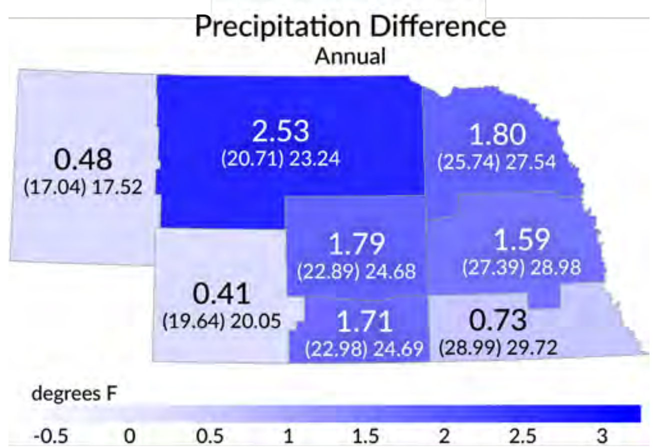


Figure 3.7. Average annual precipitation difference from 1994 to 2023 compared to 1895–1960. The number in parentheses in row 2 represents the average precipitation from 1895 to 1960, and the number outside of the parentheses represents the temperature from 1994 to 2023.

Winter

The winter season—defined climatologically as December, January, and February—has had the strongest warming signal of the four seasons, with an average temperature increase of 0.025°F/year since 1895. All climate divisions in Nebraska, except south central, were more than 2°F warmer in the winter months from 1994 to 2023 compared to 1895 to 1960 (Figure 3.8). Furthermore, the difference in temperature between 1994 and 2023 and 1895 and 1960 was larger in the winter than in any other season for all eight climate divisions in Nebraska. Precipitation changes in the winter have been more mixed. The Panhandle, west central, central, and northeast climate divisions have seen slight decreases in precipitation. In contrast, the north central, south central, southeast, and east central divisions have seen increases in precipitation (Figure 3.9). Statewide, short-term precipitation has increased while the long-term trend is flat (Figure 3.10).

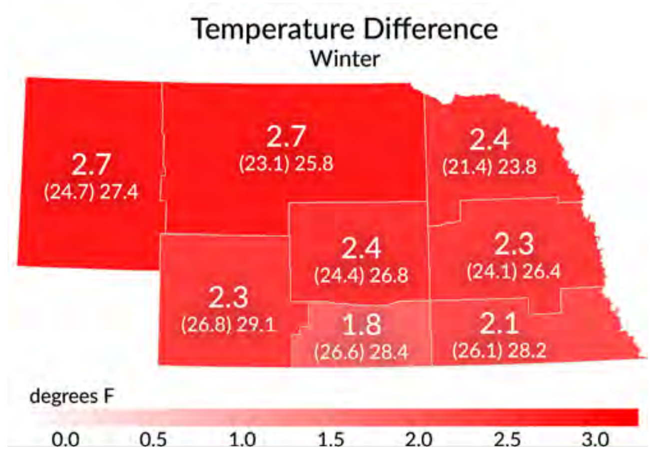


Figure 3.8. Average winter season temperature difference from 1994 to 2023 compared to 1895–1960. The number in parentheses in row 2 represents the average temperature from 1895 to 1960, and the number outside of the parentheses represents the temperature from 1994 to 2023.

While winter overall is warming (Figure 3.11), February has shown a cooling trend over the short term (Figure 3.12). Over the past few decades, there have been several Februarys with average temperatures well below the 20th-century average. This resulted in an overall negative trend in winter temperature over the short term. The five-year moving average has often been below the 20th-century average over the last 20 years. This negative trend is consistent across all climate divisions. The recent trend toward colder February temperatures has been linked to the increasingly erratic behavior of the polar vortex (Cohen et al., 2020; Cohen et al., 2021; Cohen et al., 2022), including the long stretch of bitterly cold weather in February 2021 that encompassed Nebraska and much of the central U.S. (Millin & Furtado, 2022) (Chapter 2, Case Study 1).

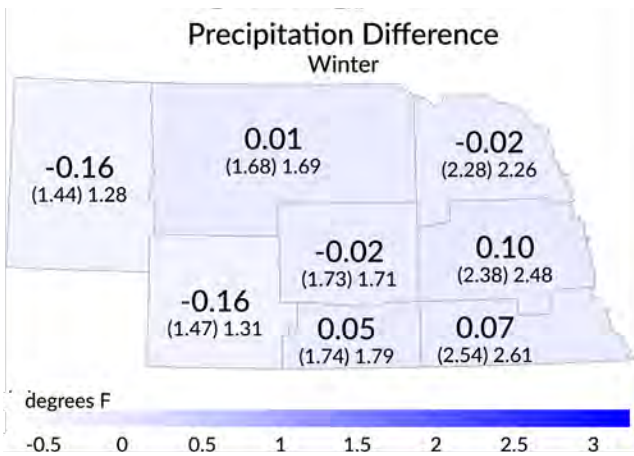


Figure 3.9. Average winter season precipitation difference from 1994 to 2023 compared to 1895–1960. The number in parentheses in row 2 represents the average precipitation from 1895 to 1960, and the number outside of the parentheses represents the temperature from 1994 to 2023.

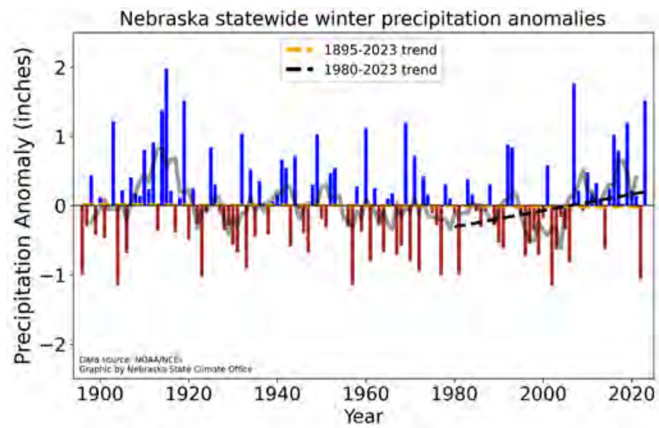


Figure 3.10. Time series of winter precipitation anomalies (blue for wet, brown for dry) from 1895 to 2023 with respect to the 20th-century average. It also shows precipitation trends over the long term (1895–2023; orange dashed line) and the short term (1980–2023; black dashed line). The solid gray line denotes a moving five-year average.

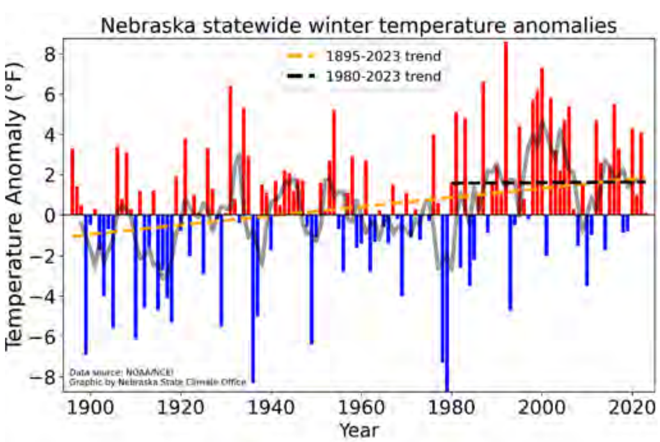


Figure 3.11. Time series of statewide winter temperature anomalies (red for warm, blue for cool) from 1895 to 2023 with respect to the 20th-century average. It also shows temperature trends over the long term (1895–2023, orange dashed line) and the short term (1980–2023, black dashed line). The solid gray line denotes a moving five-year average.

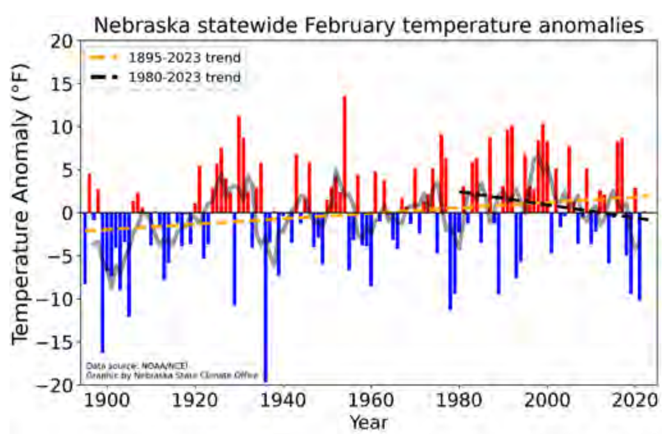


Figure 3.12. Time series of statewide February temperature anomalies (red for warm, blue for cool) for the from 1895 to 2023 with respect to the 20th-century average. It also shows temperature trends over the long term (1895–2023, orange dashed line) and the short term (1980–2023, black dashed line). The solid gray line denotes a moving 5-year average

Even though the overall rate of short-term warming in winter is not as significant as the other three seasons, other metrics show that the characteristics of winter have changed in the past few decades. For example, Figure 3.13 shows that most of Nebraska had at least four more days in a year above freezing in the period from 1991 to 2020 than over the period from 1951 to 1980, according to gridded NOAA data. This agrees well with the observed station data. For example, Lincoln and Valentine averaged seven and nine more days per year, respectively, above freezing yearly from 1991 to 2020 than from 1951 to 1980.

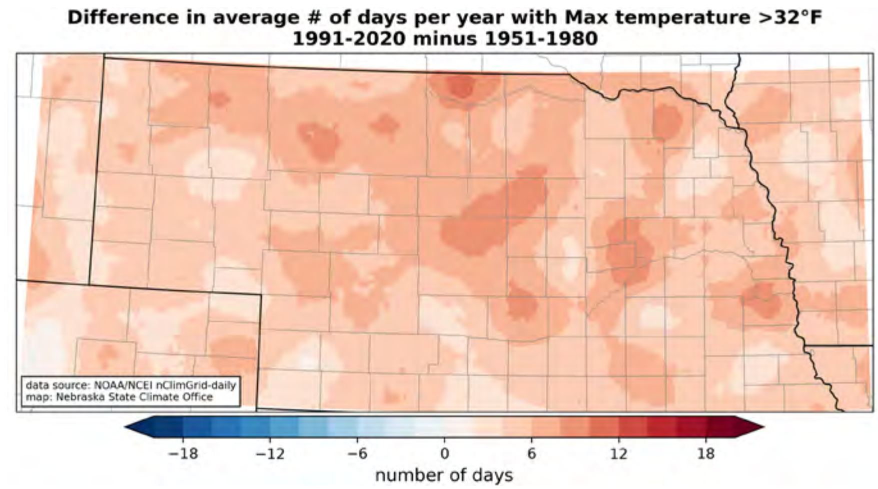


Figure 3.13. Difference in the average number of days per year with maximum temperatures above 32°F from 1951 to 1980 compared to 1991 to 2020.

Fall

Fall, defined climatologically as September to November, is becoming warmer over long- and short-term periods. This warming is especially pronounced over the short term, with a temperature increase of 0.067°F/year since 1980 (Figure 3.14). The short-term rate of temperature increase in the fall is considerably higher than the long-term rate of increase (+0.010°F/year). It is easily the most substantial rate of increase of any season over both analysis periods—short and long term. This short-term rate of temperature increase in the fall is statistically significant statewide and across all eight climate divisions. All climate divisions in the state were at least 0.7°F warmer in the period from 1994 to 2023 compared to the period from 1895 to 1960, and the southwest climate division was over 2°F warmer (Figure 3.15).

The short-term increased rate of warming in the fall is not equally distributed across the fall months. Instead, the enhanced short-term rate of warming is almost exclusively driven by September and November, when the statewide rates of temperature increase are 0.093°F/year and 0.095°F/year, respectively. By comparison, the rate of warming in October is comparably less at 0.017°F/year. September and November have statewide statistically significant increases over the short term. The increases in

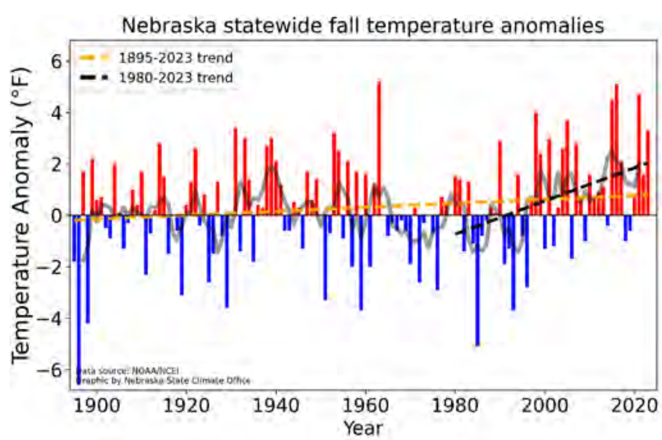


Figure 3.14. Time series of statewide fall temperature anomalies (red for warm, blue for cool) from 1895 to 2023 with respect to the 20th-century average. Also shows temperature trends over the long term (1895–2023, orange dashed line) and the short term (1980–2023, black dashed line). The solid gray line denotes a moving five-year average.

September are statistically significant for all eight climate divisions; only the southeast climate division does not have a statistically significant rate of temperature increase in November.

Fall precipitation is complicated. The long-term signal is weakly positive (Figure 3.16), and most state climate divisions were wetter from 1994 to 2023

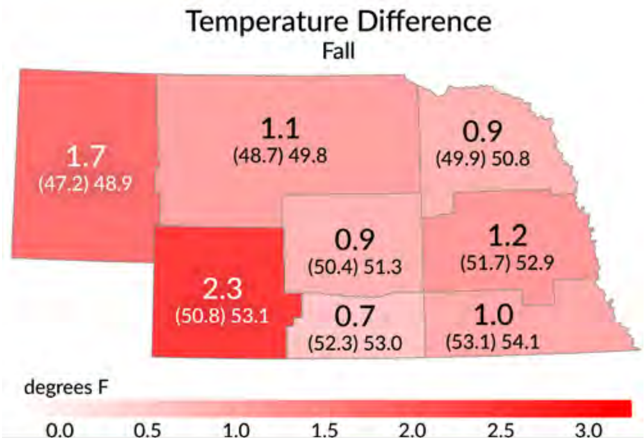


Figure 3.15. Average annual temperature difference in the fall season from 1994 to 2023 compared to 1895 to 1960. The number in parentheses in row 2 represents the average temperature from 1895 to 1960 period, and the number outside of the parentheses represents the temperature from 1994 to 2023.

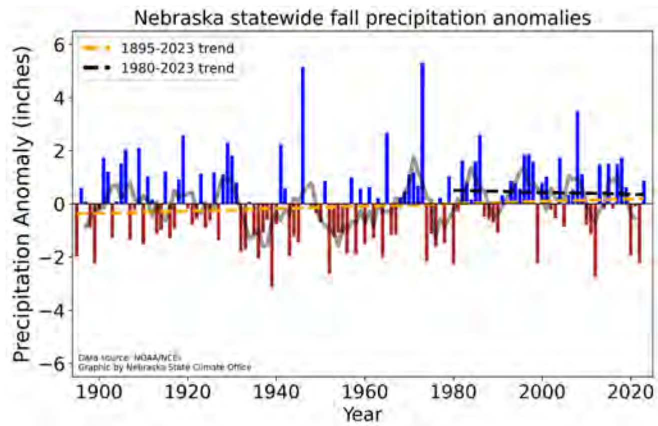


Figure 3.16. Time series of fall precipitation anomalies (blue for wet, brown for dry) from 1895 to 2023 with respect to the 20th-century average. It also shows precipitation trends over the long term (1895–2023, orange dashed line) and the short term (1980–2023, black dashed line). The solid gray line denotes a moving five-year average.

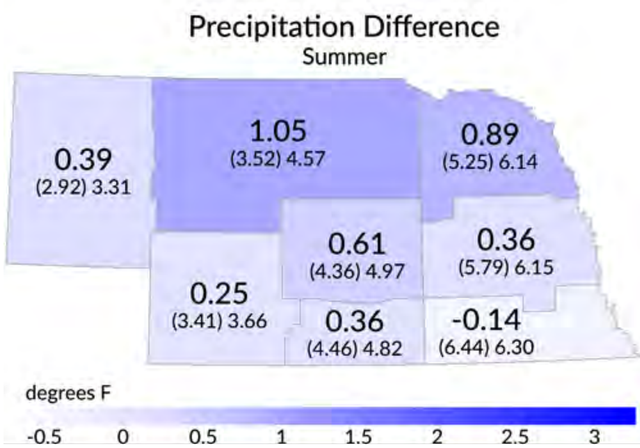


Figure 3.17. Average annual precipitation difference in the fall season from 1994 to 2023 compared to 1895 to 1960. The number in parentheses in row 2 represents the average precipitation from 1895 to 1960, and the number outside of the parentheses represents the temperature from 1994 to 2023.

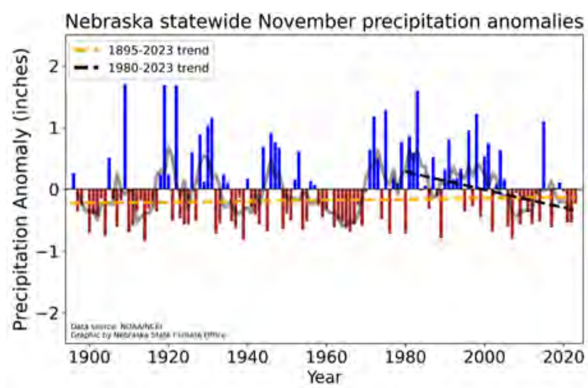


Figure 3.18. Time series of November precipitation anomalies (blue for wet, brown for dry) from 1895 to 2023 with respect to the 20th-century average. It also shows precipitation trends over the long term (1895–2023, orange dashed line) and the short term (1980–2023, black dashed line). The solid gray line denotes a moving five-year average.

compared to 1895 to 1960 (Figure 3.17). However, the statewide short-term trend in fall precipitation is weakly negative. This weak negative trend for fall is driven by the statistically significant downward trend of -0.015 inches/year in November in the short term (Figure 3.18). Historically, November in Nebraska has been variable, with prolonged stretches of below- and above-average precipitation.

Nevertheless, this downward trend is found in every climate division and is statistically significant in all climate divisions except the southeast. The downward trend in the short term has been driven exclusively by the last 25 years, where November precipitation has been almost exclusively below average.

Summer

Summer temperatures across the state have gradually warmed over the analysis period, with an enhanced warm signal in the short term (Figure 3.19). A closer inspection of the monthly data shows that the warming signal over both the long term and short term is driven mainly by accelerated warming in June, with a rate of temperature increase of 0.060°F/year over the short term. Every climate division in Nebraska has a statistically significant rate of warming over the long term, and only the north central climate division does not have a statistically significant rate of warming over the short term in June.

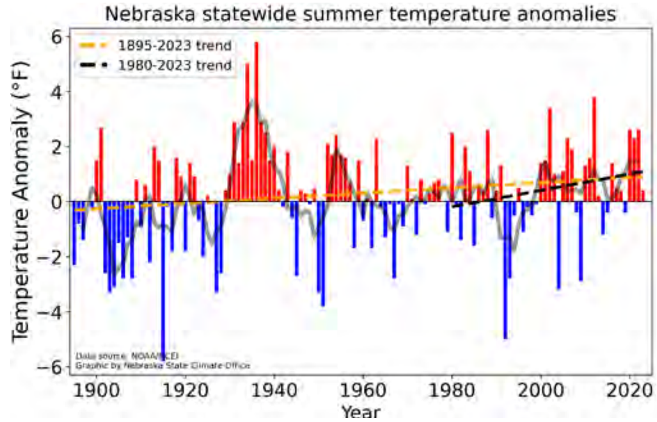


Figure 3.19. Time series of statewide summer temperature anomalies (red for warm, blue for cool) for the from 1895 to 2023 with respect to the 20th-century average. It also shows temperature trends over the long term (1895–2023, orange dashed line) and the short term (1980–2023, black dashed line). The solid gray line denotes a moving five-year average.

July and August show weak rates of warming for the state over both analysis periods. In the three eastern climate divisions, at least one summer month shows a *weak cooling trend over the short term*. Only the Panhandle has a statistically significant warming signal in July and August over the long term, and none of the climate divisions have a statistically significant rate of warming over the short term in July and August. One of the possible reasons for the relative lack of warming in midsummer is the amount of cropland and irrigation in the state and region. Recent studies (Lachenmeier et al., 2024; Mahmood et al., 2004; Mahmood et al., 2006; Rappin et al., 2021; Szilagyi & Franz, 2020) have shown that cropping systems and irrigation in the central Plains region have led to an increase in crop evapotranspiration, which in turn has led to a slight reduction in maximum midsummer temperatures in the region. According to gridded NOAA data, fewer days with maximum temperatures above 95°F were recorded over the eastern two-thirds of the state where irrigated cropland is most prevalent (Figure 3.20) in the period from 1991 to 2020 than in the period from 1951 to 1980. The northeast and southeast climate divisions had no change in air temperature in from 1994 to 2023 compared to 1895 to 1960 (Figure 3.21).

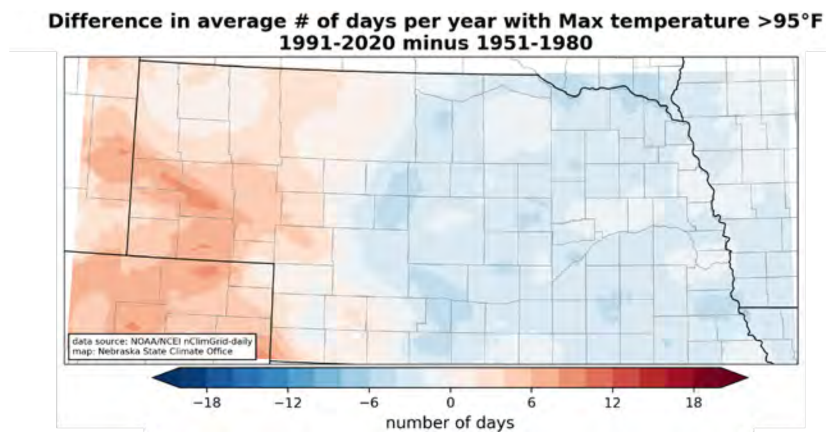


Figure 3.20. The difference in the average number of days per year with maximum temperatures above 95°F from 1951 to 1980 compared 1991 to 2020. (Source: NOAA NCEI, n.d., nClimGrid dataset)

The climatological summer months have essentially no trend in precipitation over the long term and a weakly negative trend over the short term at the state level (Figure 3.22). Furthermore, there is a lower frequency of extreme precipitation events

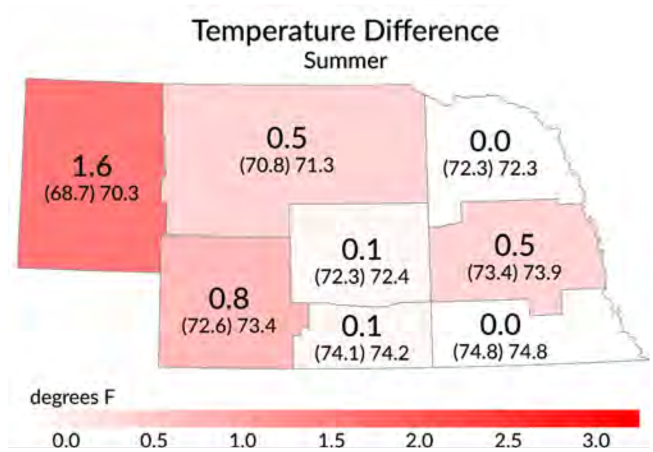


Figure 3.21. Average annual temperature difference in the summer season from 1994 to 2023 compared to 1895 to 1960. The number in parentheses in row 2 represents the average temperature from 1895 to 1960, and the number outside of the parentheses represents the temperature from 1994 to 2023.

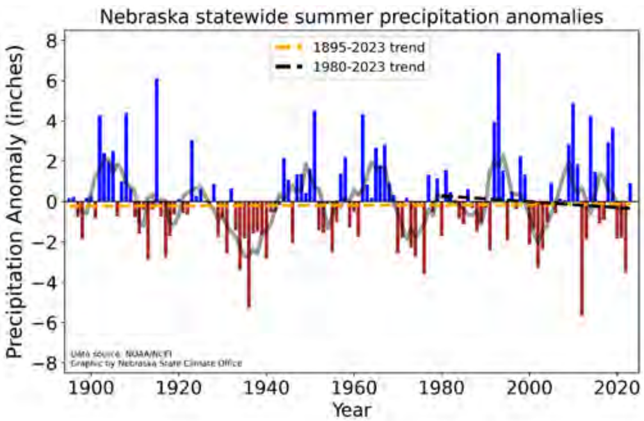


Figure 3.22. Time series of summer precipitation anomalies (blue for wet, brown for dry) from 1895 to 2023 with respect to the 20th-century average. Also shows precipitation trends over the long term (orange dashed line) and the short term (1980–2023, black dashed line). The solid gray line denotes a moving five-year average.

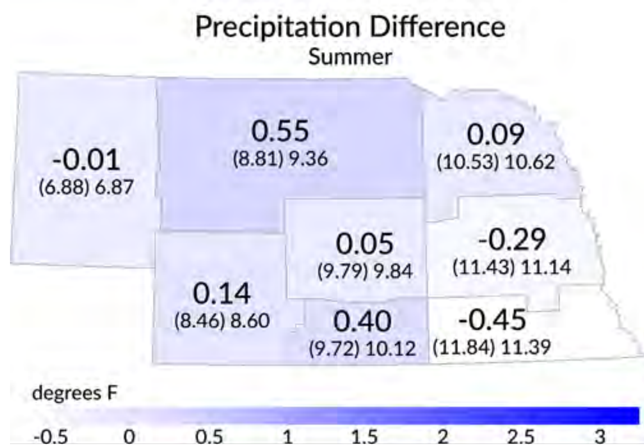


Figure 3.23. Average annual precipitation difference in the summer season from 1994 to 2023 compared to 1895 to 1960. The number in parentheses in row 2 represents the average precipitation from 1895 to 1960, and the number outside of the parentheses represents the temperature from 1994 to 2023.

compared to the spring and fall months (Flanagan & Mahmood, 2021). However, the story changes a bit at the climate division level. The three climate divisions in central Nebraska and the southwest and northeast climate divisions have seen an increase in precipitation in the period from 1994 to 2023 compared to 1895 to 1960. Conversely, the east central, southeast, and Panhandle climate divisions have seen a decrease in summer precipitation in the period from 1994 to 2023 compared to the 1895 to 1960 (Figure 3.23). Nevertheless, even a small decreasing trend in precipitation in the summer is concerning for crop production and pastures, especially rain-fed crops, when combined with a warming early summer and fall.

Spring

Precipitation shows an increasing trend in the long term (Figure 3.24), and all climate divisions were wetter in the spring from 1994 to 2023 compared to 1895 to 1960 (Figure 3.25). The central, east central, and southeast climate divisions all had increases of over an inch. However, the short-term precipitation signal in the spring is only weakly positive and is negative in the month of March (Figure 3.26). The short-term trend of decreasing precipitation in March is not statistically significant at the state level but is decreasing in seven of the eight climate divisions; the Panhandle the exception. However, recent years have had above-average precipitation in March, including in 2019, when historic rainfall occurred on frozen ground and led to historic flooding (Flanagan et al., 2020). Thus, the decline in March precipitation is a reflection that March has tended to be drier than average over the past few decades.

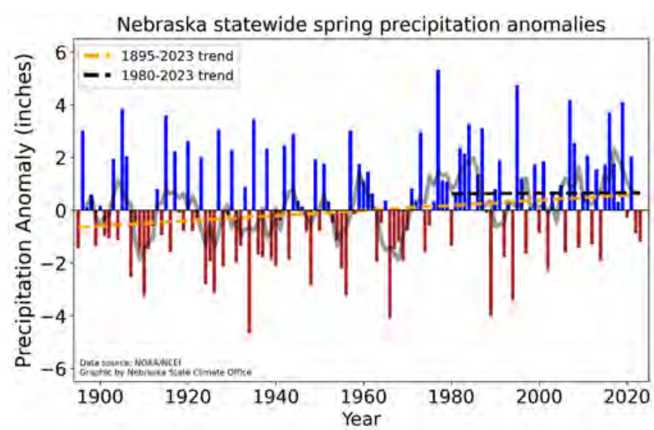


Figure 3.24. Time series of spring precipitation anomalies (blue for wet, brown for dry) from 1895 to 2023 with respect to the 20th-century average. It also shows precipitation trends over the long term (1895–2023, orange dashed line) and the short term (1980–2023, black dashed line). The solid gray line denotes a moving five-year average.

Temperatures in the spring have been warming over the long term (Figure 3.27), and all climate divisions were more than 1°F warmer from 1994 to 2023 compared to 1895 to 1960 (Figure 3.28). However, that trend has been flat in the short term. Spring temperatures rose above the 20th-century average around 1980. Since then, the short-term trend has remained relatively level and has not made another consistent upward shift. Conversely, the short-term trend in the fall season is strongly positive because the shift to predominantly above-average falls has happened more recently. In other words, the winter and spring seasons showed warming signals about 15 to 20 years earlier than the fall.

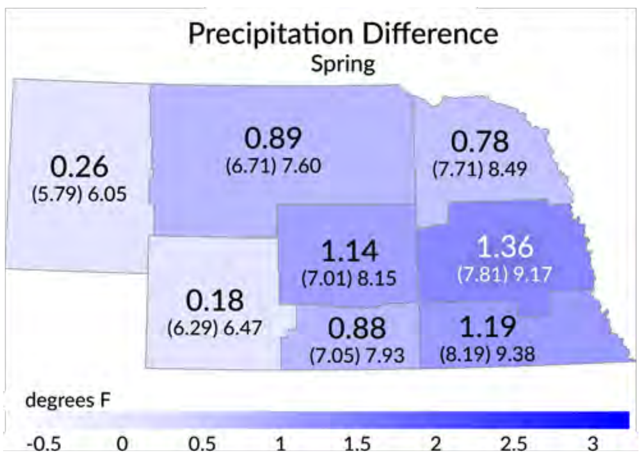


Figure 3.25. Average annual precipitation difference in the spring season from 1994 to 2023 compared to 1895 to 1960. The number in parentheses in row 2 represents the average precipitation from 1895 to 1960, and the number outside of the parentheses represents the temperature from 1994 to 2023.

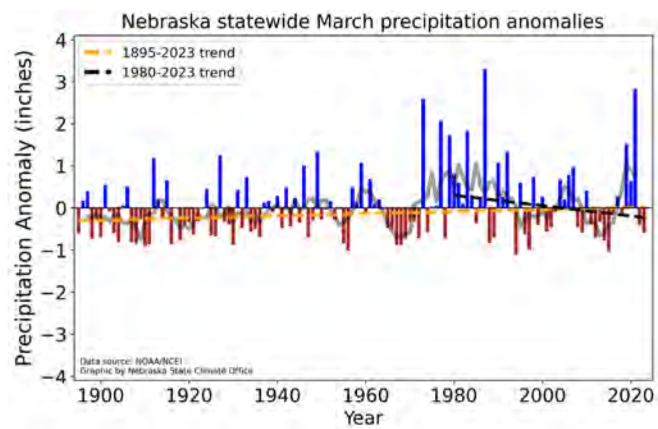


Figure 3.26. Time series of March precipitation anomalies (blue for wet, brown for dry) from 1895 to 2023 with respect to the 20th-century average. It also shows precipitation trends over the long term (1895–2023, orange dashed line) and the short term (1980–2023, black dashed line). The solid gray line denotes a moving five-year average.

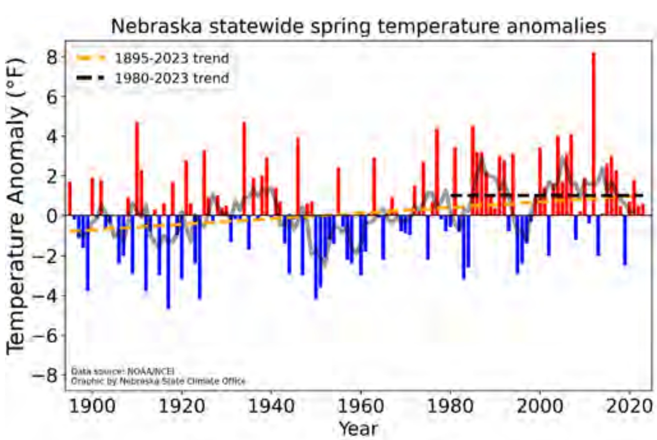


Figure 3.27. Time series of statewide spring temperature anomalies (red for warm, blue for cool) from 1895 to 2023 with respect to the 20th-century average. It also shows temperature trends over the long term (1895–2023, orange dashed line) and the short term (1980–2023, black dashed line). The solid gray line denotes a moving five-year average.

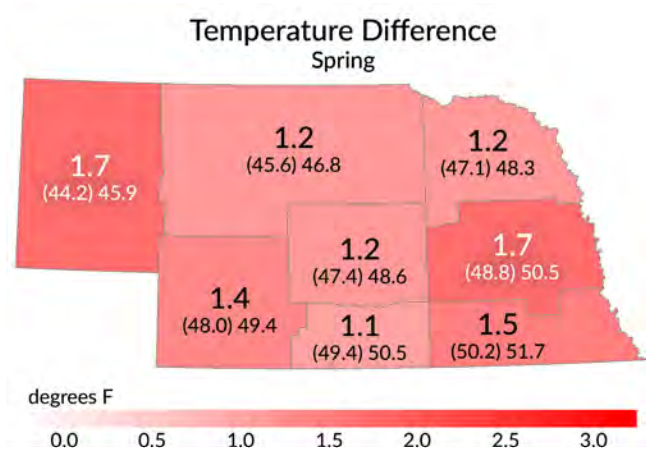


Figure 3.28. Average annual temperature difference in the spring season from 1994 to 2023 compared to 1895 to 1960. The number in parentheses in row 2 represents the average temperature from 1895 to 1960, and the number outside of the parentheses represents the temperature from 1994 to 2023.

Extreme events

Drought

Drought has a long history of causing hardship in Nebraska, including the Dust Bowl of the 1930s, the 1950s drought, and, more recently, the drought of 2012. It is a complex phenomenon that affects nearly all sectors of society. Drought is defined in numerous ways, including meteorological, agricultural, hydrological, flash, ecological, and socioeconomic (Wilhite & Glantz, 1985; Crausbay et al., 2017; Otkin et al., 2018). Given this complexity, quantifying the severity and duration of drought can be challenging. Numerous drought indices can be used to provide useful approximations. In this assessment, we chose the Standardized Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano et al., 2010) to capture the signal in precipitation and temperature. The SPEI calculation was designed to mimic the widely used Standardized Precipitation Index (SPI) (McKee et al., 1993) and can be captured over various time scales ranging from months to years. The key benefit of SPEI over SPI is that the temperature effect on drought is also accounted for, giving more insight into the overall severity of drought at a given point in time.

For this report, we used the National Drought Mitigation Center's Drought Risk Atlas (Svoboda et al., 2015) to obtain the 12-month SPEI for nine long-term stations around the state from 1951 to 2022. We used the median of the 12-month SPEI at those stations to identify extended periods when drought affected most of the state. Figure 3.29 shows multiple multiyear drought events, most notably in the 1950s, the mid-1970s, and 2000, and more extended periods with less to no drought in the state. The median of the 12 months does not reflect the actual percentage of the state in drought at a given time, nor does it give any insight into which area of the state was experiencing the worst conditions. However, it indicates the spatial prevalence of drought and gives some insight into overall severity.

Chapter 2 discussed how the time series of the SPEI suggests a decreasing trend in drought across the eastern half of the U.S. For Nebraska, the SPEI generally shows a trend toward fewer but more intense droughts. This was especially the case over the last 15 years of analysis. A negative monthly median statewide SPEI occurred just 25% of the time between April 2007 and December 2022. However, the droughts during that time have been quite intense. The lowest observed SPEI values occurred during the fall of 2012, Nebraska's driest year on record. Data from the Drought Risk Atlas was not fully available for 2023 at the time of analysis, so we stopped with December 2022. However, given the historic nature of drought conditions in central and eastern Nebraska by late spring 2023, it is likely that the 12-month SPEI values in the spring and early summer of 2023 were in the range of late 2012 for negative values.

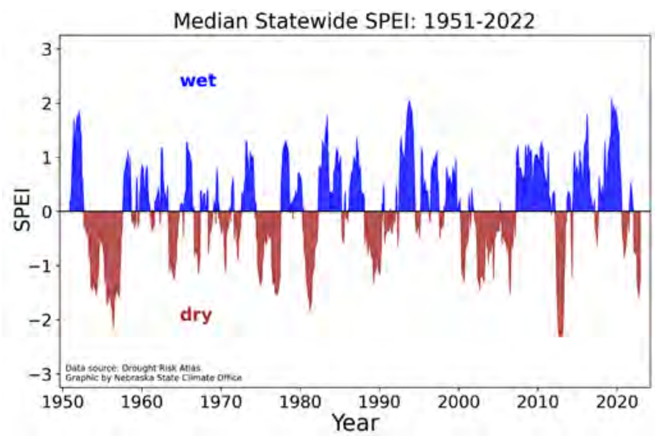


Figure 3.29. The 12-month median statewide SPEI from 1951 to 2022.

Record-breaking temperature and precipitation

Figure 3.30 shows the number of new monthly and annual temperature and precipitation records set at various locations in Nebraska since the start of the 21st century. The story about temperature is straightforward: many new record-warm months than record-cold months have occurred in Nebraska since 2000. Most locations have had at least two calendar months with record warm average temperatures (red circles), and all sites had at least one. The story related to precipitation is more complicated. More dry months (brown circles) have occurred compared to record wet months (dark blue circles), but no significant difference exists. Furthermore, little, if any, consistent spatial signal is apparent for record wet and dry months. For example, Lincoln has set more new record wet months than dry months, while its nearest neighbors (Omaha, Falls City, and Grand Island) have set more record dry months.

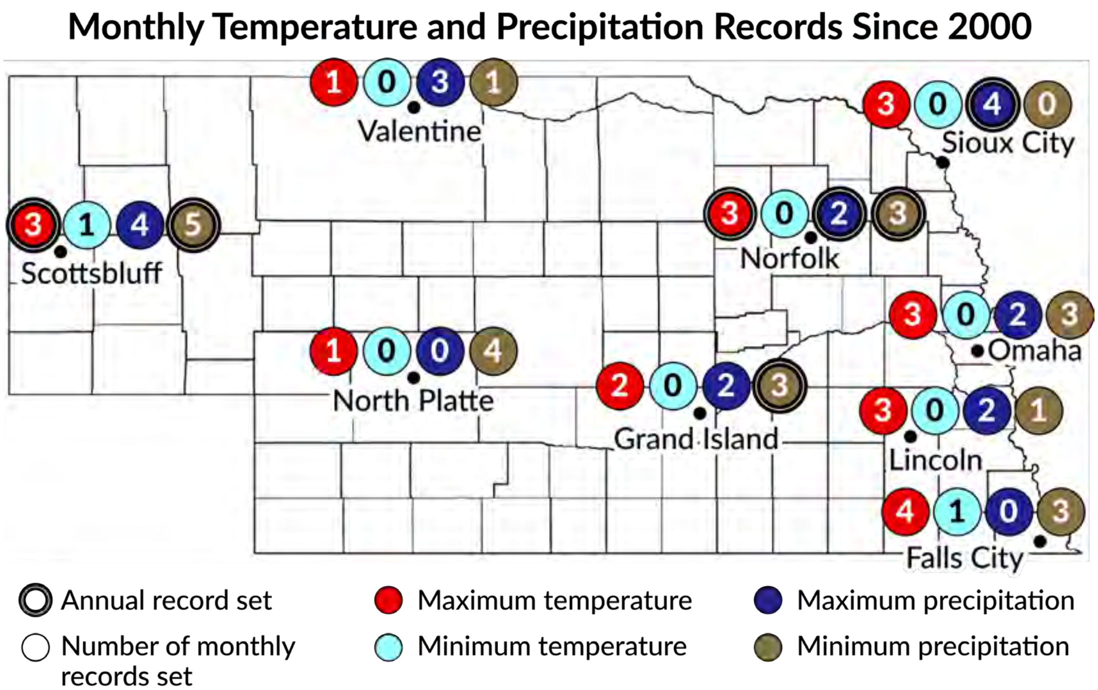


Figure 3.30. Bubble plot of monthly and annual temperature and precipitation records set since 2000. A record warm (cold) month is denoted by the red (light blue) circle with a number corresponding to number of occurrences. A record wet (dry) month is denoted by the dark blue (brown) circle with a number corresponding to number of occurrences. An annual record in any of the four categories is denoted with a bold black line around the circles. (Source: ACIS, 2024)

Scottsbluff stands out as more exceptional than the rest regarding the number of new records. It is the only location that sets records for average temperature and precipitation on the maximum and minimum sides. It also is one of only two sites that set a new highest annual average temperature record and a new lowest annual precipitation record. Also, it is the only site out of the eight that set new records for a warm average temperature during a summer month. In this case, all three climatological summer months have established new records since 2000. The number of record-warm months was lower at the west central sites (North Platte and Valentine had one each) than elsewhere in the state and was highest in Falls City (four total). January 2006 and March 2012 were the most common record-warm months, but no month was a record-warm month at all nine sites. Both Scottsbluff (October 2009) and Falls City (April 2018) have had a record cold month (light blue circles) since the start of the 21st century, but no location was close to setting a new record cold year. Norfolk (2007) and Sioux City (2014) set new annual maximum precipitation records. Norfolk also had its driest year on record (2022) and is joined by Scottsbluff and Grand Island (both during 2012) as having set new record minimum precipitation values.

Frost-free days

The number of days in a year with minimum temperatures remaining above freezing increased statewide over the 30-year period of 1991 to 2020 compared to the 30-year period between 1951 to 1980 (Figure 3.31), according to NCEI's nClimGrid data (NOAA NCEI, n.d.). The annual increase in the number of days with above-freezing minimum temperatures was most prevalent in the east central section of the state. Indeed, areas around Columbus, Lincoln, Wahoo, and Omaha had 10 to 14 more days per year of above-freezing minimum temperatures between 1991 and 2020 compared to 1951 and 1980. A secondary maximum of increased above-freezing minimum temperatures was also noted around the northern portion of the Panhandle between Chadron and Gordon.

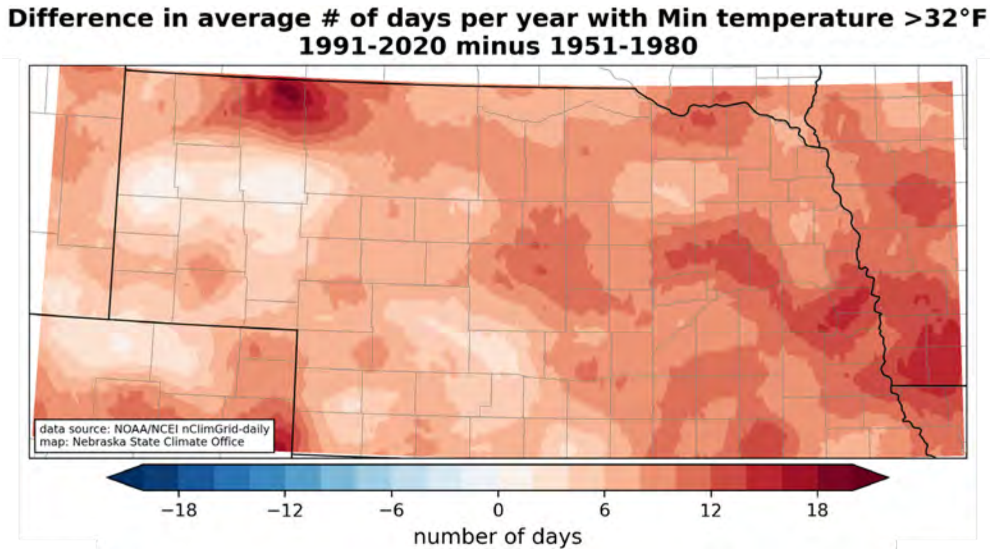


Figure 3.31. The difference in the average number of days per year with minimum temperatures above 32°F from 1951 to 1980 compared to 1991 to 2020. (Source: NOAA NCEI, n.d., nClimGrid dataset)

Heating- and cooling-degree days

Heating (HDD) and cooling (CDD) degree days relate the average daily outdoor temperature to the energy used to heat or cool buildings. Degree days are calculated by taking the daily average temperature and calculating it against a base temperature of 65ºF. Nebraska has historically experienced substantially more heating-degree days (average >6000 HDD) than cooling-degree days (average ~900) in a year.

Our analysis shows that Nebraska has been losing 4.8 HDDs per year and gaining about 1 CDD yearly over the long term. The HDD decline is even more pronounced in the short term, with a 7.7 days per year decline since 1980 (Figure 3.32a). In addition, an increase of 2 CDDs per year occurred over the short term (Figure 3.32b). Over recent decades, the increased number of CDDs is mainly due to the increased average temperature in months like June and September. The decrease in heating-degree days is spread out more evenly, but declines are more noticeable in the late fall and early winter.

While the demand for cooling is increasing with an increased trend in CDDs, the demand for cooling is not increasing as quickly as the demand for heating is decreasing. If these trends continue in the coming years and decades, the overall energy consumption needed to keep buildings comfortable will likely be less than it is currently in the coming years.

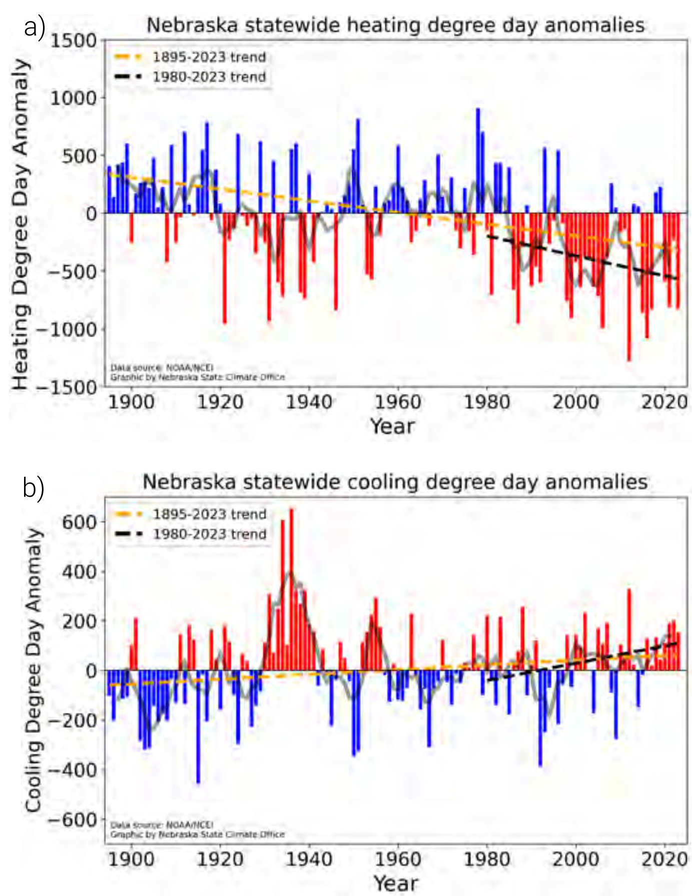


Figure 3.32. Time series of (a) heating and (b) cooling degree day anomalies. Blue bars indicate values greater than the average, while red bars denote values less than the average from 1895 to 2023 compared to the 20th-century average. It also shows temperature trends over the long term (1895–2023, orange dashed line) and the short term (1980–2023, black dashed line). The solid gray line denotes a moving five-year average.

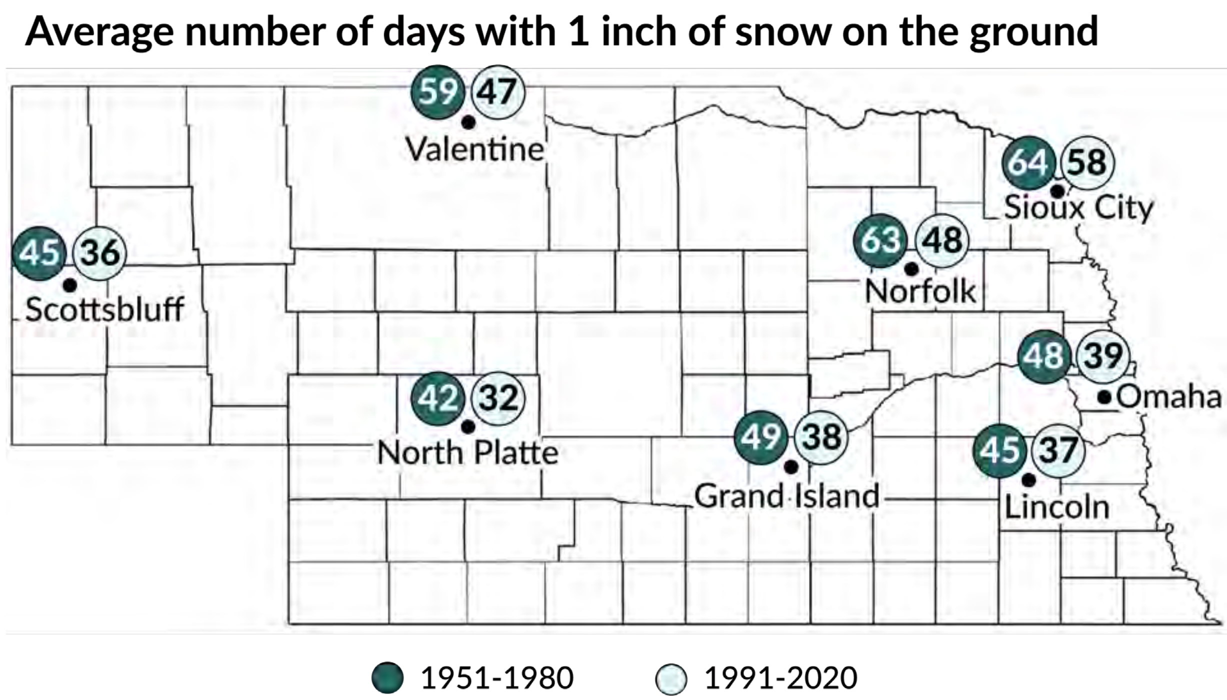


Figure 3.33. The average number of days in a year with one inch or more of snow cover from 1951 to 1980 (darker circles) compared to 1991 to 2020 (lighter circles).

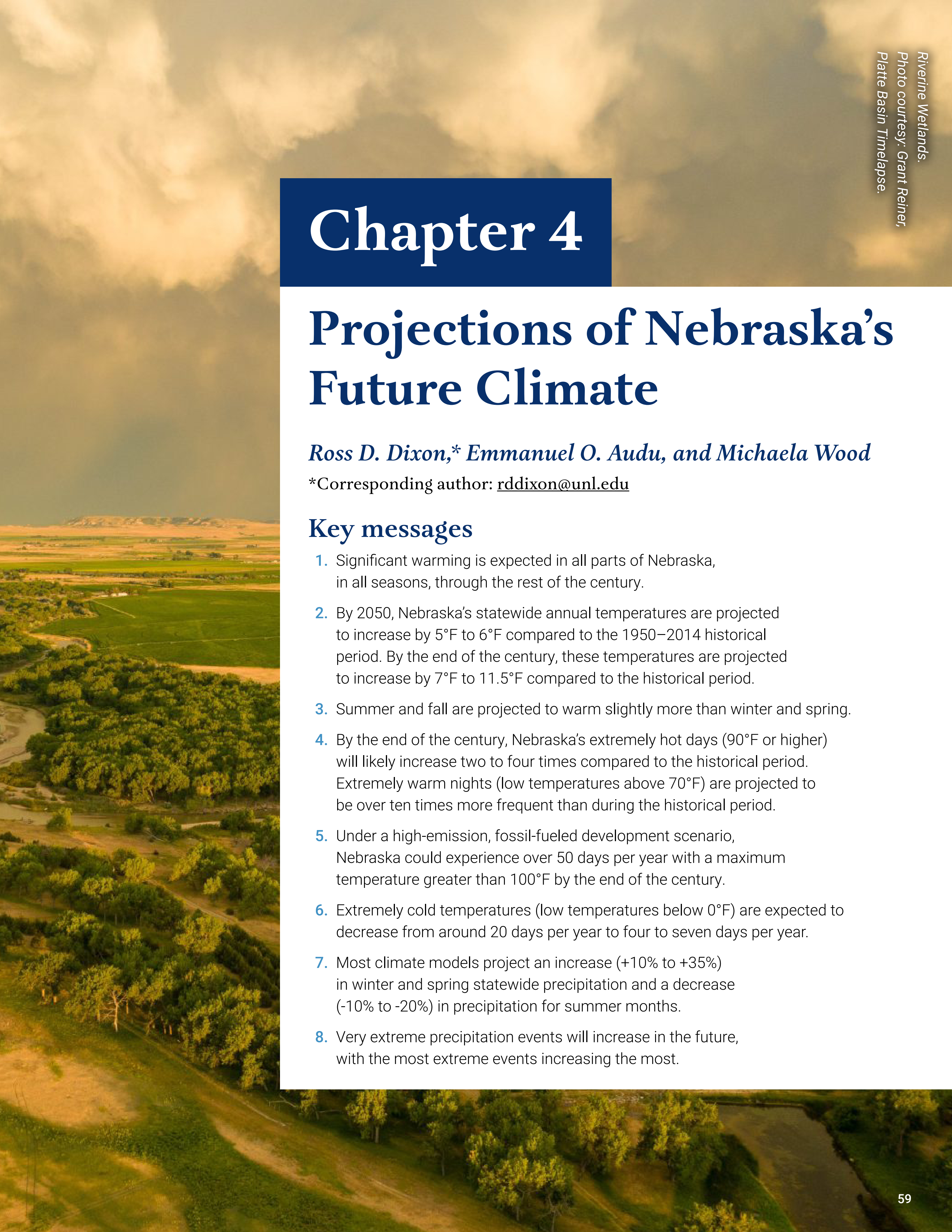
Snow cover

Annual average snowfall in Nebraska has a decreasing gradient from northwest to southeast and considerable year-to-year variability. The number of days with snow cover in a year depends on the snowfall received and temperatures cold enough to preserve it on the ground. The trend toward warmer temperatures in the winter has led to a decrease in the number of days with snow cover of at least 1 inch at all eight sites in Nebraska, as shown in Figure 3.33. Most sites had around 10 fewer days of snow cover in the period from 1991 to 2020 compared to the period from 1951 to 1980. The decrease in the number of days with 1 inch of snow cover was most pronounced in Norfolk, with an average of 48 days between 1991 and 2020 compared to 63 days between 1951 and 1980.

Gaps and needs

» **Robust statewide Mesonet.** A robust Nebraska Mesonet will provide high-resolution, localized weather data. By providing near real-time information, Mesonet data can help predict and disseminate life-saving warnings for extreme events. In addition, by providing continuous data over time, a Mesonet can improve the monitoring of climate events and trends and help evaluate the impacts of climate change on sectors such as agriculture and water resources.

» **Statewide climate data portal.** Improved internet access to historical climate data will enable Nebraska's residents to use historical data from the Mesonet for decision-making. Furthermore, it would facilitate the development of climate-related tools to help manage climate-related risks, develop future opportunities and investments, and build resilience to extreme events.



Riverine Wetlands. Photo courtesy: Grant Reiner, Platte Basin Timelapse.

Chapter 4

Projections of Nebraska's Future Climate

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Key messages

1. Significant warming is expected in all parts of Nebraska, in all seasons, through the rest of the century.
2. By 2050, Nebraska's statewide annual temperatures are projected to increase by 5°F to 6°F compared to the 1950–2014 historical period. By the end of the century, these temperatures are projected to increase by 7°F to 11.5°F compared to the historical period.
3. Summer and fall are projected to warm slightly more than winter and spring.
4. By the end of the century, Nebraska's extremely hot days (90°F or higher) will likely increase two to four times compared to the historical period. Extremely warm nights (low temperatures above 70°F) are projected to be over ten times more frequent than during the historical period.
5. Under a high-emission, fossil-fueled development scenario, Nebraska could experience over 50 days per year with a maximum temperature greater than 100°F by the end of the century.
6. Extremely cold temperatures (low temperatures below 0°F) are expected to decrease from around 20 days per year to four to seven days per year.
7. Most climate models project an increase (+10% to +35%) in winter and spring statewide precipitation and a decrease (-10% to -20%) in precipitation for summer months.
8. Very extreme precipitation events will increase in the future, with the most extreme events increasing the most.

Introduction

Scientists use global climate models to understand how the climate has changed in the past and may change in the future. These models use mathematical equations to simulate how energy and matter interact in the atmosphere, land, and oceans. Modelers must make many choices on how these simulations are produced, including the model's resolution and how small-scale features are represented. This results in an ensemble of global simulations led by modeling groups worldwide. The Coupled Model Intercomparison Project Phase 6 (CMIP6) is the most recent generation of these simulations, which produces output for past, present, and future periods (Eyring et al., 2020).

These simulations are forced in the historical period (1950–2014) by setting observed changes in greenhouse gas emissions, solar activity, volcanoes, and land use. Future simulations (2015–2100) are forced with projections of greenhouse gas emissions, which are controlled by population growth, economic development, energy use, and technologies for efficiency and sources of energy. In CMIP6, these scenarios for future greenhouse gas emissions are referred to as shared socioeconomic pathways (SSP) (O'Neill et al., 2014). The moderate emissions scenario (SSP2-4.5) pictures a world where socioeconomic factors follow the path of their historical trends and carbon dioxide emissions decline by mid-century. The high emissions scenario (SSP5-8.5) is a "business as usual" pathway that doubles carbon dioxide emissions by 2050 with fossil fuel and energy-driven lifestyles.

The output from global climate models provides useful estimates of future climate change. However, these simulations are typically run at resolutions from 100 to 250 km (about 60 to 150 miles), which is too coarse to provide useful regional information or to force agricultural and hydrological models. These impact models require information at much higher spatial resolutions (1 to 25 km or about 0.5 to 16 miles), so global climate model output is typically downscaled through dynamical and statistical methods. In this section of the assessment, we use the statistically downscaled climate projections from LOCA (Localized Constructed Analogs) version 2 developed by Pierce et al. (2023), which is applied to 23 CMIP6 models and produces daily maximum and minimum temperatures and precipitation at 6 km resolution.

Temperature projections

Simulations reproduce the observed increase in annual temperature across Nebraska for the historical period (Figure 4.1). By mid-century, both emission scenarios suggest that the average temperature in Nebraska will increase by about 5°F to 6°F compared to the historical period. However, by the end of the century, the high emissions scenario produced an average of 11.5°F of warming from the historical period, around four additional degrees of warming compared to the moderate emissions scenario. This highlights the importance of reducing greenhouse emissions, allowing us to avoid the largest amounts of warming and the worst impacts of climate change.

The highest annual temperature in Nebraska's history was 52.7°F, which occurred in 1934 at the beginning of the Dust Bowl. These projections suggest that by the end of the century, the statewide average temperature

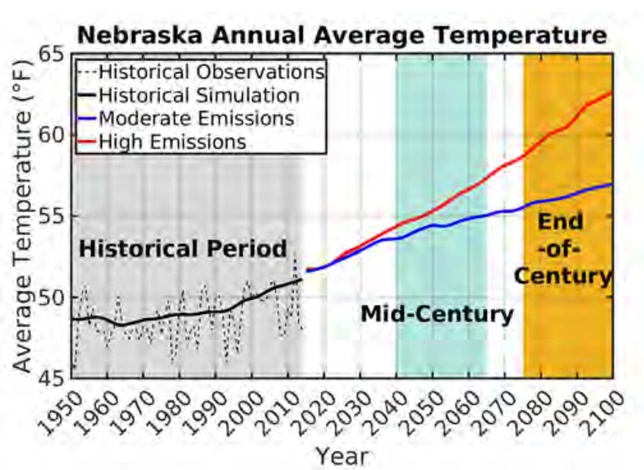

Figure 4.1. Annual temperatures averaged across Nebraska for the historical period (black lines) and two emissions scenarios: moderate emissions (blue line) and high emissions (red line).

will be 3°F to 7°F warmer than this extreme period in Nebraska's history. During the historical period, the average temperature of Oklahoma was approximately 60°F, which will be comparable to the average temperature of Nebraska by the end of the century under the high emissions scenario (NOAA NCEI, 2024a).

Nebraska will warm across all seasons in the coming century (Figures 4.2, 4.3, 4.4, and 4.5). Warming is projected to be uniform across the state, with

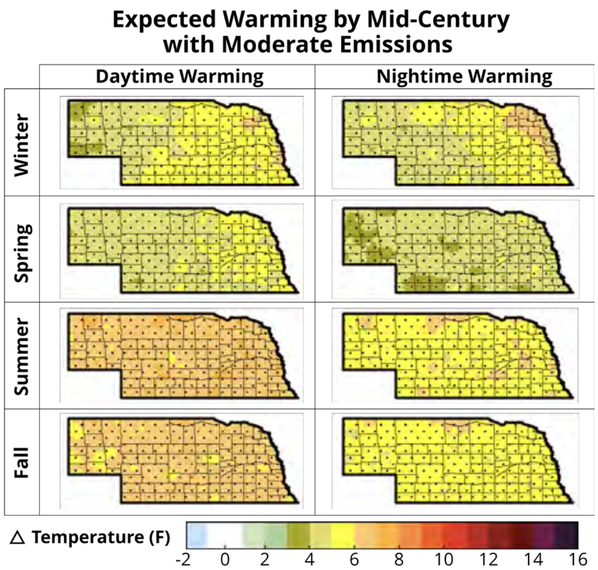

Figure 4.2. These maps show the expected warming by the middle of the century compared with the historical period for the moderate emissions scenario. Stippling indicates regions where 80% of the downscaled models agree on the direction of temperature change.

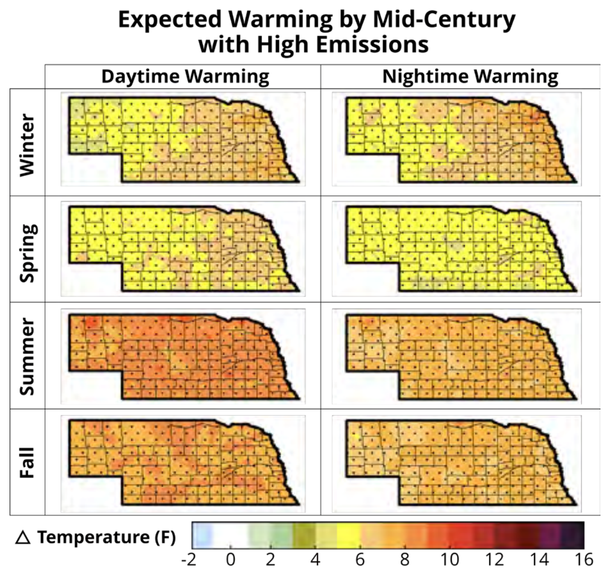

Figure 4.3. These maps show the expected warming by the middle of the century compared with the historical period for the high emissions scenario. Stippling indicates regions where 80% of the downscaled models agree on the direction of temperature change.

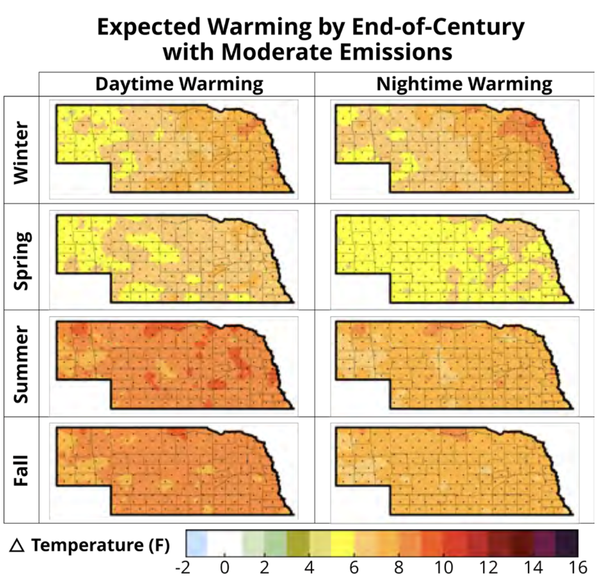

Figure 4.4. These maps show the expected warming by the end of the century compared with the historical period for the moderate emissions scenario. Stippling indicates regions where 80% of the downscaled models agree on the direction of temperature change.

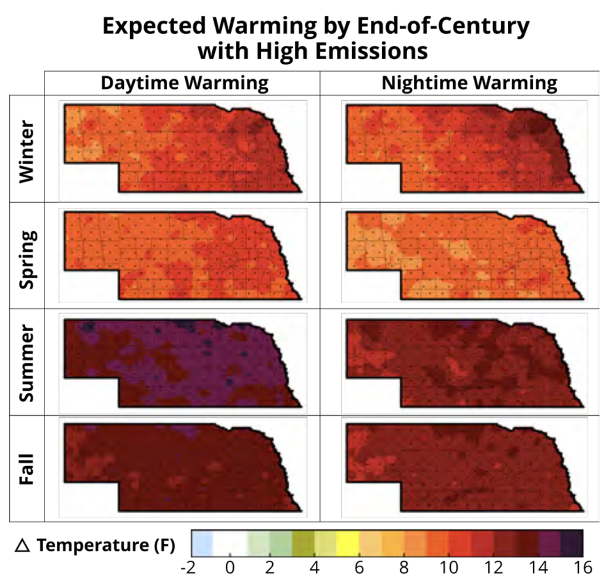

Figure 4.5. These maps show the expected warming by the end of the century compared with the historical period for the high emissions scenario. Stippling indicates regions where 80% of the downscaled models agree on the direction of temperature change.

a slightly increased warming toward the east. Summer and fall are the seasons with the largest amount of warming. During spring and summer, daytime temperatures increase more than nighttime, but the opposite is seen in fall and winter.

These changes in average temperature will increase the magnitude and frequency of extreme weather events. By the end of the century, Nebraska could experience two to four times more days over 90°F than in the historical period. Days with temperatures above 100°F were observed on average less than 10 days per year across Nebraska during the historical period. Under the high emissions scenario, Nebraska could experience over 50 days per year with these extremely high daytime temperatures by the end of the century (Figure 4.6).

Extreme nighttime temperatures are also expected to change, especially toward the southeastern part of the state (Figure 4.7). During the historical period, most of the state experienced less than five days per year with temperatures that did not fall below 70°F. This is projected to increase to a statewide average of 60 days per year with minimum temperatures above 70°F, with the southeastern part of the state experiencing around 100 days per year with these extremely warm nighttime temperatures by the end of the century. Cool nighttime temperatures are critical for agriculture and human health, so this increase in both emissions scenarios is highly important.

Extremely cold winter temperatures are important for controlling pest populations. During the historical period, Nebraska observed around 20 days per year with a minimum temperature below 0°F. By the end of the century, under the moderate emissions scenario, these extremely cold days decreased to approximately seven days per year, with an average of four days per year occurring during the high emissions scenario (Figure 4.7).

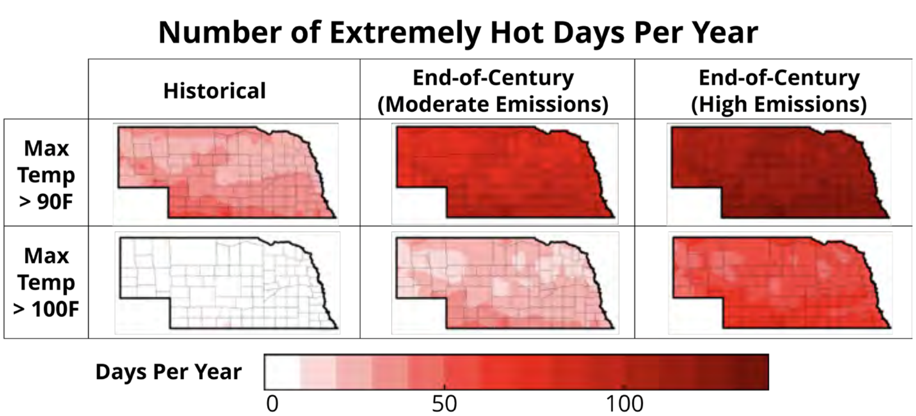

Figure 4.6. The number of extremely hot days is projected to increase under both emissions scenarios.

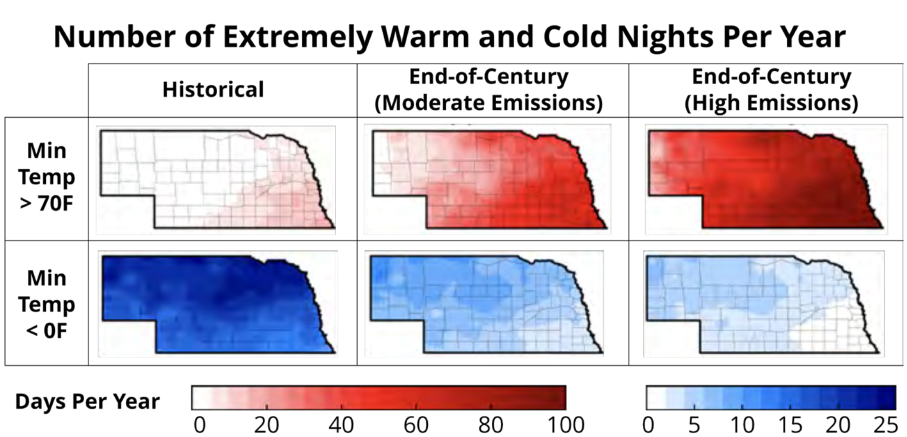

Figure 4.7. The number of extremely warm nights per year (top) is projected to increase, and the number of extremely cold nights per year (bottom) is projected to decrease under both emissions scenarios.

Precipitation projections

The projections of annual precipitation change in Nebraska are more uncertain than those of temperature change. Global climate models consistently project that the northernmost U.S. states will see overall higher annual precipitation in the future and that the Southwest and Mexico will see lower annual precipitation in the future (Figure 4.8). Since Nebraska is in the transition zone between these regions, projecting the annual change in precipitation is difficult. The downscaled precipitation allows us to see more robust signals across different seasons. Nebraska is projected to have a robust increase in precipitation during winter and spring and experience a decrease in precipitation during the summer months by the middle of the century (Figure 4.9) and the end of the century (Figure 4.10). The magnitude of these patterns is much larger in the high emissions scenario than in the moderate emissions scenario.

Extreme precipitation events are projected to increase significantly (Figure 4.11), including flooding and runoff. These events will likely remain most common in the state's southeastern part. The most extreme events (for example, days with more than four inches of precipitation) are projected to increase in frequency more than less extreme events.

The number of days between precipitation events is also projected to increase across the state (Figure 4.12). The maximum number of consecutive dry days per year (one indicator of drought) may increase by 5% to 10% by the end of the century, especially across the eastern part of the state. The increase in extreme precipitation combined with longer dry spells has important implications for flash drought and flooding events.

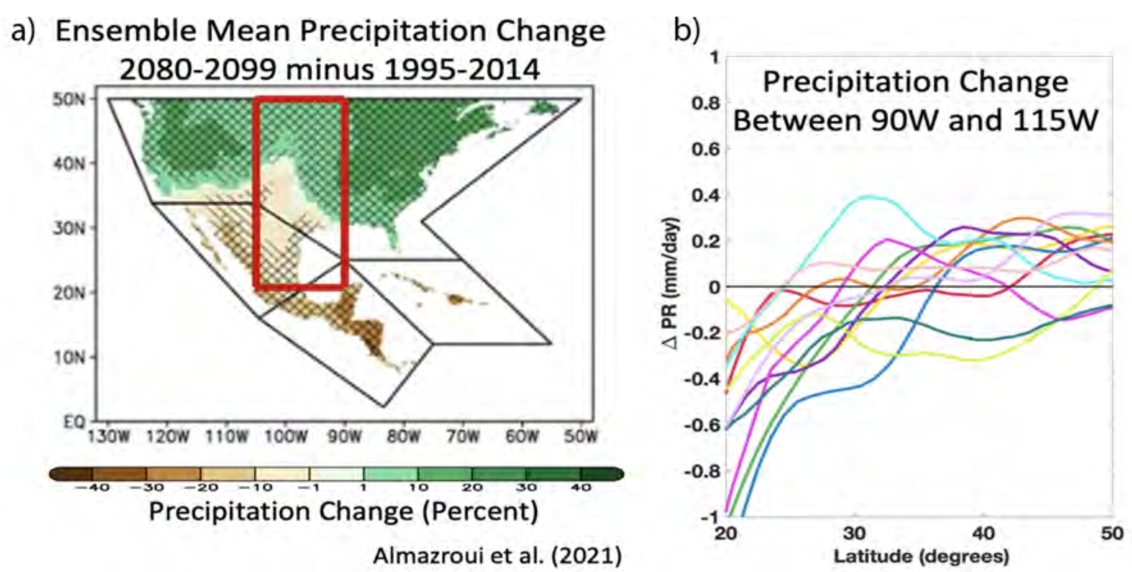

Figure 4.8. (a) The spatial distribution of changes in annual mean precipitation (%) for the end of the century under the high emissions scenario (left) in an ensemble of CMIP6 models. The backslash and forward slash indicate the grid boxes showing significant and robust changes, respectively, while hatching represents the grid boxes having both significant and robust changes (Source: Almazroui, 2021). (b) The precipitation change, averaged in the east-west direction between 90W and 115W (red box), for a selection of CMIP6 models (right) shows model uncertainty in the transition between the drying south and wetting north.

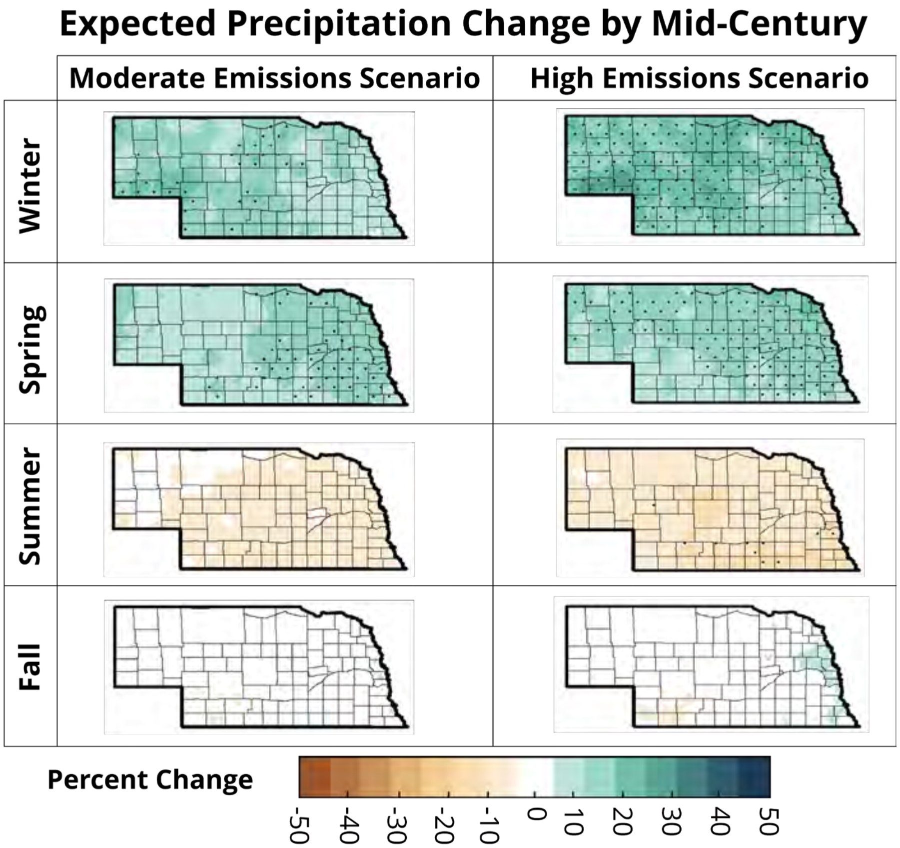

Figure 4.9. These maps show the expected change in precipitation by the end of the century compared with the historical period for the moderate (left) and high (right) emissions scenarios. Stippling indicates regions where 80% of the downscaled models agree on the direction of precipitation change.

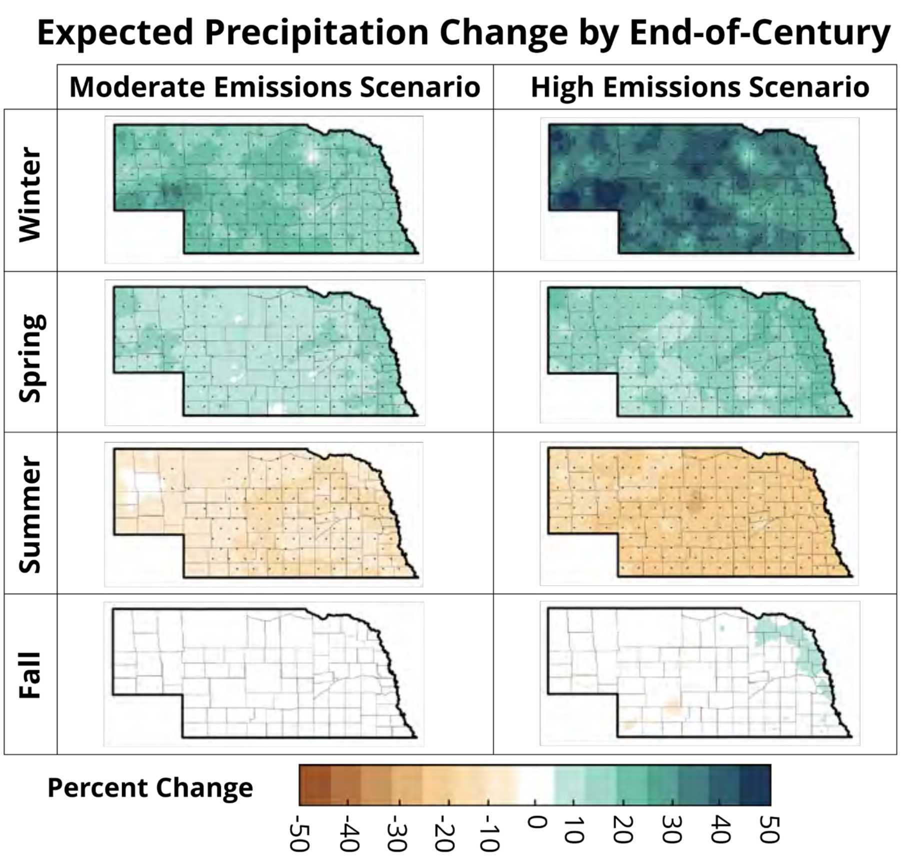

Figure 4.10. These maps show the expected change in precipitation by the end of the century compared with the historical period for the moderate (left) and high (right) emissions scenarios. Stippling indicates regions where 80% of the downscaled models agree on the direction of precipitation change.

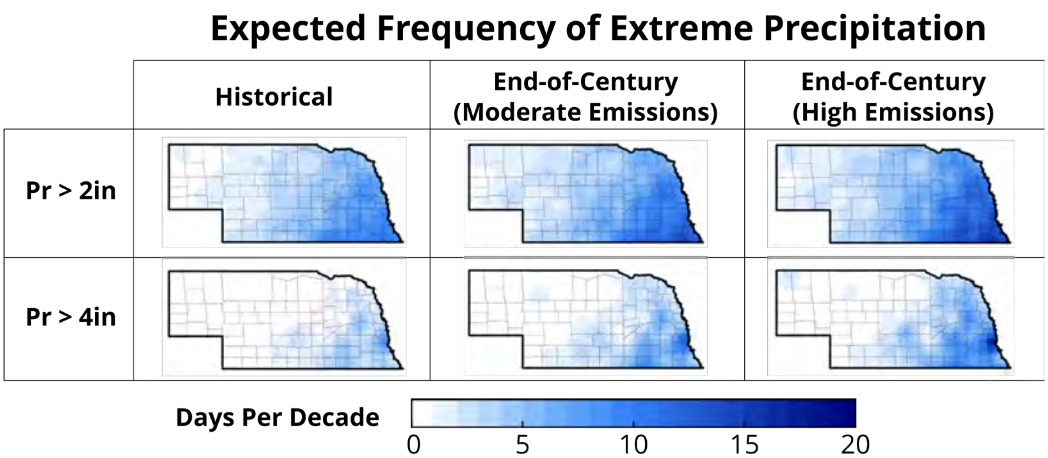

Figure 4.11. The number of days with extreme precipitation is projected to increase under both emissions scenarios.

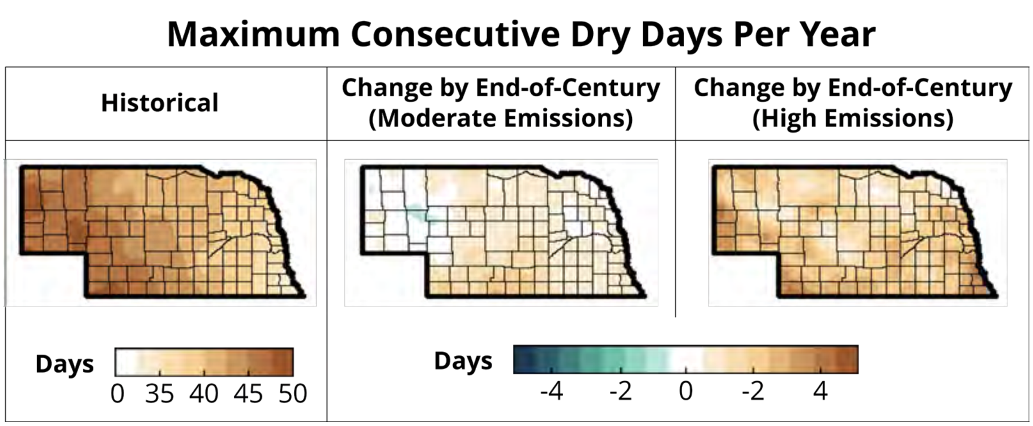

Figure 4.12. The maximum length of consecutive dry days per year is projected to increase under both emissions scenarios.

Gaps and needs

» **Decrease carbon emissions.** Every change described in this section is smaller in magnitude in the moderate emissions scenario than in the high emissions scenario. Decreasing greenhouse gas emissions can avoid climate change's most significant changes and impacts.

» **Increased observations of climate indicators.** Continued investment and extension of instrumentation across the state will allow monitoring of Nebraska's changing climate, provide vital information to better understand key climate processes, and reduce model uncertainty. This can also include opportunities for citizen science monitoring.

» **Higher-resolution regional climate simulations.** The limitations of statistical downscaling constrain the analysis in this report. For example, daily temperature and precipitation are commonly produced through this methodology, while moisture and winds are not. Producing regional simulations using models that better capture the dynamics of the climate system will allow us to provide more detailed information in our projections that can be used to help make decisions as communities prepare to adapt to changes in Nebraska's climate.

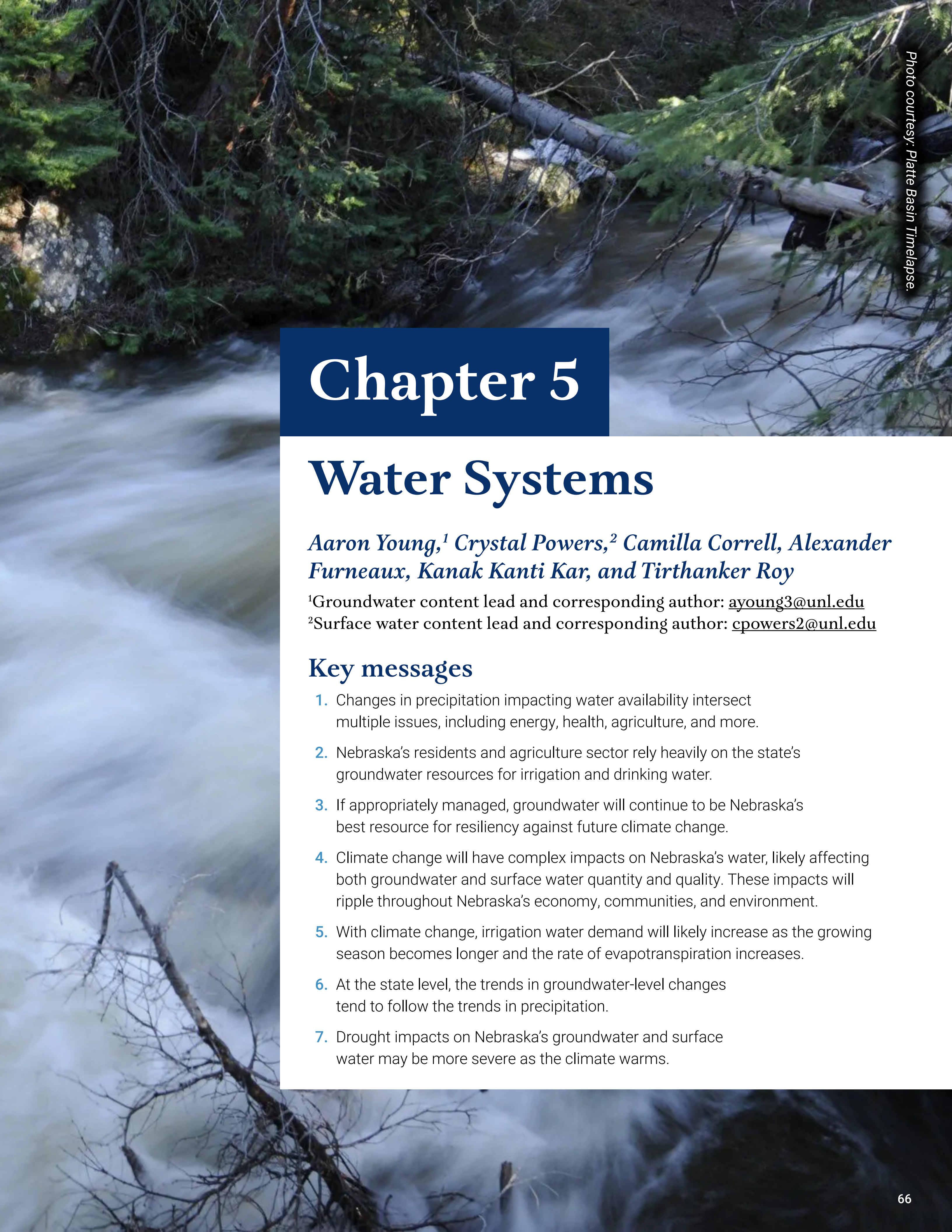

Photo courtesy: Platte Basin Timelapse.

Chapter 5

Water Systems

Aaron Young,[1] Crystal Powers,[2] Camilla Correll, Alexander Furneaux, Kanak Kanti Kar, and Tirthanker Roy

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Key messages

1. Changes in precipitation impacting water availability intersect multiple issues, including energy, health, agriculture, and more.
2. Nebraska's residents and agriculture sector rely heavily on the state's groundwater resources for irrigation and drinking water.
3. If appropriately managed, groundwater will continue to be Nebraska's best resource for resiliency against future climate change.
4. Climate change will have complex impacts on Nebraska's water, likely affecting both groundwater and surface water quantity and quality. These impacts will ripple throughout Nebraska's economy, communities, and environment.
5. With climate change, irrigation water demand will likely increase as the growing season becomes longer and the rate of evapotranspiration increases.
6. At the state level, the trends in groundwater-level changes tend to follow the trends in precipitation.
7. Drought impacts on Nebraska's groundwater and surface water may be more severe as the climate warms.

Introduction

Nebraska's water system is delicately balanced between too much and too little. Throughout the state's history, flooding and drought have been recurring events that have prompted human intervention to manage access to water. As more extreme wet and dry periods are expected due to climate change, it is essential to implement efforts that mitigate impacts and adapt to these changes to ensure the sustainability of Nebraska's communities.

Management of water resources affects the state's rivers, streams, lakes, reservoirs, wetlands, and groundwater resources, which collectively support environmental, social, and economic functions. Across Nebraska, communities use water resources for various purposes, providing a wide range of benefits throughout the ecosystem. These ecosystem services include access to drinking water, irrigation of agricultural lands, recreation, and energy production. Water is essential for life and has both direct and indirect impacts that connect with the key topics discussed in this report.

As climate change alters the water balance for Nebraska and the states with which it shares water, we will need to look to adaptation strategies to increase the absorptive capacity and retain water on the landscape to improve water use efficiency in a state. These efforts can help support the resilience of over 9 million acres of irrigated land, accounting for 91% of the consumptive water use of the state and contributing $1.5 billion in annual crop value (UNL Water, 2024). Adaptation strategies to a change in water availability will also protect Nebraska's wealth of recreational opportunities, including boating, hunting, fishing, swimming, outdoor education, and more. These recreational amenities are valued at $4 billion annually, employing more than 24,000 people (NGP, 2022). Individual events such as the annual sandhill crane migration yield over $17.2 million alone, while resources such as Lake McConaughy attract over 2 million visitors annually (UNL Water, 2024). Adaptation strategies must also focus on the increasing number of major flood events and the associated economic and recovery costs (NeDNR, 2022).

This chapter briefly overviews surface water and groundwater resources projected to be impacted by climate change and outlines their current and future impacts. It identifies areas for further research and action to make these resources more resilient and adaptable to climate change's impacts.

Nebraska's water management framework

Managing water in the state has evolved over the past 200 years, shifting away from independent management toward collaborative water planning and implementation practices that recognize water as a shared asset. Today surface and groundwater management responsibilities are shared by the Nebraska Department of Natural Resources (NeDNR), 23 local Natural Resource Districts (NRD), Nebraska Department of Agriculture (NeDA), Nebraska Game and Parks Commission (NGPC), Nebraska Department of Environment and Energy (NDEE), and Nebraska's water users (Figure 5.1). While the NeDNR, NRDs, and NDEE play the most prominent roles in this management arrangement, NeDA and NGPC also occupy important niches. Coordination and collaboration between these agencies and land managers are vital to managing the state's water resources.

Surface water quantity rights are based on "first-in-time" rule, where the oldest water rights receive water first, administered by NeDNR (UNL, n.d.). The public owns groundwater in Nebraska, and landowners are granted correlative rights, meaning access to beneficial use and "share and share alike" in groundwater-level changes, managed by the public through NRDs. However, surface water and groundwater are also physically and legally connected, so NeDNR also identifies when existing water uses may have insufficient water supplies now or in the future. These basins are called fully or over-appropriated, and surface and groundwater use limitations have been implemented through an integrated planning process involving NeDNR, NRDs, and the public (NeDNR, n.d.).

Furthermore, NeDNR plays a key role as the agency responsible for administering interstate agreements on water use. Nebraska is a member of six interstate water compacts, agreements, or court decrees with its upstream and downstream neighbors: Wyoming, Colorado, and Kansas. These compacts allocate water among states to determine appropriations for water taking and are already becoming legal battlegrounds, straining relationships between neighboring states.

Water quality management is also collaborative across local, state, and federal scales. The U.S. EPA sets maximum contaminant levels for drinking water administered through NDEE for public water supplies. Private wells are not regulated; therefore, monitoring and treatment are the well owner's responsibility. Potential point sources of pollution, such as industrial and livestock facilities, are regulated by NDEE. Each NRD establishes policies based on local conditions to address non-point sources impacting water quality, such as field agrichemical applications or erosion.

Surface water

Rivers and streams

Nebraska's rivers drain west to east toward the Missouri River. They provide an essential source of water (Figure 5.2) in areas where groundwater resources are limited or difficult to obtain. The state has 13 major river basins delineated (Figure 5.3) from north to south.

- **White River and Hat Creek:** Located in northwest Nebraska before flowing to South Dakota.
- **Niobrara River:** Located in northwest/northern Nebraska, the Niobrara River includes two U.S. Bureau of Reclamation (USBR) dam and reservoir projects irrigating 45,500 acres. The river has 76 miles of national scenic river designation.
- **Missouri River tributaries:** Located on Nebraska's northeastern edge, these tributaries drain directly into the Missouri River.

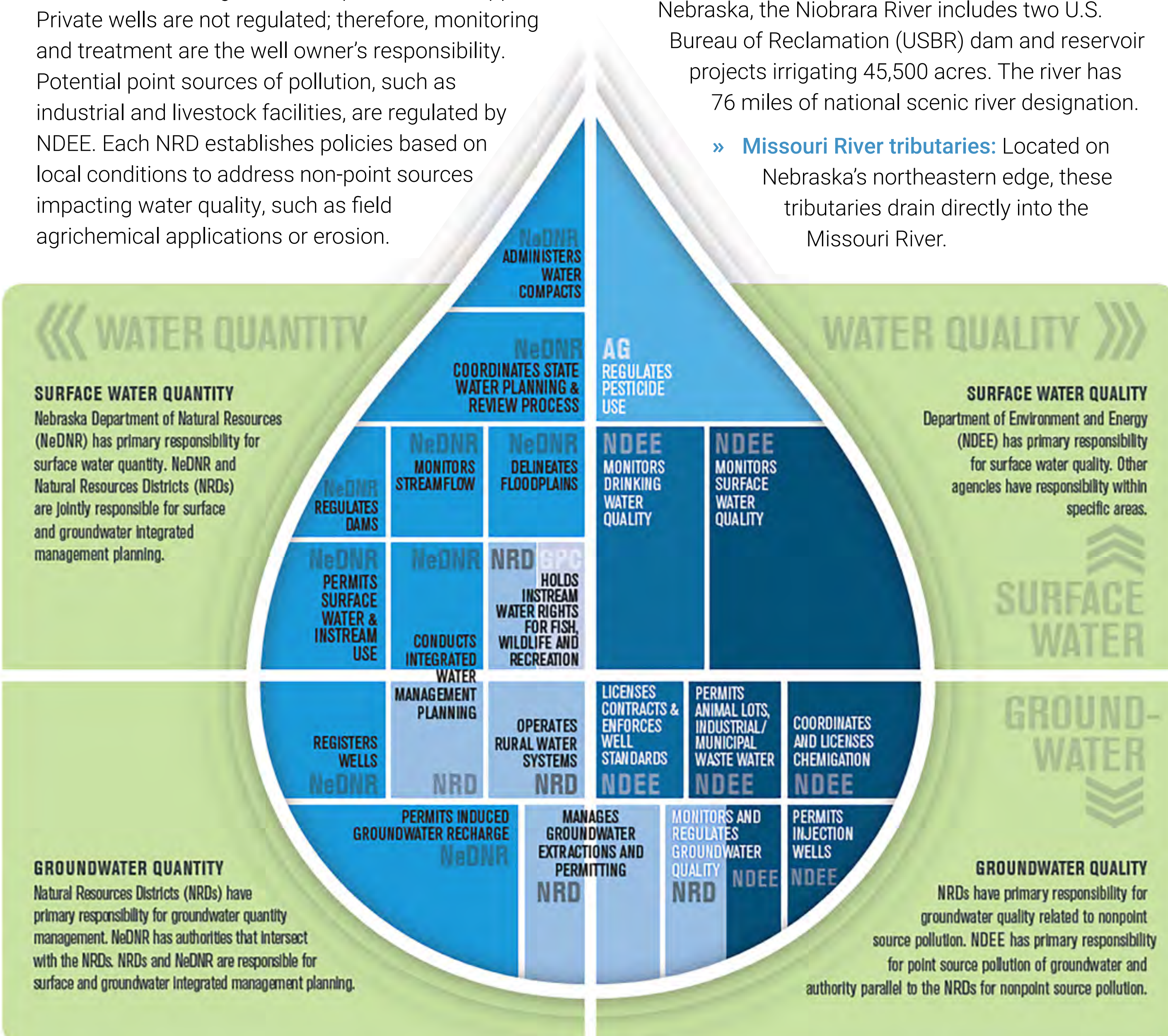

Figure 5.1. Nebraska's water management framework. (Source: NeDNR, n.d.)

- » **Elkhorn River:** Located in northeast Nebraska, the Elkhorn River flows into the Platte River.
- » **Loup River:** Located in central Nebraska, the Loup River is an important site for many recreational activities. The river also includes several reservoirs constructed by the USBR for flood management and irrigation purposes.
- » **Platte River (North, South, Middle, and Lower):** The Platte River begins in the mountains of Colorado and Wyoming and is the largest drainage system crossing the entire state. The river valley is an important passageway across the state, historically the path of multiple transcontinental trails such as the Oregon Trail, Mormon Trail, and Pony Express. It is also the corridor of major bird migration in the spring and fall through the North American Central Flyway.
- » **Blue River (Big and Little) and Nemaha River:** Located in southeast Nebraska.
- » **Republican River:** Located from southwest to south central Nebraska, the Republican River is extensively managed through dams and reservoirs for flood management and irrigation (HDR, 2006).

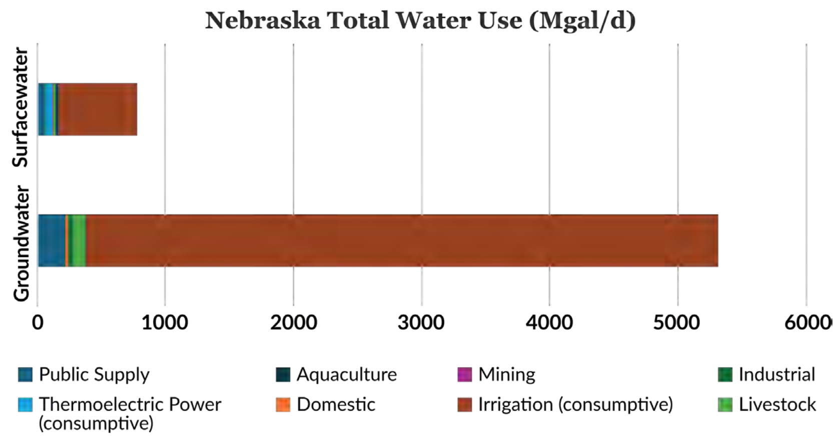

Figure 5.2. Nebraska's total consumptive water use in 2015. (Source: USGS, 2015)

Nebraska's rivers and streams have a long history of use for navigation by First Nations, including the Lakota, Ponca, Pawnee, and Plains Comanche, who regularly returned to rivers such as the Niobrara for seasonal hunting and settlements (NPS, 2023). The Lewis and Clark expedition traveled the state's rivers, and immigrants journeyed westward. Nebraska's rivers and streams provided power and water for early agriculture and commercial growth. Today, usage has expanded to include barging and recreational canoeing, kayaking, and tubing opportunities. The Missouri River is the primary navigable river route in the state, though other rivers provide localized navigation needs. Along the Missouri River, multiple projects by the U.S. Army Corps of Engineers (USACE) have altered its course to stabilize its banks, create a clear navigable channel, and manage its flow. These projects have dramatically altered the river's landscape, removing river edge habitat and disturbing natural channel processes such as channel migration and sediment uptake, transport, and deposition (USACE, 2018). Recent efforts to re-naturalize river edges throughout the state's river system aim to reintroduce habitat and provide localized flood mitigation. However, much work remains to restore these riverine ecosystems to benefit from these services.

Climate change threatens Nebraska's rivers and streams, most notably due to changing flow conditions and water quantity. Like the rest of the U.S., Nebraska

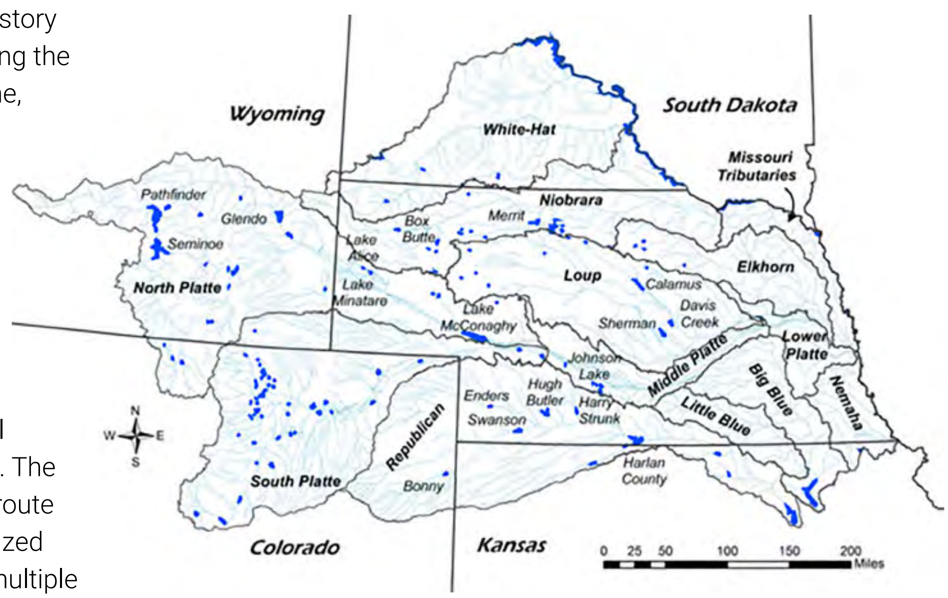

Figure 5.3. Distribution of Nebraska's watersheds and location of principle irrigation reservoirs. (https://cropwatch.unl.edu/nebraska-reservoir-response-recent-rains)

is expected to experience a greater number of very heavy precipitation events and longer dry spells, contributing to large fluctuations in river and stream flow (see Chapter 4). Research indicates that certain river basins, such as the Platte River, present a risk of more frequent floods in the near future (USACE, n.d.). Drought and flood conditions threaten Nebraska's navigable waterways by making river travel unsafe or unsuitable based on flow conditions. Particularly in drought conditions, natural flows on the Missouri are supplemented by water released from the mainstream reservoir system (USACE, 2018). The changing flow will have far-reaching and disruptive impacts on access to water, water quality, and recreation activities—all carrying economic implications.

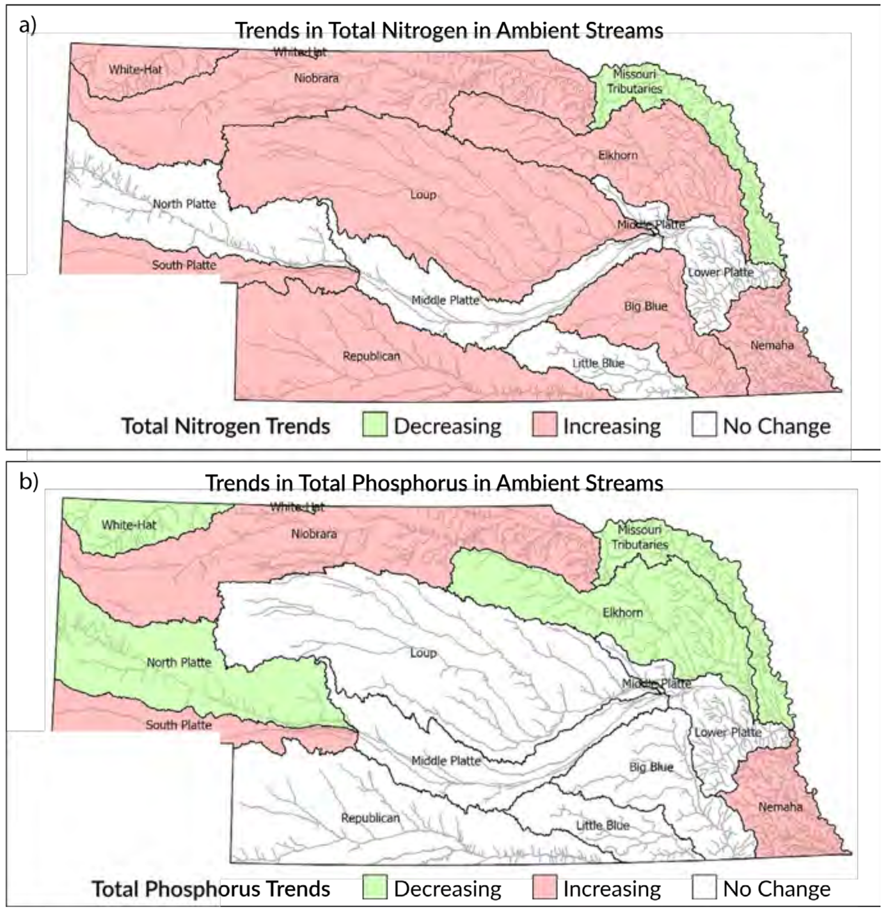

Figure 5.4. Ambient streams' (a) total nitrogen trends and (b) total phosphorus by river basin, 2002–2021. (Source: NDEE, 2023a)

Due to declining water quality, Nebraska's rivers and streams face well-documented threats. Stream and river flow changes directly impact water quality due to the concentration of nutrients in water during droughts and increased erosion during floods. Over the past decade, water quality monitoring has provided an evolving picture of nutrient concentrations in the state's rivers and streams. Figure 5.4a shows that nitrogen trends are increasing in most river basins. Phosphorus trends are stable or improving in most river basins, as seen in Figure 5.4b. Nutrient loading in rivers and streams, combined with increasing temperatures, also threatens the biological integrity of these resources, diminishing the number of plant and animal species that these streams can sustain. In addition to field nutrient runoff, an increase in major precipitation events will contribute to agrichemical leaching into surface and groundwater resources.

These rivers and streams also expose infrastructure and agriculture to potential damage from flooding (Figure 5.5). Wetter winters and springs, combined with warmer winters and more extreme precipitation events due to climate change, lay the groundwork for more damaging floods. For example, the spring 2019 floods caused over $3 billion in property and infrastructure damage (Nguyen-Wheatley, 2020). Over the past four decades, Nebraska has experienced an increase in the number of billion-dollar flood events and the associated costs of recovery (NeDNR, 2022). Additional risks compound given the age and hazard potential of many of the state's dams and levees. Of the over 2,900 dams, 85% are estimated to have been constructed before 1960, with 12% considered high or significant hazard potential (NeDNR, 2022).

Lakes and reservoirs

Nebraska has over 2,000 natural lakes and over 1,000 reservoirs and sandpit lakes, which provide important water sources for irrigation, flood mitigation, recreation, and power generation (NeDNR, 2022). Notably, the

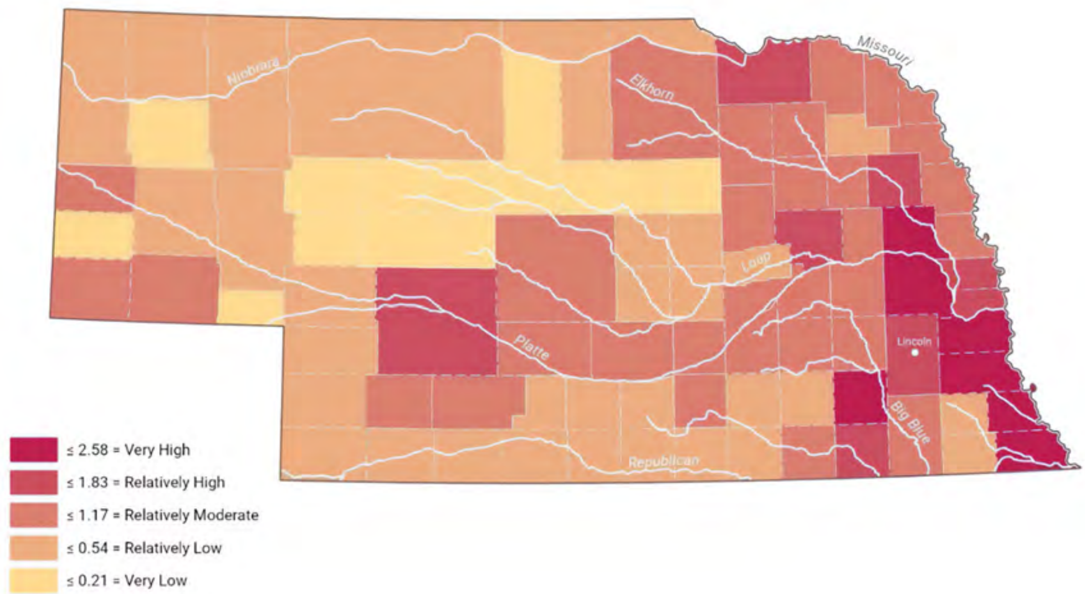

Figure 5.5. Annualized frequency of riverine flooding by county. (Source: NeDNR, 2022)

USBR manages 21 dams throughout the state in the Niobrara River basin, the Loup River basin, the Platte River basin, and the Republican River basin, creating reservoirs used primarily for irrigation and recreation.

Like rivers and streams, nutrient loading and warming temperatures due to climate change expose these resources to water quality risks. For example, eutrophication is the excessive richness of nutrients in a lake or other body of water, frequently due to runoff from the land. This causes a dense growth of algae and plant life and the death of animal life from lack of oxygen. Public lakes surveyed displayed elevated levels of eutrophication, with 43 of 45 lakes assessed meeting the Trophic State Index threshold for either hypereutrophic or eutrophic conditions (NDEE, 2023a). Between 2010 and 2019, 187 No Swim warnings were issued in 22 lakes and reservoirs due to harmful algae blooms (HABs) (Powers et al., 2020). Other contaminants, such as mercury entering water resources through runoff, have prompted fish consumption advisories in 130 lakes and seven stream segments as of 2021 (NDEE, 2023a). Eutrophic conditions, HABs, and pollutant loading all impact the recreational function of these resources by lowering habitat quality that supports wildlife and fish for hunting, fishing, and observation and swimming and boating opportunities. Fewer opportunities to access these recreational opportunities hurt the state's recreation economic sector, extending beyond outfitters, campgrounds, and guides to indirect recreation supports provided by communities close to recreation areas such as hotels, restaurants, and other attractions.

Wetlands

Wetlands are important water resources that provide many ecosystem services impacting the environment, social and recreational opportunities, and the economic viability of the state's agricultural resources. Their impact on water movement plays a key role in groundwater recharge, filtration of pollutants, and flood storage. The unique hydrology of wetlands and their supported ecosystems provide habitat for many migratory and non-migratory species. In Nebraska, the state's more than 5,000 wetlands (NeDNR, 2022) account for 990 plant species, 13 amphibian species, 18 reptile species, 176 bird species, and 29 mammal species that use these water resources at some point in their life cycle (LaGrange, 2022).

Among its neighboring states, Nebraska has the largest acreage of wetlands despite a 35% loss in wetland acreage in the past 200 years (LaGrange, 2022). The state contains multiple wetland complexes grouped into four categories: playa, riverine, saline/

alkaline, and sandhills. However, wetlands in Nebraska continue to face substantial threats contributing to their degradation or disappearance. Human activity, including urban and rural development expansion, threatens wetlands—though the impacts are more acute to smaller and riverine wetlands (LaGrange, 2022). Eastern saline wetlands are particularly imperiled by these development patterns, prompting the need for conservation and restoration efforts to protect these unique ecosystems in eastern Nebraska. More broadly, throughout the state, invasive species such as reed canary grass (*Phalaris arundinacea*) and European common reed (*Phragmites australis*) threaten to outcompete native vegetation, lowering the capacity of wetlands to provide native habitat and filtration functions.

Climate change is expected to impact wetlands due to changes in temperature and the timing and amount of precipitation. These changes will likely alter wetland conditions and processes (i.e., functions and values), including the types of habitats they provide and their ability to manage water quality and flooding. Wetlands also play a key role in greenhouse gas cycling. While they can be a source of some greenhouse gases when disturbed, they are also an important sink for greenhouse gases by storing carbon and preventing it from entering the atmosphere. The effects of climate change on wetlands include the loss of carbon stored in the soil, changes in soil structure, and more frequent drying or flooding, which can result in a change in wetland types and changes in plant or animal communities. For example, playa wetlands are renewed annually through precipitation and dry up as the season progresses. As the supply of water trends toward extreme oversupply and undersupply, this can stress this hydrologically sensitive resource. Drought periods necessitate the pumping of water into wetlands for wildlife, recreation, and groundwater recharge by local, state, and federal agencies and their partners (NGP, 2024).

Groundwater

Nebraska's groundwater resources are vast compared to other states overlying the High Plains Aquifer (HPA), sometimes known locally as the Ogallala Aquifer. The HPA underlies parts of eight states, including South Dakota, Nebraska, Kansas, Oklahoma, Texas, Wyoming, Colorado, and New Mexico. Nebraska's portion of the HPA, which covers all but the easternmost part of the state, encompasses approximately 64,600 mi^2 or about 36% of the total area of the HPA. However, by volume, Nebraska contains approximately 2.040 billion acre-feet of saturated sediments, or around 69% of the total HPA volume (McGuire et al., 2012). In parts of Grant, Cherry, and Hooker Counties, the thickness of the HPA exceeds 1,000 feet, the greatest saturated thickness in all the HPA (Korus et al., 2013).

Nebraska's groundwater resources are crucial to our way of life, providing residents with access to private drinking water supplies, municipal water systems, and water for industrial and agricultural uses. Approximately 88% of Nebraskans rely on groundwater as a source of domestic water (Woita, 2023). Even though more than 1.7 million people rely on groundwater as a source of drinking water in our state, groundwater withdrawals for domestic and municipal water system use are only a fraction of our total water withdrawals. As of 2015, it is estimated by the U.S. Geological Survey that irrigation accounts for nearly 91% of water use in Nebraska (Figure 5.2).

Since the state's inception in the 1850s, agriculture has been the main driving force of the economy. However, precipitation rates vary widely across the state, ranging from as little as 11 inches in the Panhandle to more than 32 inches in eastern Nebraska (Chapter 3). While most precipitation falls during the summer, total annual precipitation can vary significantly from year to year. By providing supplemental crop irrigation, farmers can provide consistent moisture to fields in parts of the state where natural precipitation may not provide optimal yields. Early irrigation projects beginning in the first decade of the 20th century provided irrigation to farms near surface water sources through early canal systems. With rapid advancements in drilling technology following World War II, groundwater-fed irrigation systems began to expand rapidly (Figure 5.6).

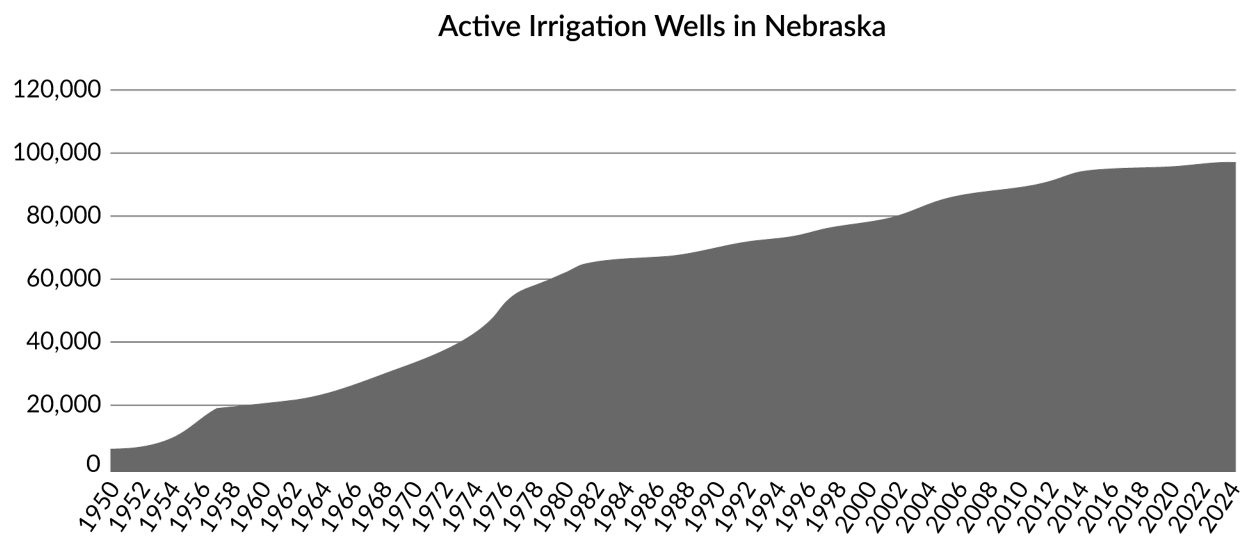

Figure 5.6. The number of active irrigation wells registered in Nebraska by year, beginning in 1950. (Source: NeDNR, 2024)

By the early 1950s, about 7,500 irrigation wells were in use statewide. In the following decades, the number of irrigation wells registered in Nebraska rapidly expanded to nearly 90,000 by 2010, reaching about 97,000 by early 2024. Over the last decade, the installation of high-capacity wells in Nebraska has greatly slowed down due to local regulations and restrictions on the installation of new high-capacity wells in highly pumped regions. Nebraska had 9.4 million acres of irrigated cropland in 2022 (NDRPRA, 2022). Of the 9.4 million irrigated acres, more than 9.1 million acres are irrigated using groundwater (NARD, 2023). As of 2022, Nebraska has the most acres of irrigated cropland in the U.S., surpassing California's 8.2 million irrigated acres reported by the 2022 Census of Agriculture (USDA, 2022). These statistics represent all acres of farmland in Nebraska that are equipped to be irrigated during a given year. However, due to crop rotations, use allocations, and local precipitation patterns, not all land capable of being irrigated each year is irrigated.

Although Nebraska's groundwater resources are vast, withdrawing water from our aquifers at rapid rates does not occur without consequence. Fluctuations in the distance from land surface to groundwater, also known as the depth to groundwater, result from the changing balance between recharge and discharge from water stored in our aquifers. Rapid and extensive groundwater withdrawals do not leave enough time for replenishment through recharge. Before widespread irrigation development, recharge to and discharge from Nebraska's aquifers were generally in equilibrium. Water levels changed minimally, primarily reflecting long-term changes in precipitation trends. However, as groundwater withdrawals increase, this balance becomes much more complicated. Although many variables contribute to changes in depth to groundwater levels at a local level, at a statewide scale, trends in changing groundwater levels tend to follow patterns of statewide precipitation changes (Figure 5.7).

In exceptionally wet years, more water is available for aquifer recharge, and less supplemental irrigation water is pumped, resulting in a modest groundwater-level rise. Conversely, less water is available for recharge in extremely dry years, and more water is pumped, resulting in a net decline in water levels. During years of drought, groundwater-level declines tend to be more substantial than recoveries in extremely wet years. For example, although it is difficult to compare the magnitudes of extreme drought events to extreme flooding events from a climate perspective, following the extreme flooding of 2019, statewide average depth to water in wells experienced an average rise of 1.60 feet (Figure 5.7). Following the extreme drought of 2012, the average depth to water in wells declined by 2.54 feet. Both climate events were extremes for Nebraska, but the decline from the extreme drought was nearly one foot greater than the increase from the 2019 extreme flooding. Groundwater-level changes resulting from drought events tend to have roughly double the impact on groundwater levels compared to years of much-above-average precipitation. This ratio appears to increase as more water is pumped from our aquifers.

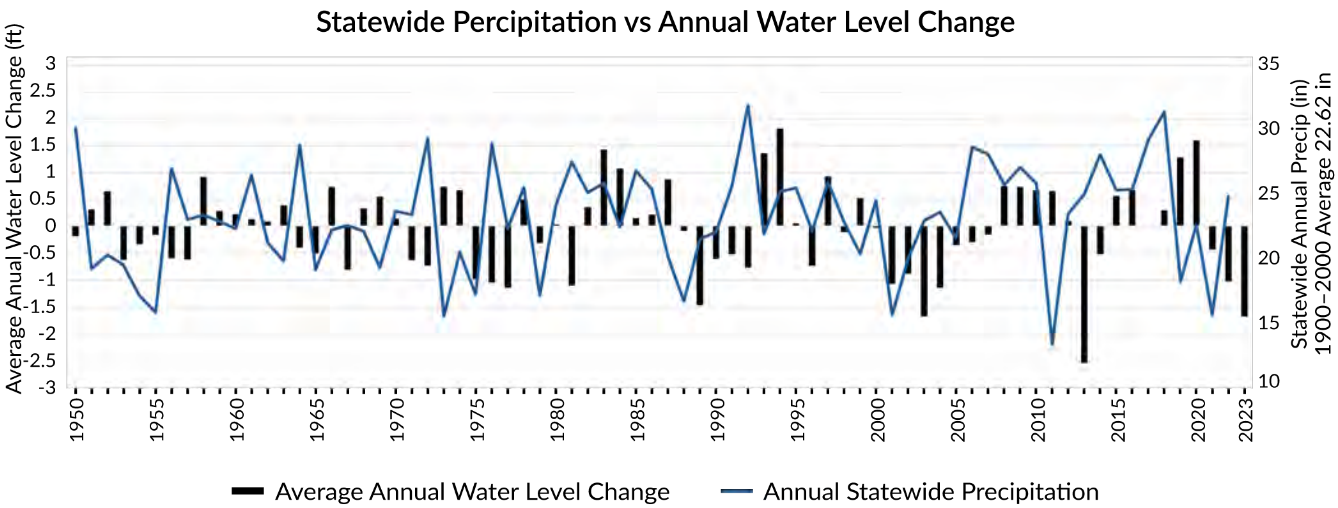

Figure 5.7. Black bars represent the average annual change in depth to groundwater measured in wells in Nebraska in feet. The blue line represents the departure from the statewide average annual precipitation, with the long-term statewide average precipitation of 22.62 inches on the X-axis.

Annually, groundwater levels are measured in the spring from thousands of wells statewide. The results of these measurements are illustrated in the annual *Nebraska Statewide Groundwater-Level Monitoring Report* available from the Conservation and Survey Division at the University of Nebraska–Lincoln. Statewide trends in Nebraska's aquifers are evaluated by comparing the departure of annual spring groundwater- level measurements to estimated predevelopment groundwater levels or the depth to groundwater before the widespread installation of high-capacity wells. Figure 5.8 illustrates the average variation of annual spring water levels from predevelopment estimated values. Figure 5.9 illustrates the long-term trend in groundwater levels in individual wells for each location over the past 30 years. Generally, water levels in wells in the state's western portion have steadily declined for several decades. In parts of Box Butte County, groundwater-level declines have reached nearly 130 feet from predevelopment (Figure 5.8). These western regions receive relatively little precipitation and pump groundwater from deep aquifers, which receive little recharge. In the southeastern region of Nebraska, depth to groundwater in wells fluctuates by a few feet yearly due to variability in annual precipitation trends and varying irrigation withdrawals. However, since the early 1980s, groundwater in this region has slowly increased or remained steady. This is likely due in part to increasing irrigation efficiencies, regulation of groundwater pumping, and stabilization of groundwater levels as aquifers equilibrate to decades of pumping (Korus & Burbach, 2009).

Significant rises in groundwater levels have also occurred. Long-term data suggests that water levels in the Sandhills region have steadily risen since at least the 1970s, and in some parts of the Sandhills, slowly rising since as early as the 1940s. This region has little impact from pumping and other human use. Studies are ongoing to determine why water levels in the Sandhills region continue to increase. Water infiltration from unlined irrigation canals installed in central Nebraska in the early 1900s has caused significant local groundwater-level rises. Since predevelopment, water levels have risen more than 120 feet in parts of Gosper and Phelps Counties. Similarly, reservoirs such as Lake McConaughy, Calamus, and Merritt have locally raised water levels by as much as 80 feet.

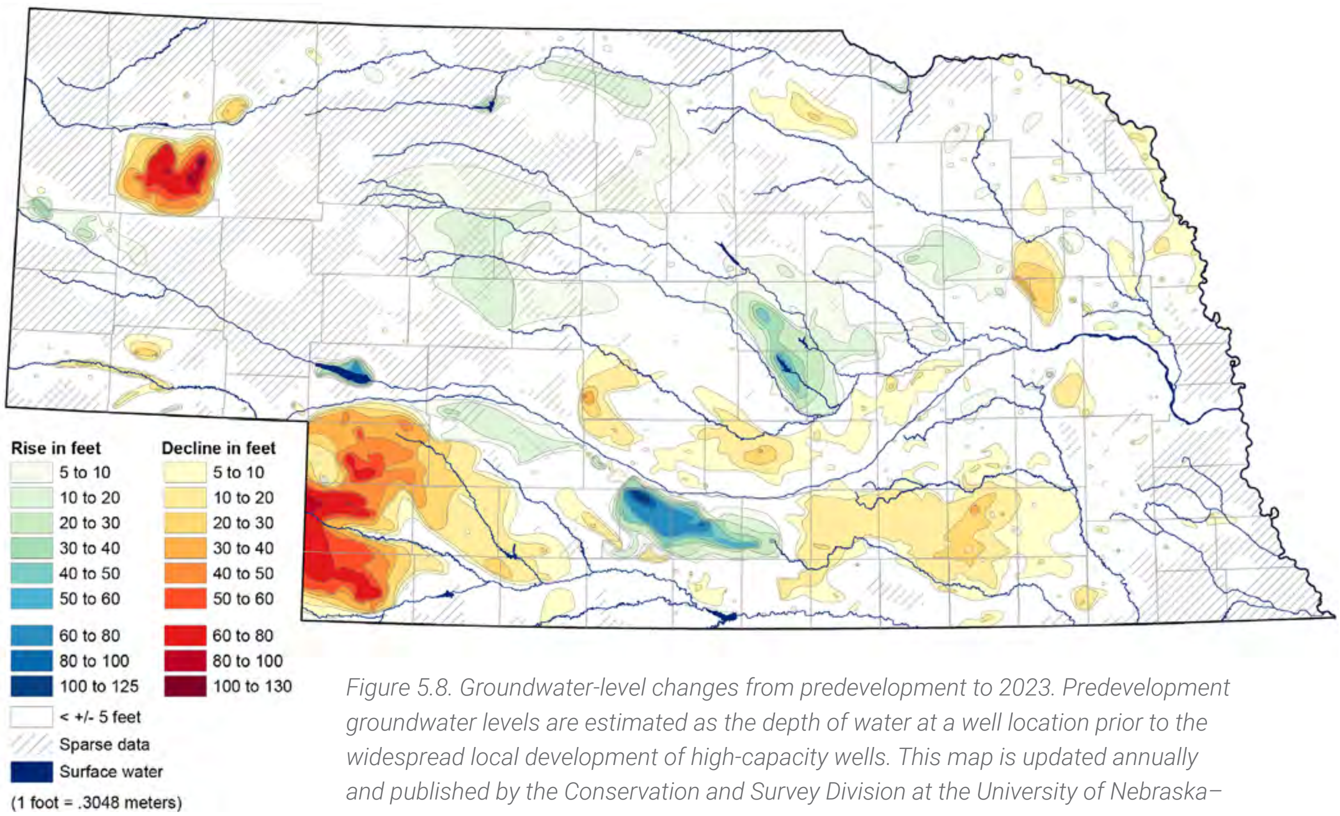

Figure 5.8. Groundwater-level changes from predevelopment to 2023. Predevelopment groundwater levels are estimated as the depth of water at a well location prior to the widespread local development of high-capacity wells. This map is updated annually and published by the Conservation and Survey Division at the University of Nebraska–Lincoln in the annual Groundwater Level Monitoring Report. More information can be found at https://go.unl.edu/groundwater. (Source: UNL CSD, 2024)

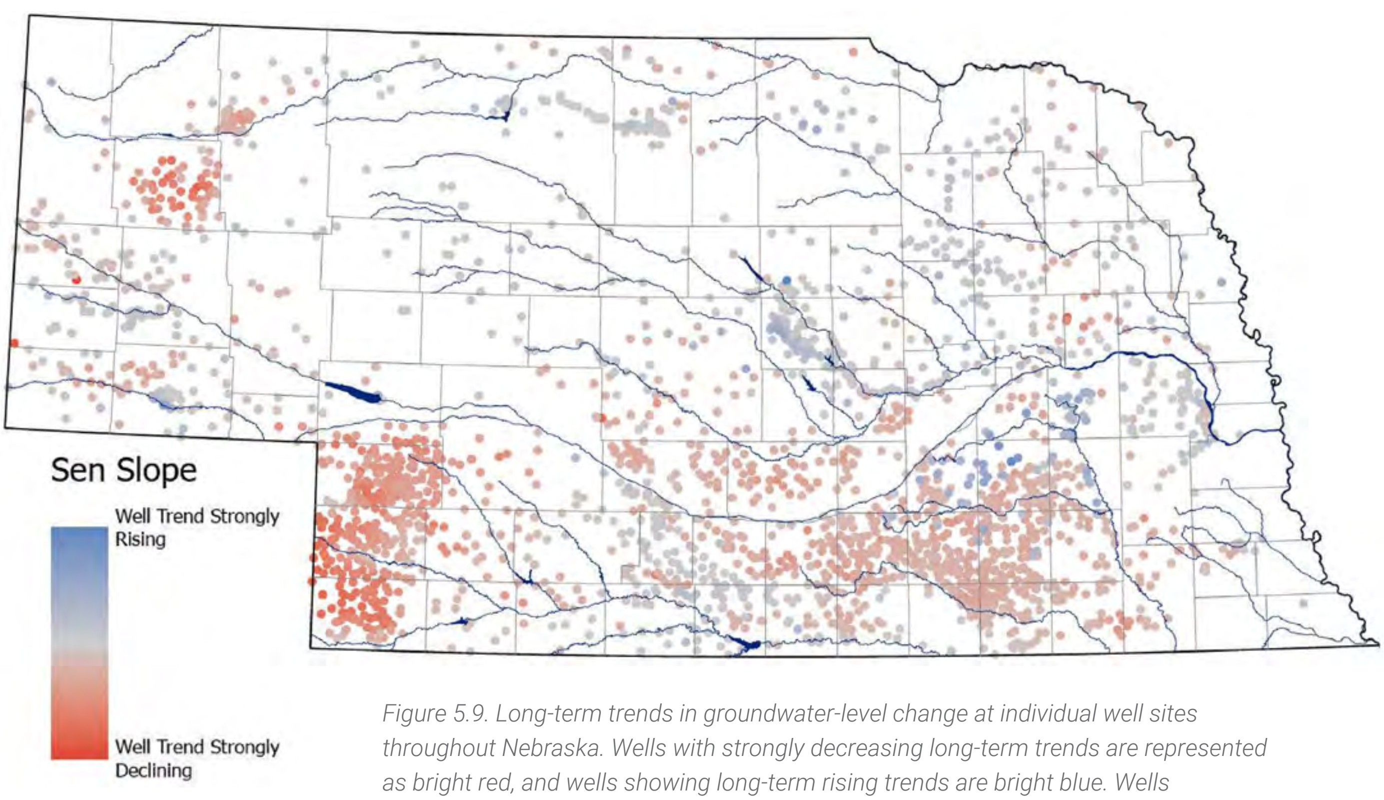

Figure 5.9. Long-term trends in groundwater-level change at individual well sites throughout Nebraska. Wells with strongly decreasing long-term trends are represented as bright red, and wells showing long-term rising trends are bright blue. Wells trending neither up nor down are gray. Trends are calculated using Sen Slope.

Several factors buffer statewide average groundwater-level departures from predevelopment.

- In the early 1970s, 23 NRDs were developed to conserve the state's groundwater resources. The NRDs were given statutory authority to manage Nebraska's groundwater quantity and quality through a board of locally elected officials. Each establishes locally tailored planning and policy. These policies often begin with incentive programs for adopting technology and management to improve water and other input efficiencies. If groundwater quantity or quality continues to degrade, a phased set of regulations is implemented, including water allocations and moratoriums on new high-capacity wells.
- Nebraska's farmers and ranchers, through education and more than a century of inherited knowledge and experience, have become stewards of the land that is their livelihood. During the 1970s, for example, some producers attempted to grow irrigated corn in the nutrient-poor soils of the Sandhills. Most of these ventures were unsuccessful and left lasting scars and reduced soil fertility in the region, some of which are still visible today. Even with today's financial incentives to grow corn on marginal lands, it is extremely rare to find row-crop agriculture in the Sandhills despite abundant water supplies.
- Technological advancements have allowed Nebraska farmers to apply irrigation water much more efficiently. Moving away from flood irrigation and toward center pivot irrigation improves efficiency and reduces the impact on groundwater quality.

At a local level, many variables contribute to changes in depth to groundwater. This includes natural variables such as changes in climate or microclimate (especially precipitation), local geology, groundwater transit time, flow direction, and aquifer confinement, as well as anthropogenic variables including groundwater withdrawal, altered stream flows, artificial recharge projects, and local and statewide pumping regulations. Furthermore, due to regional variations in travel times for water in the subsurface, the complete effects of major climate events may not be apparent for months to several years following the event. These factors, particularly the direct regulation of groundwater withdrawal, make forecasting long-term supply changes difficult. Multiple modeling studies are ongoing to better understand the future of our water resources in a changing climate. Although these studies are not yet complete, preliminary findings include the following.

- Statewide trends in groundwater-level changes will continue to follow trends in statewide precipitation. Extreme weather events are expected to increase in the coming decades (see Chapter 3). Due to the contrasting impacts of drought and extreme precipitation events, and assuming current water-use regulations remain near current limits, water levels will likely continue to decline very slowly over the long term as in recent decades (Figure 5.10).
- As more high-capacity wells are installed in Nebraska, the impacts of drought on groundwater will likely become more severe compared to the recharging effects of extremely wet years.
- The future impacts of climate change on groundwater will likely result from limits set on pumping by regulations developed by Nebraska's NRDs. Historically, compared to other states in the HPA, these regulations set forth by our NRDs have managed to keep groundwater-level declines to a minimum. The regulations developed by the locally elected boards in response to the changing climate will likely be the key to conserving groundwater resources.
- With proper management, groundwater will continue to be one of many resources available to provide resiliency against future climate change.
- Longer growing seasons and higher rates of evapotranspiration (ET) may increase the demand for irrigation water.

Groundwater quality is critical for the 88% of Nebraskans who rely on it for drinking water, as well as Nebraska's industries, farmers, and ranchers. Nebraska's NRDs, state and federal agencies, and the University of Nebraska conduct extensive groundwater quality testing and report in the Quality-Assessed Agrichemical Contaminant Database (NDEE, 2024b). Nebraska's groundwater already faces challenges with both agrichemicals and naturally occurring chemicals in the water. However, more research

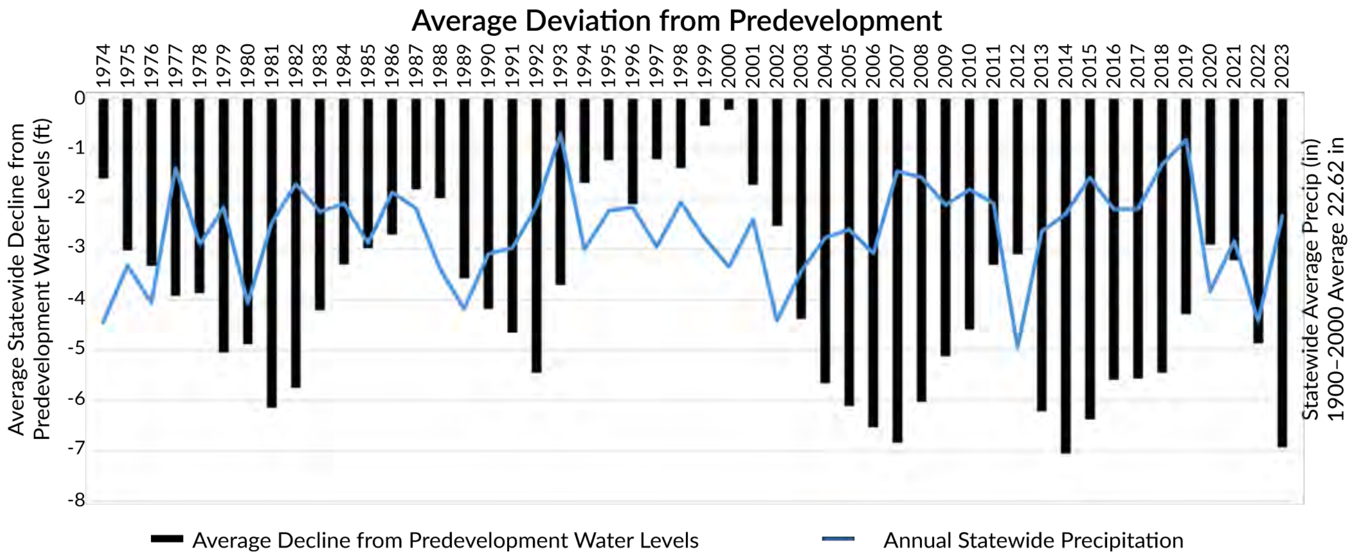

Figure 5.10. Black bars represent the average annual departure of wells measured from predevelopment groundwater-level estimates. Predevelopment groundwater levels are estimated as the depth of water at a well location prior to the widespread local development of high-capacity wells. The blue line represents the statewide average annual precipitation.

will be needed to determine the impacts of climate change on groundwater water quality. Soluble agrichemical loss to groundwater is sensitive to the type of land use, amount and timing of precipitation and irrigation, soil type, and depth of groundwater (Nebraska Water Center, 2024), several of which may be impacted by future climate change.

Gaps and needs

- Continued research on the interaction between surface water and groundwater, and the potential future impact of climate change on Nebraska's water resources.
- Research and modeling of the impact of global climatic teleconnections on Nebraska's groundwater quantity and quality.
- Analyses and case studies of the impact of conservation practices on groundwater and surface water quantity and quality.

Photo Courtesy: Marc Morrison, Adobe Stock.

Chapter 6

Energy

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Key messages

1. Energy-related emissions (burning fossil fuel for electricity, transportation, heat, steam, and fertilizer production) are Nebraska's leading cause of greenhouse gas emissions.
2. Nebraskans consume energy directly (fuel and energy purchases) and indirectly (in products and services).
3. Reducing emissions can have a positive financial impact (reduced energy and fertilizer costs).
4. Nebraskans will need to consider where the most significant impacts from energy efficiency and fuel switching can be made at all levels. This includes residential (heating and cooling), commercial (heating and cooling), transportation (vehicles), business-level policy, local policy, state-level policy, and national policy.
5. Emissions reduction goals should be compatible with reliability goals.

Introduction

Energy is a power or force derived from physical or chemical resources used to perform work, such as operating machines and providing light and heat. Energy is necessary for individuals and societies to survive and thrive. Humans use energy every day in various forms to refrigerate and freeze our food, cook our food, heat and cool our homes, manufacture products, and travel from place to place. Modern society is built on reliable energy sources and thrives on low-cost and reliable sources. Energy use results in emissions driving global climate change and reduced environmental quality. Emissions from energy use depend on the type of energy and how much is used. Greenhouse gas (GHG) emissions from energy generation are mainly carbon dioxide, yet other GHGs, such as methane, also contribute to total GHG emissions. Emissions are usually represented in carbon dioxide equivalents. Energy generation emissions can also include air pollution, such as particulates, volatile organic compounds, and nitrogen oxides. Air pollution and GHGs are both emitted when burning fossil fuels. Sixty-nine percent of Nebraska's total energy use comes from fossil fuels.

Total energy use in Nebraska (Figure 6.1) is led by petroleum used for transportation, followed by coal (electricity), renewables (electricity and transportation), natural gas (electricity and heating), and nuclear (electricity) (NDEE, 2023b). Nebraska's renewable energy consumption in 2023 comprised 11.5% biofuels, 8.9% wind, 1.35% hydroelectric, and less than 1% of others (wood and waste, geothermal, and solar). The national trend of total energy consumption has plateaued somewhat since 2000, yet total consumption is expected to grow from 0% to 15% between 2022 and 2050 (EIA, 2023a). The 2023 Annual Energy Outlook (AEO) contains estimates of future consumption and production based on various price and demand scenarios (EIA, 2023a). The AEO concludes a likely increase in electrification due to cheaper electricity driven by improved end-use technologies, efficiency, and declining costs of generation technologies. The greatest increase in electricity demand is predicted to come from increases in cooling demand and electric vehicles. Total energy consumption will depend on the growth of the economy. Nebraska will likely follow these trends of increased energy use as the economy grows.

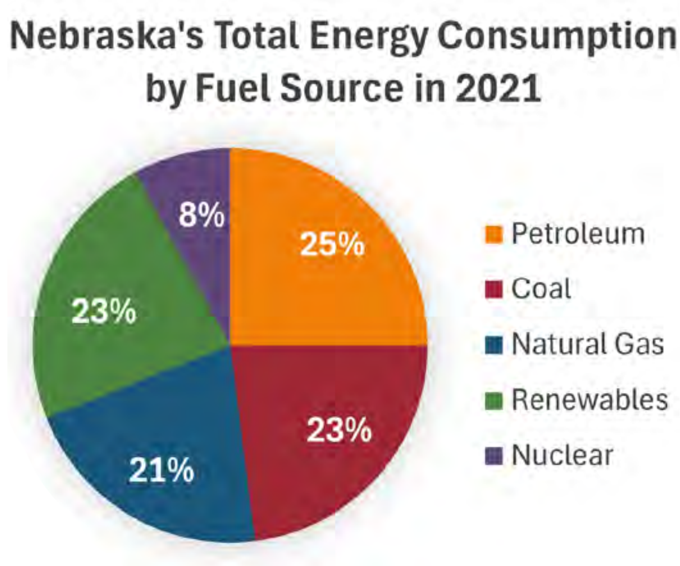


Figure 6.1. Nebraska's total energy consumption by fuel source, 2020. (Source: NDEE, 2023b)

Petroleum use in Nebraska is about half gasoline and half diesel fuel, with a smaller amount of aviation fuel. Coal burned in Nebraska is used exclusively for electrical generation. Nebraska's renewable sources are about half biofuels (mostly ethanol), about 40% wind power, 6% hydroelectric, and 0.3% solar. Natural gas consumption in Nebraska is 54% industrial use for manufacturing, 22% residential heating and water heating, 18% commercial heating and water heating, and 6% electricity production. Nuclear energy consumption is exclusively for electricity production. Individual Nebraskans are part of the energy system as they purchase fuel for their cars, trucks, and tractors and pay electricity and natural gas bills in their homes.

Nebraska's energy consumption by sector yields more details on how Nebraskans use energy (Figure 6.2). The industrial sector is Nebraska's largest energy user and accounts for energy used in manufacturing, mining, construction, and agriculture. Transportation mainly uses gasoline and diesel fuel, with a smaller amount of aviation fuels and natural gas. Electricity is a growing transportation fuel, and electric vehicle purchases are growing. Commercial energy use is mainly from buildings, with major energy use from warehouses, storage, offices, services, mercantile, public assemblies, religious worship, education, and food services. Residential energy use is dominated by space heating,

water heating, and air conditioning. Nebraskans may not directly
purchase energy used in commercial and industrial sectors, yet they indirectly purchase that energy through their use of services and purchase of products. From a cost standpoint, transportation dominates the total energy expenditure in Nebraska. Although only 23.6% of total energy consumption is transportation fuels, they are more expensive than fuels used in industrial applications, leading to higher total expenditures. Nebraska's electricity consumption in the commercial sector is seeing substantial increases due to economic growth, including growth in the data center and data mining fields. This increased need for electrical cooling at data centers will continue nationally, with greater use of data on computers and mobile devices and artificial intelligence. Consumers use data in mobile devices and computing, driving demand for more data centers, which is an example of indirect emissions. The direct and indirect use of energy in Nebraska leads to emissions. These emissions drive both climate change and increase air pollution.

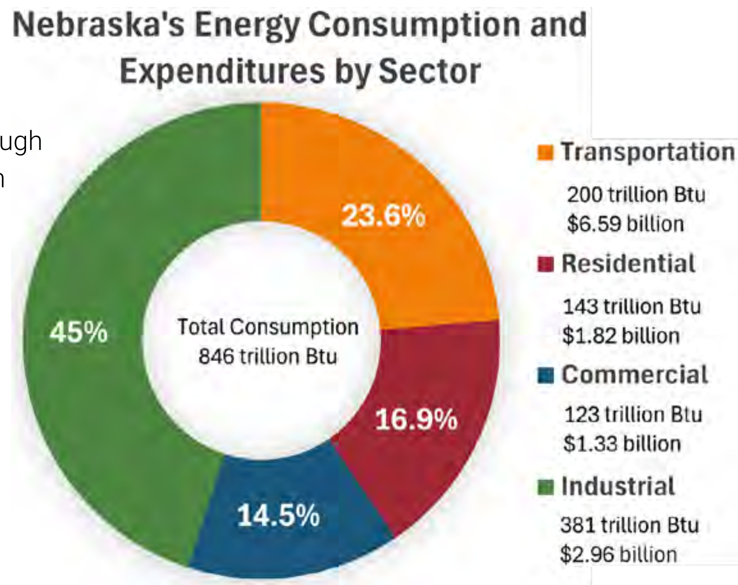


Figure 6.2. Nebraska's energy consumption and expenditures by sector. (Source: EIA, 2024)

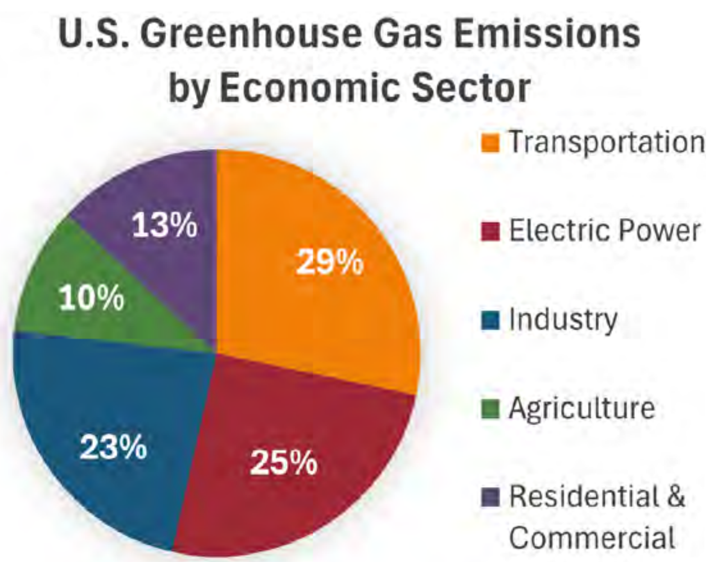


Figure 6.3. U.S. greenhouse and gas emissions by economic sector (EPA, 2024e). (Bottom, left) Nebraska greenhouse and gas emissions by economic sector in 2021 (NDEE, 2024). (Bottom, right) Nebraska greenhouse and gas emissions by economic sector in 2021 (Source: NDEE, 2024b)

Energy is the primary source of emissions in the United States. Figure 6.3 shows the total U.S. greenhouse gas emissions by economic sector. For the U.S. the primary source of emissions is burning fossil fuels, except for agriculture, whose primary emission sources are methane from enteric fermentation and nitrous oxides from soils. Nebraska's breakdown of emissions (Figure 6.4) is led by agriculture (41.7%), electricity production (24.2%), transportation (15.2%) and industry (11.4%).

Fossil fuel emissions from greenhouse gases and air pollutants such as nitrogen oxides and particulates can be broken into direct emissions, such as the emissions from burned fuels, and indirect emissions from upstream processes to extract and transport fuel, manufacturing construction, and conversion equipment. Indirect emissions are also important to consider for all energy sources, including fossil fuels and renewables. Some energy systems, like wind and solar, do not produce fuel emissions. As a result, most of their emissions come from indirect emissions. Advertising commonly declares renewables like wind, solar, or electric cars as having zero emissions. These claims may be valid if the emissions are only looked at narrowly after wind and solar installation or only during the electric car's operation. However, when total life-cycle emissions are included, renewables and electric cars have emissions that should be considered.

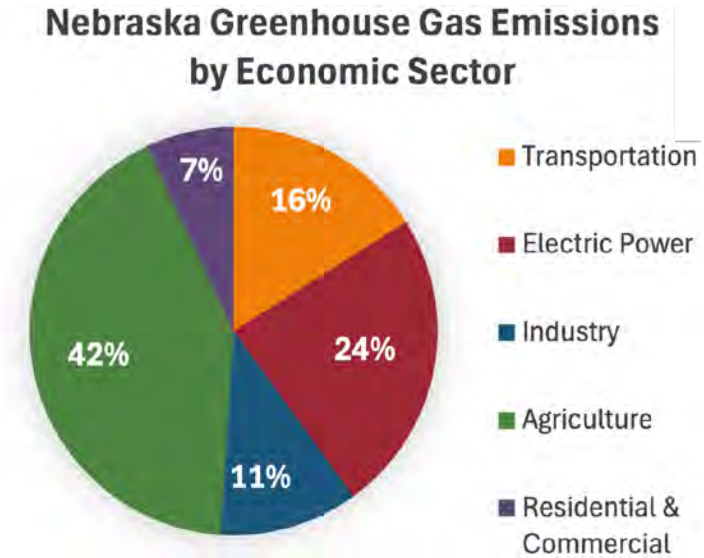


Figure 6.4. Nebraska greenhouse gas emissions by economic sector in 2021 (Source: NDEE, 2024b).

Table 6.1 contains a list of life-cycle emissions for different fuel types. These emissions are reported per unit of energy. To calculate these, the direct and indirect emissions are totaled for the planned lifetime of the project or product and divided by the estimated total energy produced or consumed during its lifetime. Units for Table 6.1 are carbon dioxide equivalent (CO2e) emissions per unit of energy generated or used in kilowatt hours (kWh). Carbon dioxide equivalents are used to standardize emissions values regardless of emissions type. For example, when methane is emitted, it would equal 28 CO2e. Comparisons of these values should only be made between similar fuels; for example, comparing diesel with biodiesel or renewable diesel compares fuels that work in equipment with similar efficiencies and shows bio and renewable diesel to have considerably fewer emissions than petroleum diesel fuel. Care should be taken when comparing fuels that cannot directly replace the other. For example, comparing electricity used for transportation with gasoline leads to comparison problems because of the difference in efficiency between these two systems. To make this comparison more informative, the values could be converted to CO2e per mile driven. For example, a gasoline car has emissions of 412 grams of CO2e per mile driven, while a similarly sized electric car (charging from the Nebraska Grid Mix in 2021) has 283 grams of CO2e per mile driven. Electricity has larger emissions per unit of energy than gasoline, yet the per mile emissions are lower because of electric motors' higher efficiency than gasoline engines (Argonne National Laboratory, 2022). Similarly, a comparison of emissions from electricity generation should be made with consideration to the type of generation. Dispatchable generation sources such as natural gas, coal, and nuclear can be turned on or off, or their output can be increased or decreased, to match electricity demand as needed, although each has limits on how quickly or flexibly it can be adjusted. By contrast, renewable energy sources such as solar and wind are non-dispatchable or intermittent, producing power only when their natural resources (wind and sunlight) are available. However, innovative solutions such as energy storage and smart grids address concerns related to intermittency. Ensuring a continuous electricity supply requires a balanced mix of resources, including renewables, dispatchable generation, and storage. Future planning for electricity generation and emissions reductions will need to consider the availability and characteristics of different sources to provide both reliability and lower emissions.

Table 6.1. Life-cycle greenhouse gas emissions by fuel type

TRANSPORTATION				
FUEL TYPE	**EMISSIONS** (GCO_2E/KWH)	**EMISSIONS** (GCO_2E PER MILE DRIVEN)	**RANGE FROM LITERATURE** (GCO_2-E/KWH)	**SOURCE**
Gasoline	326	412	320–393	Argonne National Laboratory, 2022; Rahman et al., 2015
Diesel	323	340–2800	321–397	Argonne National Laboratory, 2022; Rahman et al., 2015

TRANSPORTATION				
FUEL TYPE	**EMISSIONS** (GCO_2E/ KWH)	**EMISSIONS** (GCO_2E PER MILE DRIVEN)	**RANGE FROM LITERATURE** (GCO_2-E/KWH)	**SOURCE**
Ethanol (corn grain)	200	(E85) 288 (E10) 407	135–234	Argonne National Laboratory, 2022; Scully et al., 2021a

TRANSPORTATION				
FUEL TYPE	**EMISSIONS** (GCO_2E/ KWH)	**EMISSIONS** (GCO_2E PER MILE DRIVEN)	**RANGE FROM LITERATURE** (GCO_2-E/KWH)	**SOURCE**
Ethanol (biomass, switchgrass and corn stover)	90	92–139 (E85) 100 (E10) 278	-13– -108	Argonne National Laboratory, 2022, Liu et al., 2020 Murphy & Kendall, 2015
Biodiesel/ Renewable Diesel	113	(biodiesel B20) 298 (renewable diesel) 240–424	75–113	Argonne National Laboratory, 2022; H. Xu et al., 2022
Electricity	466	(U.S. mix) 165 (NE mix 2021) 283	12–1,001	Argonne National Laboratory, 2022

ELECTRICITY GENERATION			
FUEL TYPE	**EMISSIONS** (GCO_2E/KWH)	**RANGE FROM LITERATURE** (GCO_2E/KWH)	**SOURCE**
Coal	1001	675–1,689	Whitaker et al., 2012
Natural Gas Combined Cycle	460	420–480	O'Donoughue et al., 2014
Natural Gas Combustion Turbine	640	486–750	O'Donoughue et al., 2014
Heavy Fuel Oil	830		Tarannum & Mohammed, 2019
Nuclear	13	3.1–220	Warner & Heath, 2012
Wind (onshore)	12	1.7–81	Dolan & Heath, 2012

ELECTRICITY GENERATION			
FUEL TYPE	**EMISSIONS** (GCO_2E/KWH)	**RANGE FROM LITERATURE** (GCO_2E/KWH)	**SOURCE**
Solar (photovoltaic)	43	18–129	Hsu et al., 2012
Solar (Thermo Electric)	28	7–240	Burkhardt et al., 2012
Geothermal	37	15–245	Eberle et al., 2017

ELECTRICITY GENERATION			
FUEL TYPE	**EMISSIONS** (GCO_2E/KWH)	**RANGE FROM LITERATURE** (GCO_2E/KWH)	**SOURCE**
Hydroelectric	21	4–165	Kumar et al., 2011
Biomass	52	20–69	*Literature Review and Sensitivity Analysis of Biopower Life Cycle Assessments and Greenhouse Gas Emission*, 2013

STORAGE			
FUEL TYPE	**EMISSIONS** (GCO_2E/KWH)	**RANGE FROM LITERATURE** (GCO_2E/KWH)	**SOURCE**
Pumped Hydro Storage (PHS)	86	58–530	Kumar et al., 2011; Simon et al., 2023
Lithium Ion Battery	33	33–600	Nicholson et al., 2021; Oliveira et al., 2015
Hydrogen Fuel Cell	38	30–315	Frank et al., 2021; Khan et al., 2005
Compressed Air Energy Storage	230	30–750	Oliveira et al., 2015

Trends

Electricity

The energy industry is changing due to new technology, resource availability, and resource costs. The Energy Information Administration (EIA), in its Annual Energy Outlook (AEO), uses possible scenarios to estimate the generation mix in future years. Scenarios allow for estimates based on possible future costs, such as high oil and gas prices, low oil and gas prices, and high or low renewable energy prices. In the 2023 AEO, the predicted trend for all economic scenarios is for the retirement of older coal and nuclear power plants and the addition of natural gas, wind, solar, and energy storage. Coal and nuclear retirements are fewer for scenarios with low oil and gas supplies and high costs for renewables. Scenarios with high oil and gas supplies and low renewables costs saw higher coal and nuclear retirements and higher wind and solar additions. In all cases, the trend shows the retirement of coal and nuclear and the addition of natural gas, wind, and solar (EIA, 2023a). These are just predictions, and the reality will depend not only on supplies and costs but also on changes in public policy, consumer demand, and geopolitics.

Oil

Through 2024, the U.S. has been the world's leading oil producer. Production is predicted to be high through 2050, with variability based on changes in supply.

Exports of refined products drive oil production, and predictions vary widely due to possible changes in price and international policy. U.S. oil consumption is predicted to remain steady, with little to no increase through 2050. Although the total number of cars may increase, oil demand is predicted to remain steady due to the continued increase in fuel efficiency of gasoline and diesel vehicles, as well as an increase in non-fossil fuel vehicles such as electric vehicles (EIA, 2023a).

Natural gas

The Annual Energy Outlook (EIA, 2023a) predictions for natural gas suggest little to no increase in demand. A more detailed look shows industrial uses are predicted to increase through 2050 while electrical generation uses decline. The decline in electrical use prediction has substantial variability and will depend on economic growth, the price of electricity storage (batteries), and the cost of low-carbon generation technologies.

Innovation and uncertainty

Although trends show growth in natural gas, wind, and solar, other technologies, such as coal and natural gas with carbon capture and storage and advanced nuclear, may emerge. Numerous technologies are in various stages of development, which may impact future generations and emissions. Some examples, such as hydrogen, small modular nuclear, enhanced geothermal, and nuclear fusion, are regularly seen in the news. Unforeseen circumstances, such as changes in policy and geopolitical events, challenge predictions of energy production and consumption.

Federal policy and subsidies

One definition of a subsidy is a sum of money a government gives to assist a business in keeping the price of a commodity low or competitive. However, some economists broaden the definition beyond just payments: "A subsidy is a benefit given to an individual, business, or institution, usually by the government" (Investopedia Team, 2023). This broadened definition can help when considering energy subsidies. The U.S. government has given energy subsidies ubiquitously for all types of energy generation. However, this report will focus only on more recent policy activity impacting generation and consumption now and in the near future.

Subsidies for electricity

Renewable energy technologies have long benefited from federal and state subsidies to promote renewable energy generation. The most recent iteration is the Inflation Reduction Act (IRA) of 2022 (White House, 2023). Changes in presidential administrations have led to an on-again, off-again nature of subsidies, including portions of the IRA. The recently passed One Big Beautiful Bill Act, signed by President Trump in 2025, significantly modifies provisions of the IRA (H.R.1 - 119th Congress, 2025). For example, portions of the IRA subsidizing wind and solar are set to expire early, while subsidies for nuclear, hydroelectric, and geothermal are retained. Additionally, subsidies for carbon capture and storage were expanded. A reduction in subsidies can influence the adoption rate of technologies, and the expiration of wind and solar subsidies will likely slow growth. Other factors, such as price, the environmental goals of private industry and public entities, and market supply and demand, will likely lead to some level of continued development of new wind and solar capacity.

Subsidies for biofuels

Nebraska is a leader in ethanol production and ranks second nationally, producing over 2.2 billion gallons annually. Nebraska also consumes ethanol in the form of gasoline blends. Ethanol and biofuel subsidies have a long history. However, more recent laws, such as the Energy Policy Act of 2005, called the Renewable Fuel Standard (RFS), and later, the Energy Policy Act of 2007 (RFS2), continue to impact the biofuel market (Congressional Research Service, 2023). Tax credit subsidies paid to blenders for blending biofuels were part of the RFS and RFS2. Those tax credits expired in 2011, and now only the other RFS2 provisions require blending to impact biofuel production and consumption. The RFS and RFS2 mandate that the fuel industry blends biofuels with petroleum fuels. This mandate is a form of subsidy because it benefits the biofuel industry by creating demand for their products. The blending requirement rules require increased biofuel blending volumes and specify the blending levels for different biofuels based on their emissions compared to gasoline. Nationally, corn ethanol production and consumption has grown to over 15 billion gallons per year before reaching somewhat of a plateau. The plateau is caused by starch-based ethanol reaching the required blending maximums in the RFS2 and the limitations of using ethanol blends beyond 10%. The future of biofuels will continue to be impacted by the current RFS2 and IRA policies. However, it is important to note that the quality of the fuel characteristics of the biofuel itself also drives the demand for biofuels. The fuel industry desires ethanol's high octane and oxygenate characteristics. Nebraska has proven to be an excellent location for corn-based ethanol, as our combination of corn production and cattle feeding has benefited ethanol producers in the state. With a flat growth in gasoline use predicted, the ethanol industry will need to look to higher blends and other uses to fuel growth (EIA, 2023a). The growth of blends beyond 10% and the growth of emerging markets like ethanol and sustainable aviation fuel (SAF) are ways corn-based ethanol can maintain or grow beyond RFS2 limitations.

Biodiesel can be made from a variety of vegetable oils and animal fats. Biodiesel is made by chemical reactions, converting triglycerides into methyl esters. Biodiesel can be used in diesel engines but is usually blended with petroleum diesel. Because of its different fuel characteristics, most engine manufacturers recommend blends of 20% or less. The biodiesel industry grew rapidly in the early 2000s, using soybean oil as a primary feedstock. Soybean oil remains the primary biodiesel feedstock, with 57% of biodiesel made from soy oil. Corn oil is second with 14%, followed by recycled waste oils (11%), canola (10%), and animal fats (8%). Nebraska currently has one biodiesel producer. Like biodiesel, renewable diesel is made from vegetable oils. Renewable diesel is made using a thermochemical refinery process and has fuel characteristics chemically equivalent to petroleum diesel. Soybean oil is the primary feedstock for renewable diesel, and 68% is made from soy oil. Corn oil is second with 20%, then canola oil at 7%, and recycled oils at 5% (EIA, 2022).

Climate risks

Climate and weather extremes continuously challenge the energy sector. This section will review some of the risks faced by the energy sector in general terms and then note some examples of how Nebraska's energy sector has been impacted in the past. A look at the past will help in planning for future climate and weather conditions.

Water

Water is used extensively in electricity generation. Large volumes of water are needed in thermal power plants, such as coal, nuclear, and combined cycle natural gas. Nebraska's 2023 electric energy was 53% coal, 19% nuclear, 22% wind, about 3% natural gas, and 3% hydroelectric, with small amounts of solar, biomass, and oil (NDEE, 2023b). With reliance on thermal electric systems, access to adequate water for cooling is critical for electric grid reliability. The USGS, in the report by Harris and Diehl (2019), indicates that as much as 32 gallons of water are pumped per kWh of electricity generated. Water quantity is critical to maintaining thermal electric production, yet reduced quantity due to drought can lead to a secondary issue, which is increased water temperature. Power plants can be impacted when water levels are too low to operate, water inlet temperatures are too high, and water outlet temperatures are too high. These results could be lower thermal efficiency, plant curtailments, shutdowns, or working with permitting agencies to operate with variances. From 2000 to 2015, the National Renewable Energy Lab reported 43 instances where power plants were curtailed, shut down, or received variances due to water temperature, including one in Nebraska (McCall & Hillman, 2016). Excess water from flooding has also been a problem for electricity generation (see below, Climate Risk in Nebraska). The energy sector should continue to plan for weather and climate, preparing their systems to adjust to reduced water levels and increased water temperatures. Climate trends show reduced summer precipitation, reduced mountain snow water equivalent, and increasing duration and frequency of droughts (Chapter 3).

Climate risk in Nebraska

Climate risk is important for all forms of energy. Nebraska's energy system has experienced numerous problems due to extreme weather (Table 6.2). Some of these conditions will likely become more common as the climate changes. Flooding and drought have caused major issues for Nebraska's energy sector. However, more common weather events such as thunderstorms, wind, and falling trees caused the greatest number of utility outages from 2009 to 2019 (DOE, 2021). As severe weather events become more common, Nebraska can expect the risk of weather event–related utility outages to increase. See supplemental report 1, Table A.1. Summary of the potential climate impacts and adaptation considerations for more information (DOE, 2013).

Table 6.2. Nebraska examples of extreme weather and climate impacts on energy systems. These examples are taken from the public record and represent only the largest events.

LOCATION	YEAR	IMPACT
North Platte River Hydropower	2006	A multiyear drought caused a reduction in power production
Fort Calhoun Nuclear	2011	Floods caused shutdown
Spencer Dam Hydropower	2019	Floods caused catastrophic dam failure
Nebraska Electrical Grid	2021	A polar vortex and energy demand spike led to rolling blackouts
Solar	2023	Large hail and high winds caused significant damage to a solar farm in Scottsbluff
North Omaha Coal Nebraska City Coal	2024	The Missouri River froze at the water intake
Lincoln-, Omaha-Area Transmission and Distribution System	2024	A windstorm caused widespread outages and the largest Omaha-area outage

Nebraska's energy future

Nebraskans have many opportunities to react to the changing climate. Preparation for climate risks to minimize impact will be critically important for our energy sector. Additionally, Nebraskans can work to reduce emissions and subsequent impacts of greenhouse gas emissions. Actions to reduce emissions can be individual, local, or by governments and businesses. Some individual behaviors—such as improved fertilizer efficiency and reduced fossil fuel usage by increased efficiency—directly impact emissions. However, behaviors that impact local, state, national, and international policies and markets can have a more significant impact indirectly than individual direct impacts (Stern, 2000). This statement is not meant to discourage individual direct actions but to highlight the importance of actions such as voting and advocacy, which can impact future policies.

Agricultural emissions and strategies to reduce emissions

Nebraska's emissions from agriculture comprised 42% of the state's emissions in 2021. For the U.S., agricultural emissions comprise 10.6% of total greenhouse gas emissions. In the U.S., agricultural emissions are primarily comprised of three greenhouse gases: methane, nitrous oxides, and carbon dioxide (EPA, 2024e). Agricultural and energy emissions are connected through several pathways: the fuel used by farm equipment, the energy required to produce nitrogen fertilizers and other inputs, and the nitrous oxide released from nitrogen applications. Because of these connections, the energy chapter should briefly address agricultural emissions, beginning with methane. Most methane comes from enteric fermentation (a digestive process) in cattle and from manure. Reducing methane emissions is challenging, but new approaches, such as using feed additives, show promise (Tseten et al., 2022). Better manure management, such as using anaerobic digesters, spreading manure daily, and composting, can also help reduce methane emissions.

Nitrous oxides are emitted from soils, and emissions are higher when nitrogen (fertilizers, manures) is applied to soils. Because nitrogen is essential for high-yielding agriculture, the best way to reduce nitrous oxides is to improve nitrogen use efficiency. Practices known as the "4 Rs"—using the right source, at the right rate, right time, and right place—save farmers money (less fertilizer costs), protect water quality and human health (less nitrate leaching or runoff), and lower greenhouse gas emissions. These climate-smart farming practices align with profitable farming practices, as they maintain yields, improve soil health, reduce energy and fertilizer waste, and make farms more resilient to climate extremes.

Methane and nitrous oxide are especially important to address because they trap far more heat than carbon dioxide. Focusing on these gases can create major climate and environmental benefits. Other emissions can also be reduced through practical steps, such as upgrading to more efficient equipment, improving driving practices, and reducing pesticide use.

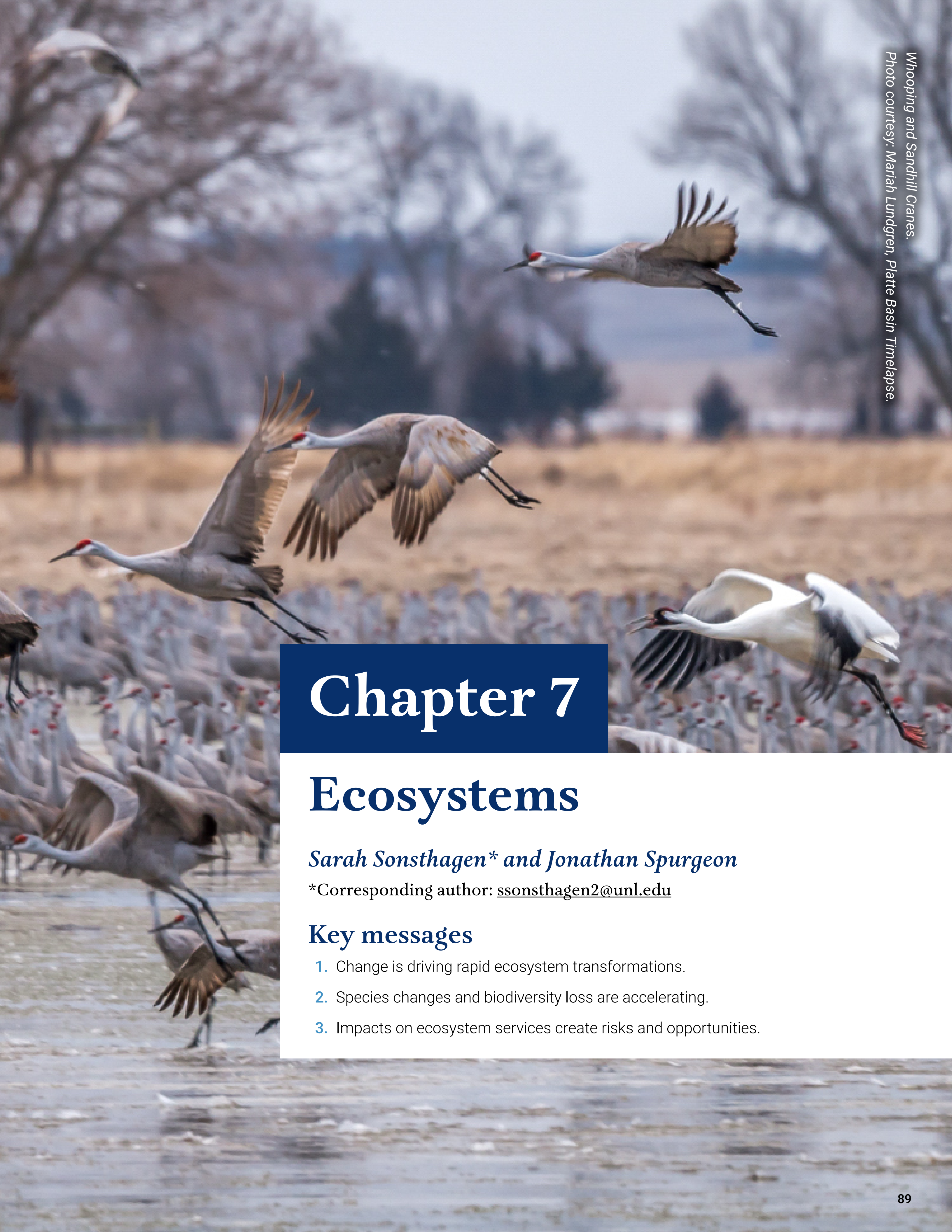
Methane and nitrous oxide are especially important to address because they are the largest and most potent emissions, trapping significantly more heat than carbon dioxide. Prioritizing emissions reductions of these gases can lead to significant benefits for the climate and the environment. Other farming emissions can be reduced through practical steps, such as upgrading to higher-efficiency machinery, driving vehicles more efficiently (gear up, throttle down), and minimizing pesticide purchases.

Conclusions

- Nebraska depends heavily on fossil fuel sources, particularly oil, coal, and natural gas.
- Nebraska must consider weather and climate extremes as it develops and implements new electricity generation and storage resources that trend toward lower emissions.
- Planning for the increased incidence of extreme weather and climate events is crucial to ensuring a reliable energy supply during these events.
- Adopting energy selection and efficiency strategies is important for meeting Nebraska's goals for the environment, the health of its citizens, and its economy.
- By electing representatives at all levels of government who reflect their goals for Nebraska's environment, the health of its citizens, and its economy, Nebraskans can help ensure that their voices are heard.
- By creating a trajectory toward increasingly efficient, cleaner, and more reliable energy systems, the state government can bring significant benefits to Nebraska, including improved energy security by diversifying sources, cost savings on energy bills, economic growth through job creation, and lower greenhouse gas emissions.
- It has been said that every little bit helps, yet physicist David MacKay says, "If everyone does a little, we will achieve only a little." We need to achieve a lot to make a big impact (MacKay, 2009). Do not dismiss individual actions, but focus on improving at larger scales, such as government policy focused on our largest uses and emissions.

Gaps and needs

- Social science research focused on accepting nuclear energy in Nebraska communities.
- Energy storage research on batteries and other utility-scale storage.
- Public perceptions and opinions on distributed generation resources and policy in Nebraska.
- Identification of markets for ethanol beyond gasoline fuel mix.
- Continued research on greenhouse gas emissions from agriculture, including reducing methane emissions from cattle, products, or practices that reduce nitrous oxide emissions.



Whooping and Sandhill Cranes.
Photo courtesy: Mariah Lundgren, Platte Basin Timelapse.

Chapter 7

Ecosystems

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Key messages

1. Change is driving rapid ecosystem transformations.
2. Species changes and biodiversity loss are accelerating.
3. Impacts on ecosystem services create risks and opportunities.

Introduction

The Fifth National Climate Assessment updates the evidence regarding how climate change influences ecosystems, biological diversity, and the implications for changes to critical ecosystem services—as noted in the key messages above (McElwee et al., 2023). Large-scale transformational changes to ecosystems are occurring, including—but not limited to—land-use conversion, hydrological alteration, and fire regimes. Implications of such transformational change include ecosystem capacity to maintain biological diversity and ecosystem services, impacting recreational opportunities (e.g., hunting and fishing, birding, ecotourism) and agriculture production (McElwee et al., 2023). A central tenet of the Fifth National Climate Assessment regarding ecosystems was the shifts to alternative states and how the Resist-Accept-Direct (RAD) framework may guide the adaptive management of ecosystems moving forward (Lynch et al., 2022).

Nebraska is in the northern Great Plains, where extremes in climate and resulting ecosystem processes are experienced (Knapp et al., 2023). Pressures on ecosystems to provide essential services, including healthy soil and water to benefit humans and animals, will inevitably impact economic development, urban and rural communities, and fish and wildlife populations as climate change continues (Knapp et al., 2023). All ecosystems will be impacted in Nebraska, but aquatic systems—wetlands, aquifers, lakes, streams, and rivers—may be most impacted, given the scarcity of water as human demand (i.e., agriculture and a growing population) persists and increases (Bathke et al., 2014). Major knowledge gaps remain regarding how fish and wildlife populations will persist in changing environments. Past changes, including large-scale land conversion, water delivery systems, and water storage (construction of reservoirs), suggest that some species can adapt to novel environments and shift distributions. However, many more species may be maladapted to the expected changes in climate. Species may be unable to move to suitable habitats, and biological constraints under rapidly changing conditions may impede adaptation—resulting in extirpation and potential extinction. Further, changing conditions open multiple pathways for invasive species and novel diseases, impacting native fish populations, wildlife populations, and human health.

Climate change challenges for fish and wildlife populations undergoing ecosystem change in Nebraska

Nebraska has distinct landscapes that host many aquatic and terrestrial species critical to healthy ecosystems and people (Schneider et al., 2011). Nebraska is broadly divided into ecoregions (Figure 7.1) that include (from west to east) the Shortgrass Prairie, Sandhills, Mixed-grass Prairie, and Tallgrass Prairie (Schneider et al., 2011). Iconic species, including swift fox, whitetail deer, channel catfish, and prairie grouse, reside in these landscapes.

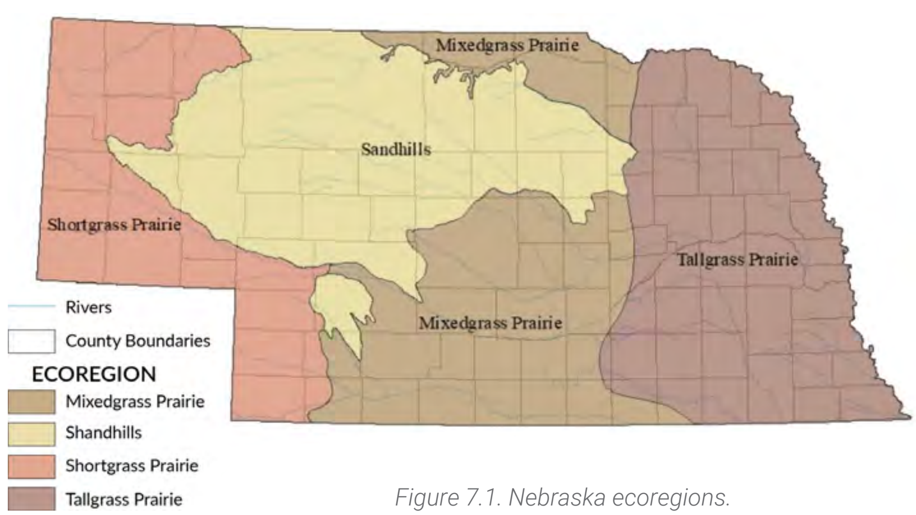

Figure 7.1. Nebraska ecoregions.
(Source: Nebraska Game and Parks Commission, n.d.)

Healthy ecosystems and the landscapes supported therein are critical to maintaining rich biodiversity within Nebraska. For instance, healthy grassland systems void of woody plant encroachment support upland bird populations, including the greater prairie chicken (Roberts et al., 2022). Migratory species access Nebraska landscapes on their way to critical habitats used for reproduction and overwintering. Given the wetlands and grasslands within the Sandhills and Rainwater Basin, Nebraska has a major role in waterfowl production. The Platte River provides a habitat for migrating sandhill cranes and endangered pallid sturgeon. As climate change alters hydrologic cycles, these species will face an unknown distribution and quantity of water that may no longer meet their habitat needs.

Climate primarily influences the distribution and abundance of species across Nebraska landscapes. Species have evolved unique adaptations to their local climate, including when and how often they reproduce, stress tolerance to extreme heat and cold, and feeding habits. For instance, temperature is critical for many physiological processes in mammals, fishes, and invertebrates across Nebraska. Temperature and other environmental cues can induce movement across the landscape. Further, many species in Nebraska are ectotherms (e.g., fish, reptiles, and amphibians) and depend on a finite range of temperatures.

Changes in climate may result in environmental regimes that overshoot the physiological limits of and alter critical biological cues for many species, which will influence biodiversity patterns in Nebraska and the surrounding region. Climate change and human alteration to the landscape have already affected ecological processes such as fire and hydrologic regimes and nutrient cycling critical to ecosystem health, particularly in the northern Great Plains (Knapp et al., 2023). Such changes alter the distribution of critical habitats needed by species. Changing precipitation patterns and extreme events, including flooding and drought, will be particularly important. Flooding and drought are not new phenomena in Nebraska or the Great Plains, but rapid movement away from the historic patterns may limit the adaptive capacity of many species. For instance, stream fish can tolerate a range of water temperatures (often termed reaction norms or phenotypic plasticity). Prolonged periods of intense heat and elevated water temperatures during extreme low-flow periods may result in additional mass mortalities or the inability to carry out life stages, including reproduction. Species confronted with changes to climate may be forced to adapt to new conditions by altering the timing of movements and reproduction. The pace at which species adapt to changing conditions may outpace evolutionary timescales. Further, if conditions are not suitable and species cannot adapt to new environments, movement to suitable locations to complete their life cycles (i.e., growth and reproduction) is needed. However, many species cannot move great distances or are prevented from movement given human infrastructure (e.g., dams) and poor connectivity among habitat patches (e.g., disconnected wetland complexes too far apart for movement). As such, climate change may also exacerbate non-climate stressors, including habitat loss and fragmentation, pollution, and the spread of invasive species.

As with other northern Great Plains states, Nebraska is expected to experience an expansion of climate extremes, including variability in precipitation, severe droughts, floods, and increases in hail frequency. Such changes directly influence fish and wildlife populations by acting on key demographic parameters. Populations are regulated through births, deaths, immigration, and emigration. Climate change can influence all such regulating processes. For instance, climate variables have a major role in regulating bobwhite quail population dynamics (Edwards et al., 2024). Prolonged periods of drought can cause stream drying and constrict species into refuge habitats where multiple species are confined. Predation may increase and direct mortality from complete desiccation (Magoulick, 2000). Movement and emigration may be influenced as continued land conversion continues and stream fragmentation intensifies, given the need to increase agriculture production and infrastructure to combat changing water distribution and quantity. Mechanisms directly or indirectly influencing births, deaths, immigration, and emigration of fish and wildlife may manifest in unexpected ways within the context of changing climate and influence the continued presence and distribution of species across Nebraska.

Conceptual frameworks for managing fish and wildlife populations under uncertain climate variability

Conceptual frameworks exist to aid managers in decision-making while facing uncertainty about how species will respond to changing climate. These frameworks are gaining traction and offer potential paths forward for informing management scenarios in the future. Two primary frameworks for viewing ecosystems under change and how to address those changes are Panarchy and The Resist-Accept-Direct (RAD) framework. Panarchy is a conceptual framework that depicts complex systems (e.g., Nebraska ecosystems such as Sandhills ecoregion) comprised of people and nature as dynamically organized across spatial and temporal scales (Allen et al., 2014). Panarchy is a way to conceptualize how ecosystems change through time and space in the context of human-mediated change and non-human processes. Depending on the ecological resilience of the system, changes may be very slow (eastern red cedar expansion) or fast (land conversion for agriculture production). Large-scale changes in climate variables may either act synergistically or antagonistically in many ecosystem processes across Nebraska. Panarchy emphasizes cycles and the periods in which an ecosystem is "stuck" in a particular part of a cycle. An example is the eastern red cedar expansion, which transformed grasslands into transitional woodlands, reducing grassland production. Another example includes the internal loading of nutrients in lakes and reservoirs, limiting the successful transformation of an aquatic system back to a less eutrophic state. Using the Panarchy framework to assess the state of an ecosystem can directly inform whether to resist change, accept change, or direct change on an alternative path.

The RAD framework, along with adaptive resource management, is suggested as a working guide for resource managers challenged with confronting changes to ecosystems under current and future changes in climate (Lynch et al., 2022). The Resist in RAD refers to efforts to maintain current ecosystem status and function, effectively resisting ecosystem changes. Resisting changes in ecosystems in Nebraska include the efforts to thwart invasive species introduction and spread (e.g., zebra mussels) and state transitions of ecosystems (e.g., removal of eastern red cedar to maintain intact grasslands). Examples of accepting ecosystem change include the large-scale conversion of grasslands for agricultural production, increased temperatures, and changes in precipitation patterns. Managers may be able to direct ecosystems to the desired state despite transformations from a previous state. For example, water infrastructure has played a pivotal role in Nebraska's agriculture production and recreation and may need to continue as prolonged periods of intense drought evolve in the future. Using a RAD framework in coordination with monitoring to reassess ecosystem conditions may benefit future management decisions as changes in climate occur and understanding of impacts to fish and wildlife and ecosystem services improves.

The future of Nebraska's rich biodiversity is uncertain, given the predicted constraints placed on species from changing ecosystems under a changing climate. Generalist species may have the adaptive capacity to shoulder future changes, as many have done under previous and current large-scale transformations. However, evidence suggests some species that were thought resistant to changes are experiencing declines (i.e., wild turkey). Specialist species dependent on the finite bounds of ecosystems may not be able to adapt and may further decline until extirpation from the state. This could include the greater prairie chicken, blacknose shiner, and many other species of conservation concern (Schneider et al., 2011). Climate change may alter many ecosystem properties, including reducing biodiversity, altering species distribution and life history strategies able to survive in historic regions, and increasing the prevalence of disease and invasive species. Such ecosystem changes in Nebraska will influence local and state economies and human health in multiple, often unexpected, ways.

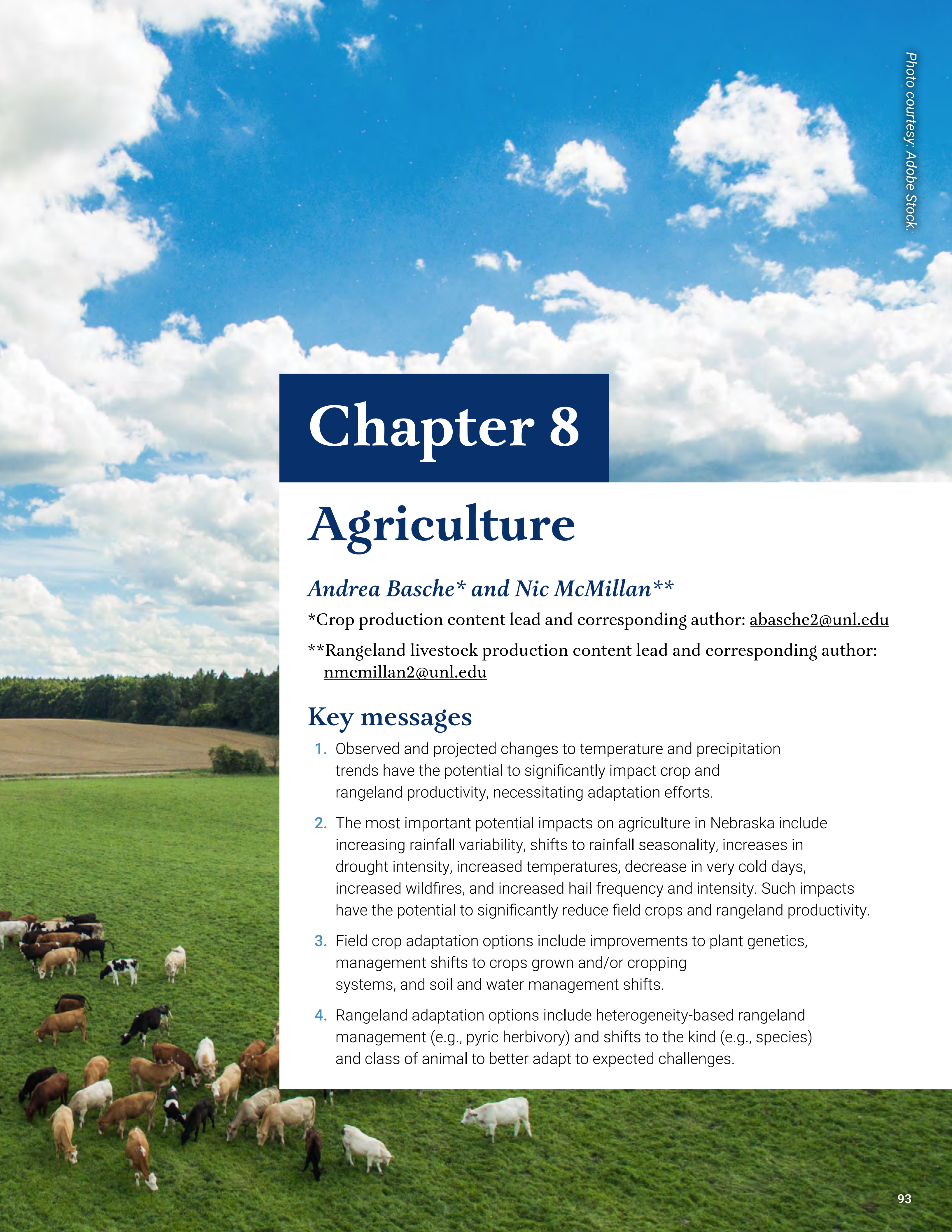

Photo courtesy: Adobe Stock.

Chapter 8

Agriculture

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Key messages

1. Observed and projected changes to temperature and precipitation trends have the potential to significantly impact crop and rangeland productivity, necessitating adaptation efforts.
2. The most important potential impacts on agriculture in Nebraska include increasing rainfall variability, shifts to rainfall seasonality, increases in drought intensity, increased temperatures, decrease in very cold days, increased wildfires, and increased hail frequency and intensity. Such impacts have the potential to significantly reduce field crops and rangeland productivity.
3. Field crop adaptation options include improvements to plant genetics, management shifts to crops grown and/or cropping systems, and soil and water management shifts.
4. Rangeland adaptation options include heterogeneity-based rangeland management (e.g., pyric herbivory) and shifts to the kind (e.g., species) and class of animal to better adapt to expected challenges.

Introduction

Understanding the potential effects of climate change on the agricultural sector in Nebraska is of critical importance, given its significant contributions to the state's overall economy, environment, land, and water use, as well as human health and well-being. Nebraska is the fifth-ranking state in the U.S. for overall agricultural sales and is within the top five producing states for crops, grains/oilseeds, cattle, and hogs, and it is one of the leading states in the country for irrigated acres (USDA, 2022; USDA NASS 2023; USDA ERS, 2017). Specific to cattle, the top cash receipt for the state, Nebraska is a leading beef production state in the U.S., with a total of 6.25 million cattle and calves as of 2024 (USDA NASS, 2024; USDA ERS, 2024a). Agricultural land use comprises over 85% of the state's area, consisting of more than 21 million acres of cropland and 21 million acres of pastureland—approximately 44 million acres of working farms (USDA NASS, 2023; U.S. Census Bureau, 2021). The potential impacts of climate change on the agricultural sector, given its critical importance to the state, make adaptation necessary (Bolster et al., 2023; Burchfield, 2022). Further, the state is increasingly recognizing the impacts, mitigation needs, and adaptation opportunities climate change presents for the agricultural sector. For example, the Nebraska Department of Environment and Energy recently published a climate action plan to identify measures to reduce greenhouse gas emissions and was awarded a significant investment from the Environmental Protection Agency through a Climate Pollution Reduction Grant (CPRG) (NDEE, 2024b; EPA, 2024b). In the following sections, we focus on known physical climate impacts and their potential to affect key elements of the agricultural sector in Nebraska. We also include some potential adaptation options from recent research.

Important climate impacts for the agricultural sector

The 2023 National Climate Assessment and research in the state of Nebraska outline many observed and predicted climatological trends for temperature and precipitation, with the potential to cause significant impacts on agricultural production (see supplemental report part 2, Table SR 8). Precipitation trends observed or predicted include increasing rainfall variability, shifts to rainfall seasonality, and increases in the days with very heavy rain (Marvel et al., 2023). Importantly, drought is projected to increase in intensity and potential frequency (Knapp et al., 2023; Chapter 3). Increases in evaporative demand, with shifts to streamflow and runoff, can strain the state's important irrigation resources. Temperature shifts include an overall increase in mean temperatures as well as a decrease in the number of very cold days. Although the total number of very hot days (>95°F) decreased slightly from 1991 to 2020 compared to the 1951 to 1980 period in the eastern portion of the state, the number of extremely hot days (90°F or higher) is projected to be two to four times larger than during the historical period (Chapter 4). Other potentially challenging risks for the agriculture sector include increased wildfire and hail frequency and intensity (Knapp et al., 2023; Chapter 4).

Impacts on crop production

Corn and soybean

Corn and soybeans are annual crops that grow and mature primarily during summer. As a result, these crops are exposed to growing season stressors, including increases in the number of very hot days and shifting rainfall variability. Risks of shifting rainfall variability include periods of too much or not enough rain, extended drought, and potential increases in hail (see supplemental report, Table A.7). Heavier rain in spring can complicate planting conditions, and drought in summer can limit yield potential. Recent research provides important evidence for how heat and water stress might impact future corn and soybean yields and their potential cultivation in the state. Yang and Wang (2023) project that corn yields in the Midwest, including much of the geographic extent of Nebraska, could decline by 12% in the mid-21st century and up to 40% by the end of the century. Their results for soybean yields were mixed; some models predict yield increases by mid-century, with significant decreases by the end of the century. Their research found that crop yields in our region are currently limited by water stress, but that is likely to shift to heat stress by the end of the century. Another estimate of corn yields in the future projects yield declines by the end of the century, ranging from 11% to 43%, depending on the representative carbon pathway—the projection of future greenhouse gas concentrations—considered (Robertson et al., 2018). However, other researchers have found that temperature stress from corn has decreased over recent years (Leng, 2017). Using future climate projections, Burchfield (2022) found that much of Nebraska could become less biophysically suitable for corn and soybeans by the end of the 21st century without further adaptation efforts.

Wheat

Wheat is a cool-season crop, planted in the fall. It begins its vegetative growth before a period of dormancy, then continued growth and development into spring and early summer. This growth habit subjects it to potential anticipated impacts, including shifting in the seasonality of rainfall, increases in drought intensity, and increases in temperatures. According to models built on experiments in eastern Colorado, Robertson et al. (2018) estimated that wheat yields could decline between 37% and 50%. Additionally, known climatic changes are anticipated to increase the range and persistence of many wheat pests, including weeds, diseases, and insects, primarily due to increased drought and high temperatures (Bajwa et al., 2020). However, when accounting for policy and market shifts in addition to projected climate change, Fei et al. (2017) suggest that wheat production could shift toward cooler conditions—northward in the southern Great Plains and westward in the Northern Plains—leading to the potential for an increase in wheat acreage in Nebraska. Burchfield (2022) similarly found that parts of southern Nebraska could become more suitable for wheat cultivation by the end of the 21st century.

Environment and irrigation

Increases in rainfall variability, higher temperatures, and changes to runoff and streamflow have the potential to impact crop production and contribute to environmental degradation. These observed and anticipated climate impacts could also constrain Nebraska's important irrigation resources. Approximately 90% of irrigated acres in Nebraska rely on groundwater, specifically the High Plains Aquifer. This water resource significantly increases crop and water productivity (Evett et al., 2020). At present, Nebraska's groundwater levels are estimated to be declining at a slower rate than that of more southern locations in the Great Plains (Evett et al., 2020). However, aquifer levels in the state's western region have steadily declined for several decades, and in the southeast, groundwater levels fluctuate annually because of precipitation (Chapter 5). In recent decades, groundwater-level declines in extreme dry years have not been recharged to the same extent as in extreme wet years; drought years tend to have approximately double the impact on groundwater levels compared to above-average rainfall years (Chapter 5).

Observed and anticipated climate impacts also pose risks to soil, water, and air quality. For example, Zhang et al. (2021) created nitrogen budgets at a county level across the Corn Belt. They found evidence that the nitrogen surplus, defined as nitrogen not recovered by crops, will be exacerbated across Nebraska when conditions are more extreme, including wetter, hotter, and drier-than-normal seasons. This work estimates that nearly 70% of crop nitrogen losses across the U.S. are derived from the Corn Belt region. This underscores the importance of understanding interventions to reduce losses given the observed and predicted increases in temperature and precipitation extremes (Zhang et al., 2021). Additionally, transitions from lower to higher rainfall seasons, as seen across the region in 2012 and 2013, significantly increased nitrate loading in surface waters due to excess soil nitrogen from drought that mobilized with heavier rain. Such "whiplash" conditions are anticipated to increase with climate change and potentially threaten water bodies to exceed safe drinking water conditions (Loecke et al., 2017). Lambert et al. (2020) found increasing dust from agricultural expansion between 2000 and 2018 across most of Nebraska, particularly in planting and harvest seasons. With the anticipated increases in drought, there is potential for further impact on economic and human health associated with dust aerosols and storms (Lambert et al., 2020). Finally, for soil quality, modeling analyses investigating soil changes with climate change find the potential for decreases in soil carbon when there are declines in crop yield (Wienhold et al., 2018). However, other research notes that crop rotation will impact the direction of potential soil carbon changes (Nash et al., 2018; Robertson et al., 2018).

Climate change adaptation strategies for crop production

While projections for yield declines and environmental impacts have the potential to be significant, adaptation options exist—including shifts to agronomy, plant breeding, crop diversity, and water management. For crop and soil management, options that include flexibility and monitoring in heavier or lesser rainfall scenarios could become increasingly important. Producers likely already use these practices to account for weather or seasonal variability. Nebraska Extension's *Weather-Ready Nebraska* tool includes several adaptation ideas. These include more frequent applications of inputs to reduce losses (i.e., split application of nitrogen), reducing seeding rates, and shifting planting timing and/or planting shorter or longer season varieties to accommodate for shifts in rain (UNL, n.d.). For example, prior to the introduction of more drought-tolerant corn hybrids, some dryland farmers would plant maturing hybrids very early in the season to harvest very early (i.e., March to August) to take advantage of spring moisture and the potential to double crop a more drought-tolerant species (T. Hoegemeyer, personal communication, September 30, 2024). Heavier rainfall seasons highlight the importance of residue management for erosion prevention (UNL, n.d.). Relatedly, Kukal and Irmak (2017) found that corn and soybean precipitation use efficiency (cropping system water use in terms of seasonal precipitation) during the period from 1982 to 2013 is higher on average in Nebraska than in other states in the region. Their results suggest that soil or other management practices sustaining the effective use of rainfall contribute to crop productivity. This could result from a high percentage of conservation tillage practices in Nebraska. Additionally, many well-known soil management practices, including those associated with soil health (such as conservation tillage, cover crops, and crop rotation), are known to improve soil hydrology and have the potential to buffer negative climate impacts in both flooding and drought conditions (Basche & DeLonge 2017, 2019). Additionally, improvements to soil health, notably water and nutrient cycling, documented recently on Nebraska farms, present an opportunity to reduce potential climate impacts and confer broader ecosystem services (Krupek et al. 2022a, 2022b). Kukal and Irmak's (2018) analysis of county-level yields in Nebraska (corn, soybean, sorghum) from 1968 to 2013 found that irrigated yields were robust across years, suggesting this as a potential adaptation strategy.

For crop genetics, recent research has highlighted the mechanisms by which corn plants will experience heat stress, suggesting some adaptation options. Li et al. (2020) exposed corn plants in a field setting to heat stress during V12-VT (max temperature of 41.7°C or 107°F compared to 35.3°C or 96°F in control plots) and found significant impacts on photosynthesis in corn. This included disruptions to chloroplasts, mitochondrial membrane structure, and stomatal conductance. Li and Howell (2021) described how the genes behind heat shock proteins and how hormonal responses contribute to thermotolerance and, therefore, could be targeted for future plant breeding. Relatedly, the motivation for "short corn" plant breeding efforts includes its reduced vulnerability to windstorms and the potential for increased productivity with higher plant populations (Stokstad, 2023). Adaptation efforts for wheat, including plant breeding for higher temperatures during critical reproductive growth stages and to account for the potential of longer and sometimes wetter growing seasons, will become more important (Morgounov et al., 2018). Additionally, exploring different genetic resources for wheat varieties may be another beneficial adaptation strategy, as a variety of kamut has been found to be more resistant to diseases from pests such as wheat stem sawfly (Adhikari et al., 2018). Continued investments in plant breeding efforts are important to sustain the viability of important field crops.

Although Burchfield (2022) finds that there will be a reduction in the biophysical suitability of corn and soybean production in Nebraska, their agricultural suitability is driven by the significant existing investments in programs such as crop insurance and other government support. Given anticipated changes, the investments needed to sustain current crops may have a high cost; for example, crop insurance payouts have increased in recent decades due to weather events (Reyes & Elias, 2019). As a result, there is a need to simultaneously explore adaptation options that include crop diversification—specifically, identifying crops that may be more biophysically adapted to be incorporated into future cropping systems. For example, a recent report projecting the potential for crops grown in Kansas by 2050 found opportunities associated with a shift from crops with lower water demand, such as planting sorghum instead of corn, millet instead of soybean, and rye or oats instead of wheat (Suttles et al., 2024). However, to be successful, these new crops need reliable support via infrastructure, markets, knowledge, equipment, and more. Such needs present significant challenges for producers and potential new business opportunities. Producers in the region note current time and resource limitations as barriers to shifting crops grown (Kasu et al., 2019).

A longer growing season presents expanded opportunities for cover cropping, relay cropping, perennial grain or forage crops, and the potential for increased livestock integration on cropland. Utilizing tools such as advances in plant breeding and crop and climate models could support the optimization of such cropping systems (Basche et al., 2016; Gesch et al., 2023; Jungers et al., 2023; Smart et al., 2021; Thivierge et al., 2023). Growing a variety of crops, especially those tolerant to waterlogged conditions, can help farmers spread risk and reduce the overall impact of extreme rainfall on their operations (USDA, n.d.). However, these crop diversification practices would similarly require continued and new investments in infrastructure such as markets, equipment, and knowledge.

Although irrigation could be considered an adaptation strategy, it cannot be assumed that the same quantity of water will always be available, given the historical trend of extremely dry years leading to more significant groundwater declines compared to recharge from extremely wet years (Chapter 5). Conservation irrigation efforts include shifts to irrigation technologies such as methods of application and scheduling of application, shifts to crops grown, and improved crop genetics for water use (Evett et al., 2020). Gibson et al. (2019) found that Nebraska's irrigated water use for corn and soybean production could be reduced without sacrificing yields. Groundwater withdrawal limits put in place by Natural Resources Districts and conservation efforts since at least the 1970s have been somewhat effective at increasing water resource sustainability (Evett et al., 2020; Chapter 5). In the future, however, increases in aridity, decreases or shifts to runoff and streamflow, increased evapotranspiration, and the lengthening of the growing season have the potential to put additional pressure on groundwater resources (Chapter 5; Knapp et al., 2023). Installing on-farm drainage systems, such as retention ponds or drainage ditches, can help manage excess water and prevent flooding (Magdoff & Van Es, 2021).

Impacts on rangeland livestock production

Increasingly variable timing, intensity, and frequency of rainfall events will likely alter plant communities across Nebraska's rangelands, impacting traditional livestock production strategies in the state. Rangelands are often water-limited landscapes, and their ability to support different kinds (i.e., species) and classes (e.g., stocker cattle, cow-calf, etc.) of livestock is determined, in part, by spatial and temporal patterns of rainfall (Holechek, 2011). Increased intensity and frequency of drought are expected under all emissions scenarios by the mid- to late 21st century, with summer drought more probable than spring drought (Knapp et al., 2023). Early season precipitation, when coupled with mid- to late growing season drought, is predicted to favor a shift from highly productive warm-season (C_4) to less productive cool-season (C_3) dominated plant communities in mesic rangelands (i.e., tallgrass prairie), a characteristic that was also observed during the Dust Bowl in the 1930s (Knapp et al., 2020). Summer drought is also expected to lower rangeland productivity in arid and semi-arid short and mixed-grass rangelands. Specifically, studies in mixed-grass and shortgrass rangelands across the U.S. and southern Canada—similar to some of those found in Nebraska—suggest steep reductions in forage and litter production and increased bare ground during times of frequent and sustained summer drought (Carroll et al., 2021; Erichsen-Arychuk et al., 2002). Drought-induced plant community changes, like shifting from warm-season- to cool-season-dominated rangelands, will impact the timing and duration of grazing, as many producers currently tailor their management strategies on rangelands to follow seasonal changes in warm-season forages. Likewise, concomitant reductions in annual rangeland forage productivity following drought-induced plant community shifts will likely reduce livestock production across affected rangelands (Allred et al., 2013).

Increased drought frequency, especially during the late growing season, is likely to increase the frequency and impacts of wildfire on rangeland livestock production. However, specific effects are likely dependent upon the scale (i.e., acreage) of affected operations. Increased biomass production following high precipitation events early in the growing season, coupled with later season drought, increases the likelihood of wildfire by increasing the abundance and density of fine fuels (like standing dead biomass or litter). While the effect of fire on rangeland vegetation is often positive for livestock producers (Scasta et al., 2016), increased fire frequency is well known to promote the spread and establishment of many invasive annual grasses of concern to the livestock industry in Nebraska, like cheatgrass (*Bromus tectorum* L.; Hobbs & Huenneke, 1992; Lear et al., 2020).

Changes to plant community composition resulting from altered precipitation patterns are likely to decrease—or significantly alter—livestock production across Nebraska's rangelands due to declining forage availability and quality throughout the growing season. However, the effect of invasive species and other plant compositional changes on rangeland function is debated and suspected to be scale-limited (Fridley et al., 2007; McMillan et al., 2023; Peng et al., 2019). It is also likely that the effect of many drought-driven disturbances, like wildfire, on rangeland livestock production is also tied to the relative spatial extent of the disturbance compared to that of the affected operation(s) and the inherent heterogeneity (e.g., spatial variability in soil texture, topography, soil depth, etc.) of the affected operations (Briske et al., 2020). Variance scaling—the idea that increasing scale leads to increased variance—is a universal phenomenon widely studied well beyond rangeland ecology and management, including fields like astrophysics, mathematics, and geography (Hulshof & Umaña, 2022; Levin, 1992). It is intuitive that ranches operating at larger spatial scales (i.e., more acreage) are more likely to hold more inherent heterogeneity than smaller operations and are more likely to overcome expected challenges stemming from drought-driven disturbances. The effect of other drought-driven disturbance feedbacks on rangeland livestock production—like the positive feedback between wildfire and cheatgrass invasion—is, consequently, also exacerbated by grazing management practices that focus on uniform forage consumption, like high-density short duration stocking strategies (Allred et al., 2014; Fuhlendorf et al., 2012, 2009b; Fuhlendorf & Engle, 2001; Scasta et al., 2016). Therefore, smaller operations and those that utilize homogeneity-based grazing management practices face an elevated risk of being negatively impacted by the increased frequency and intensity of drought-driven disturbances expected from continued climate change.

Increased drought frequency and intensity will pressure livestock producers to develop and maintain permanent or semi-permanent water facilities (e.g., water tanks) to meet their livestock's basic physiological requirements during drought. Ungulate grazers, like cattle, can get most, or nearly all, of their daily water requirement from the forage they consume (Kay, 1997; King, 1983). However, plant moisture depends upon soil moisture, and during severe drought, livestock must use permanent or ephemeral water sources to meet their daily water requirement (Kay, 1997). As drought becomes more intense and frequent, plant growth and photosynthesis rates decline (Chaves et al., 2003), and high-quality forage becomes spatially limited over time. Livestock experiencing long-term severe drought conditions will have more restricted movement as areas that effectively meet their basic physiological (nutrient and water) requirements become increasingly limited with persistent drought conditions, and providing those resources becomes more difficult for producers.

However, it is important to note that significant effort has been made to develop water facilities for livestock across rangelands in Nebraska, which will buffer these adverse effects for many producers. Other producers also utilize irrigated crop fields or hay meadows in their grazing plans. While producers who can integrate irrigated pastures or cropland into their grazing management plans will be buffered from some of the adverse effects of severe drought, irrigated acres do not—and likely cannot—represent a significant proportion of Nebraska's rangeland livestock production capacity (e.g., Sandhills upland range). For example, 46% of the state (22.7 million acres) is considered unirrigated rangeland compared to 11% of the state (5.4 million acres) that is considered irrigated, sub-irrigated, or planted for silage, pasture, other seeded forages, and hay (Nebraska Rangelands, n.d.). Even without experiencing drought, cattle consistently spend more time in riparian habitats and the water when air temperature exceeds 75 to 81°F (24 to 27°C) (Allred et al., 2013). Therefore, the combined effects of drought and increased temperatures expected under current climate predictions will continue to intensify livestock and producer demand for ground and surface water, as well as the potential adverse effects of heavy livestock selection for riparian areas across Nebraska's rangelands.

Woody plant encroachment into grasslands significantly threatens rangeland livestock production, specifically in highly productive grassland ecosystems like the tallgrass prairie (Engle et al., 2008). However, data on the specific effects that climate change will have on woody plant expansion and the effect on livestock production are mixed at best. For example, eastern redcedar (*Juniperus virginiana* L.) expansion into rangelands is considered a major threat to livestock production in Nebraska, and significant resources have been dedicated to combating its spread (Fogarty et al., 2023). However, recent species distribution models for eastern redcedar under current and future climate conditions across Kansas, Oklahoma, and Texas suggest a significant eastward shift in its distribution, driven by an anticipated increase in aridity across the region (J. Yang et al., 2024a). Although recent modeling efforts did not include Nebraska, it is logical to assume that effects will not be arbitrarily limited to states in the southern Great Plains and similar population shifts can be expected with future climate change. Despite changes to eastern redcedar distribution due to climate change, the expansion of other woody plants that are more difficult to control—those that are not easily managed with prescribed fire like smooth sumac (*Rhus glabra* L.)—will likely continue. Further, elevated atmospheric CO_2 has been tied to increased growth rates in woody plants, likely accelerating woody expansion into rangelands (Dodds et al., 2023; Kgope et al., 2010) and exacerbating the negative effect of woody plant encroachment on rangeland livestock production. However, specific effects of climate change on the spatial distribution of encroachment at the local, state, and regional scales—and the effects on livestock production—remain largely unresolved.

Climate change adaptation strategies for rangeland livestock production

Many of the adverse effects of climate change on rangeland livestock production in Nebraska are tied to processes occurring at scales much larger than a single landowner parcel or even an ecoregion (e.g., the Sandhills). For example, changing wildfire frequencies and intensities in Nebraska's rangelands cannot be solely attributed to singular changes in management, like decades of fire suppression that encourages invasive species, but are more likely the result of highly complex, interactive, multi-scale processes ranging from local to global scales (Dodds et al., 2023; MacDougall & Turkington, 2005). Continuing top-down, "command and control" rangeland management strategies or policies are unlikely to enable livestock producers to meet the increasing demand for rangeland-derived products despite the adverse effects of climate change (Holling & Meffe, 1996). Instead, management strategies and policy actions aimed at embracing rangeland variability (i.e., heterogeneity) instead of trying to reduce or control it will be key to building resilient rangeland systems to meet the growing demand for rangeland livestock products despite continued climate change (Allred et al., 2013; Fuhlendorf & Engle, 2001; Fuhlendorf et al., 2009b; McMillan et al., 2023, 2022b; Scasta et al., 2016).

Heterogeneity-based rangeland management remains the only strategy known to enable livestock producers to overcome the challenges of climate change and simultaneously improve other ecosystem functions that are important to Nebraskans. Pyric herbivory—fire-driven grazing—is perhaps the most well-known and studied rangeland management strategy in the Great Plains explicitly employed to promote rangeland heterogeneity (Fuhlendorf & Engle, 2001). Pyric herbivory relies explicitly on the highly interactive relationship between fire and grazing, where cattle are disproportionately more attracted to recently burned areas than unburned ones, to increase rangeland heterogeneity (Allred et al., 2011). For example, when applied in patches, pyric herbivory promotes biomass variability across rangelands where the average biomass in a patch depends upon time since fire; more recently burned patches have significantly less biomass than patches with a longer time since fire. Increased heterogeneity created by pyric herbivory is known to buffer livestock producers from the negative effects of invasive species (Cummings et al., 2007; McMillan et al., 2022a; Sherrill et al., 2022) and drought (Allred et al., 2014), while promoting broader ecosystem function and resiliency (Fuhlendorf et al., 2009a; Hovick et al., 2015; McGranahan et al., 2018). Other rangeland and grazing management strategies have been proposed to solve the climate crisis using high-density, short-duration livestock grazing (Savory, 1983; Teague & Barnes, 2017; Teague et al., 2013). However, despite their growing popularity with the public and among several nongovernmental organizations, the expected benefits of high-density, short duration livestock grazing strategies have been largely rejected by decades of rangeland ecology research in the U.S. (Briske et al., 2008, 2011, 2013; Carter et al., 2014).

Livestock producers in Nebraska may also alter their kind (i.e., species) and class of animal to better adapt to expected challenges stemming from climate change. It is well documented that most cattle breeds change their behavior in response to heat at 75°F (24°C). At those temperatures, cattle selection for riparian zones, wetlands, and woody vegetation (broadly) is significantly higher than for other parts of the landscape (Allred et al., 2013). American plains bison (*Bison bison* L.), on the other hand, do not start to alter their behavior in response to air temperature until anywhere from 82 to 90°F (28 to 32°C) (Allred et al., 2013; McMillan et al., et al., 2022b). As a result, some livestock operations across the U.S. have started to adopt bison as a potential alternative to traditional livestock to cope with the effects of climate change. Other potential strategies include altering the class of animals (e.g., moving from cow-calf to stocker steers) or increasing the diversity of animal kinds and classes in a livestock operation to better balance the risk and uncertainty of future climate change effects. For example, multispecies grazing—i.e., utilizing multiple species simultaneously in a livestock grazing operation—may be a way to improve the profitability and resiliency of livestock production in a variable climate (Wilcox et al., 2022). When combined with pyric herbivory, diversifying the suite of livestock kinds and classes in an operation may also help livestock producers combat woody plant encroachment, which is expected to accelerate with continued climate change (Ding & Eldridge, 2024; Wilcox et al., 2022).

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Chapter 9

Human Health

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Key messages

1. Climate change is associated with adverse health outcomes in Nebraska, including heat-related morbidity and mortality during heat waves, physical and mental health impacts during drought and flood events, and increased risk of certain infectious diseases like West Nile virus due to changing temperature and precipitation patterns.
2. Some Nebraskans are more impacted by the health impacts associated with climate change than others.
3. Adaptation and mitigation efforts addressing the health impacts of climate change can protect Nebraskans.

Complex relationships between climate and human health

Climate change impacts individual-level physical and mental health and community-level health. The exposure pathways through which climate affects health are complex and varied. Climate drivers (i.e., the climatological and meteorological conditions that impact the environment and ecosystems) include increased temperatures, precipitation extremes, and other extreme weather events. These drivers influence or initiate the exposure pathways, or main routes, through which climate affects health. Examples of such pathways are extreme heat, poor air or water quality, changes in the distribution of infectious diseases (e.g., the expanded geographic range of ticks that carry Lyme disease, changes in the seasonality of *Salmonella* species), climate and extreme weather-related disasters, and population displacement (USGCRP, 2016; Liu et al., 2021). These exposure pathways can impact human health directly (the climate or weather factor affects human health via some mechanism of bodily harm without a mediating or intervening factor) or indirectly (the climate or weather factor initiates a chain of events that leads to harm). Direct impacts may include heat-related illness, injury, or death. Indirect impacts may include food, water, and vector-borne diseases; hunger and malnutrition; and mental health impacts.

These impacts on human and community health may be further exacerbated when climate- and weather-related extreme events occur simultaneously or in proximity to each other (i.e., compounding hazards) or when one such extreme event leads to a series of subsequent events (i.e., cascading hazards) (Hayden et al., 2023). An example of compounding climate-related hazards is a heat wave and drought occurring together, leading to higher rates of heat-related illnesses and hospitalizations. Some related examples of cascading hazards might be when this initial heat wave–drought combination leads to the following:

- Widespread wildfires and reduced air quality, increasing emergency department visits and hospitalizations for asthma and other respiratory conditions.
- Water shortages that impact the agricultural industry (e.g., through crop or livestock losses), leading to local and regional food insecurity or increased mental health impacts among farmers.
- The failure of overloaded energy grids, increasing the risk of carbon monoxide poisoning from generators, heat-related illness hospitalizations and deaths from loss of cooling systems, and disruption of other systems (e.g., water treatment plants, transportation, hospitals).

Additional factors that intensify the impacts of climate on health are existing social inequities, including systemic racism and discrimination (Berberian et al., 2022). We know that climate- and extreme-weather-related hazards disproportionately impact certain communities, those with a greater vulnerability or those that have historically been marginalized. These include people of color, Indigenous communities, women, children, aging populations, people with disabilities and chronic health conditions, and sexual and gender minorities (Hayden et al., 2023). Some communities are already facing environmental threats to their health and well-being due to the historical practice of redlining. These communities received less investment and are now under resourced relative to healthcare, infrastructure, education, economy, housing, and other basic needs (Egede et al., 2023). The combined impacts of climate change and these existing environmental hazards greatly exacerbate health inequities in these communities. Environmental justice challenges are described in further detail in Chapter 12, "Climate Justice and Equity."

Given the multiple, complex, and interacting climate hazards and exposure pathways, it can be challenging to fully understand the extent to and the mechanisms by which climate impacts human health. However, the evidence is clear that every American is impacted by climate change (USGCRP, 2023); climate and extreme weather affect mental, physical, and community health (Hayden et al., 2023); and continued efforts to understand these impacts and use this knowledge to drive adaptation and mitigation actions are needed to protect human health.

Climate and health in Nebraska

Climate and extreme weather also affect Nebraskans' health. As described in Chapters 2 through 4, Nebraska faces impacts from climate extremes, including severe drought, flooding, increasing temperatures, and wildfires. We describe these hazards' exposure pathways and health impacts based on available scientific evidence, specific to Nebraska and the Midwest, where possible.

Increasing temperatures and heat waves

Global warming is leading to increasing daytime and nighttime temperatures, higher humidity, and longer and more frequent heat waves. Extreme heat is associated with a variety of health outcomes, including heat-related illnesses (i.e., heat exhaustion and heat stroke), cardiovascular diseases and stroke, respiratory disease, renal disease, dehydration, diabetes, mental health conditions and behavioral disorders, and death. These risks are increased for certain people who are more vulnerable to the effects of heat (e.g., very young or very old, people with certain chronic conditions or taking certain medications, those who rely on the environment for their livelihood, people with lower education or income, and people who are incarcerated) and people living in urban areas.

Heat vulnerability mapping has highlighted Omaha, Nebraska's largest city, as having distinct geographical and socioeconomic characteristics compared to the rest of the state (Figure 9.1). Rural and urban areas of Nebraska have distinct differences in what makes each area vulnerable to extreme heat. For example, heat vulnerability in Omaha is largely driven by disability, poverty, and urbanization. In many other parts of the state, heat vulnerability is determined by education, race other than White, and land class, including grasslands and pasture (Fard et al., 2021). Historically, Omaha has been shaped by redlining practices that segregated racial and ethnic minority communities, creating persistent disparities in residential distribution. This segregation has been linked to various health disparities and environmental challenges (Puvvula et al., 2023).

Urban heat islands experience elevated temperatures due to their built environments, which absorb and re-radiate heat more than natural landscapes. Roads, parking lots, buildings, and other infrastructure contribute to these higher temperatures (NIHHIS, n.d.). The National Oceanic and Atmospheric Administration (NOAA) Urban Heat Island Mapping Project provided data on Omaha's hottest neighborhoods. On August 6, 2022, 68 volunteers collected 43,714 temperature measurements across eight routes, revealing a maximum temperature of 102.9°F with a daily temperature variation of 9.4°F (Fard, 2024). The study identified three key findings for the Omaha area. First, residential areas with significant tree cover generally have cooler temperatures and retain less heat throughout the day. Second, regions with high-density industrial land use tend to retain more heat. Third, large expanses of asphalt in commercial areas contribute to higher temperatures due to increased heat retention. These insights underscore the impact of urban design and land use on local heat vulnerabilities.

From 2018 to 2022, 2,406 emergency department visits and 193 hospitalizations were reported from heat-related illnesses in Nebraska. Emergency department visits were the lowest in 2020 (n = 343) and highest in 2022 (n = 611). The age-adjusted rates of emergency department visits during this period ranged from 16.9 to 30.6 per 100,000 population. During this same period, average summer (May through September) temperatures in Nebraska ranged from 67.1°F (19.5°C) to 69.8°F (21°C) . The average temperature in 2022 was the highest during the observation period (69.8°F (21°C) , or a 2.5°F (1.39°C) anomaly from the base period), coinciding with the highest reported emergency department visits. The average temperature in 2020 was 68.5°F (20.3°C) , or a 1.2°F (0.67°C) anomaly from the base period (1901 to 2000), not the lowest average temperature of the period (NOAA NCEI, 2024a). Lower emergency department visit rates during 2020 may be somewhat attributable to the COVID-19 pandemic. Emergency department visits for heat-related illnesses were most common in males, non-Hispanic White individuals, and those aged 20 to 29 and 30 to 39 years; they were also more likely to occur in July. Hospitalizations were the lowest in 2021 (n = 34) and highest in 2022 (n = 44), with age-adjusted rates ranging from 1.6 to 1.9 per

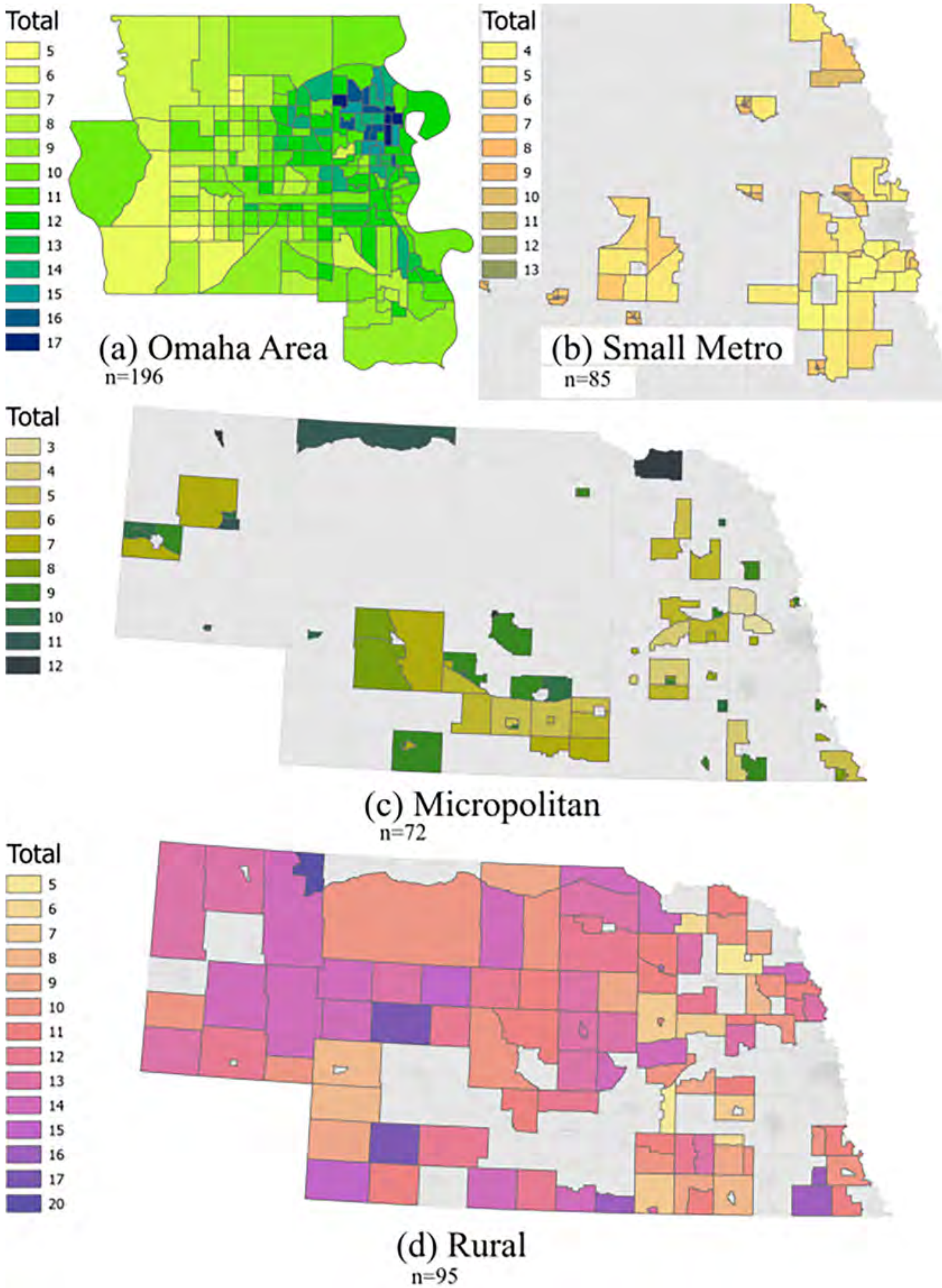


Figure 9.1. Maps of heat vulnerability level values in each of the four urban classes in Nebraska: (a) Omaha, the most populated Medium Metropolitan area; (b) part of Small Metro area (eastern Nebraska as in Fig. 1[a]); (c) micropolitan areas; (d) rural areas. (Source: Fard et al., 2021)

100,000 population. Hospitalizations for heat-related illnesses were also common in males and non-Hispanic White individuals and were more likely to occur in July. However, hospitalizations were more likely to occur in individuals over the age of 60 (CDC, n.d.).

Precipitation extremes: drought

Drought is one of the costliest climate-related disasters in the United States. Nebraska alone has suffered losses exceeding $10 billion since 1980, making it the state's most expensive natural disaster (NOAA NCEI, 2024c). The impacts of a single drought event are often compounded by previous droughts and other weather-related hazards, creating complex interactions. These include reduced water quality, air quality issues, more intense heat waves, wildfires, dust storms, and decreased water availability (Bell et al., 2023). Research indicates that drought can increase arsenic levels in private wells, which are linked to cancer, adverse birth outcomes, and developmental issues (Lombard et al., 2021). Additionally, drought can cause pulmonary inflammation from dry weather and dust, increase vector-borne diseases due to standing water from reduced water levels, and heighten gastrointestinal and infectious diseases due to decreased sanitation. Mental health also suffers due to various hardships caused by drought (Hayden et al., 2023).

Studies show that severe droughts disproportionately affect rural communities and individuals over the age of 65, increasing the risk of mortality from all causes, cardiovascular issues, and respiratory conditions. For example, research in Nebraska has found that all-cause mortality increases for White populations aged 25 to 34 and 45 to 64 during severe droughts (Abadi et al., 2022). A broader study of the northern plains, including Nebraska, found that severe droughts also increase mortality among those over 65, White subgroups, and females. Additionally, areas with fewer drought conditions have exhibited higher mortality risks, highlighting the complex relationship between drought and health impacts (Gwon et al., 2024).

Further research has shown that severe droughts lead to a significant increase in respiratory-related mortality, affecting both White and Black subgroups, with females experiencing a greater impact than males. Rural populations are particularly vulnerable, experiencing higher increases in respiratory-related mortality compared to urban areas (Gwon et al., 2023). Another study focusing on Nebraska and the surrounding region found that severe droughts also increase cardiovascular-related mortality, with higher risks observed among females, White individuals, and those over 65 (Gwon et al., 2024).

Drought has also been shown to impact mental health. Farmers' occupational psychosocial stress—job strain—in the Midwest was significantly higher with drought conditions during the growing season compared to the non-growing season. Specifically, psychological job demands increased by 109% when drought occurred during the growing season (Berman et al., 2021). In the U.S., firearm and non-firearm suicides were associated with all phases of drought. In severe drought periods, the risk of suicide was increased overall and in older adults, women, and individuals living in rural areas (Abadi et al., 2024).

Precipitation extremes: flood

In 2019, Nebraska and other midwestern states experienced an inland flooding event that caused an estimated $13.4 billion in economic losses. The event inundated millions of acres of agricultural lands, cities, and towns and caused widespread damage to infrastructure across eight states (NOAA NCEI, 2024c). In Nebraska, 104 cities, 81 counties, and 5 Tribal nations (Figure 9.2) received state or federal disaster declarations because of this event (Bell et al., 2020), with an estimated $2.6 billion in economic losses, including damage to homes, businesses, infrastructure, farmland, and livestock (Reed, 2022). The Federal Emergency Management Agency (FEMA) processed and approved over 3,000 individual assistance applications and more than $27 million in Individual and Household Program funds (Figure 9.2). The flooding caused severe damage to infrastructure, including bridges, dams, levees, and roads. The 2019 floods exacerbated the hardships faced by already vulnerable communities, with many Tribes and Indigenous peoples enduring additional challenges that compounded historical trauma, including delayed responses from outside emergency services and inadequate resources for evacuations (Bell et al., 2020).

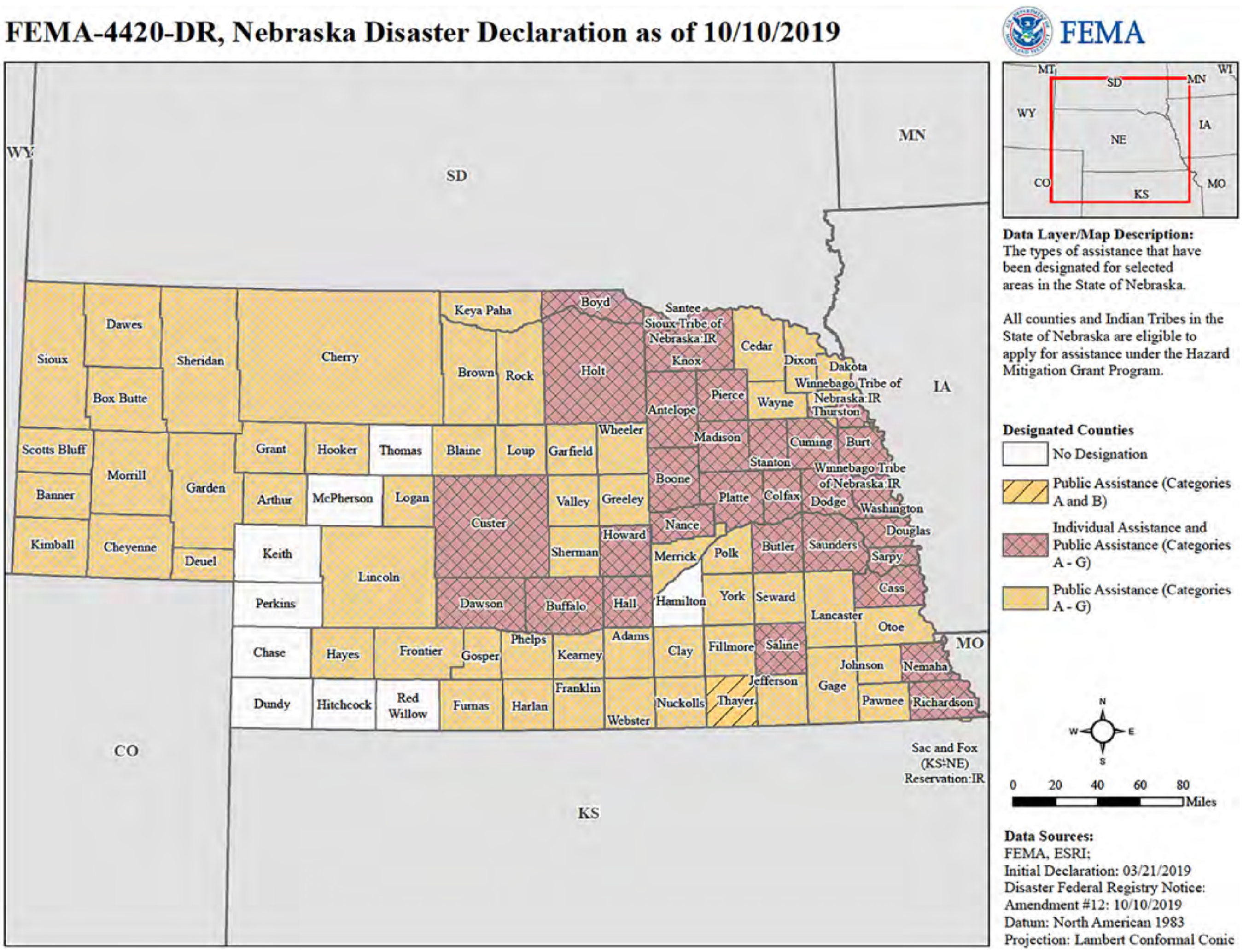


Figure 9.2. Map of the types of assistance designated for selected counties in Nebraska related to the Federal Emergency Management Agency (FEMA) disaster declaration for 2019 Missouri River flooding (FEMA Disaster 4420). (Source: FEMA, n.d.)

Four deaths were recorded (Reed, 2022) due to drowning, but the hidden health impacts were extensive and went beyond immediate flood-related injuries. In the aftermath, individuals in affected areas were exposed to additional hazards, such as chemicals, electrical shocks, and debris. Contamination of water sources, including wells, increased gastrointestinal illness risks, particularly for children. Stranded residents depended on emergency services, volunteer organizations, and community support for essential supplies like clean water (Bell et al., 2020). Infrastructure was also compromised after the flood, including mold development in homes. Mold growth is a common occurrence after major flooding. Exposure to mold affects the skin, eyes, and respiratory system and may lead to infections and allergic reactions (Metts, 2008).

The disaster highlighted significant challenges in response and recovery efforts for resource-limited communities. The lack of equipment and limited transportation options further complicated evacuation and relief efforts, leaving many residents in dire conditions. This situation calls for reevaluating disaster preparedness and response strategies to better support vulnerable populations in future emergencies.

The 2019 flood disaster mirrored previous flooding events in terms of health impacts and disruptions to the healthcare system, disproportionately affecting vulnerable populations, particularly Tribal and Indigenous communities. This situation underscores the urgent need for policy interventions to minimize health risks, improve health equity, and enhance community resilience as the frequency of such weather events rises. The disaster displaced hundreds of people, inundated millions of acres of agricultural land, killed thousands of livestock, and hindered crop planting. FEMA disaster declarations were issued throughout the region, allowing affected individuals to seek financial and housing assistance, although remaining in their homes still left them at risk of future flooding.

Air pollution

Nebraska's air quality will likely worsen due to climate change as wildfires and dust storms become more common. These issues can compound underlying inequities. Marginalized communities, particularly those affected by social vulnerabilities such as race, ethnicity, and poverty, face higher exposure to harmful pollutants, including carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), and particulate matter ($PM_{2.5}$ and PM_{10}) (West et al., 2023). Research has shown these disparities through community-scale and personal monitoring studies (Hajat et al., 2015).

In Douglas County, Nebraska, one study found strong links between elevated criteria pollutants (like CO, $PM_{2.5}$, NO_2, and SO_2) and factors such as race (particularly non-Hispanic Black and Hispanic/Latino populations), financial stability, and literacy. Additionally, neighborhoods with higher proportions of Non-Hispanic Black children, uninsured children, and households lacking vehicle access experienced more pediatric asthma emergency visits (Puvvula et al., 2023). Another study highlighted the impact of specific pollutants, such as $PM_{2.5}$, sycamore and grass pollen, and mold (including *Helminthosporium*, *Peronospora*, and *Erysiphe*), in exacerbating pediatric asthma in Douglas County (Puvvula et al., 2022). These findings underscore the complex relationship between air quality and health outcomes in vulnerable communities.

Vector-borne diseases

Climate change can broaden the range and increase the activity of disease vectors like mosquitoes and ticks by creating more favorable conditions for their reproduction and survival. Warmer temperatures and altered precipitation patterns can also extend the transmission season of vector-borne diseases, leading to increased infection rates in previously unaffected areas. In Nebraska, four mosquito-borne viruses pose a significant risk: West Nile virus, St. Louis encephalitis, western equine encephalitis, and Jamestown Canyon virus. Additionally, ticks in Nebraska can transmit serious diseases such as Lyme disease, ehrlichiosis, Rocky Mountain spotted fever, and tularemia.

A study on West Nile virus in Nebraska found that dry years following wet ones, especially with warm temperatures, increased the likelihood of infection, with drought contributing to approximately 26% of cases from 2002 to 2018 (Smith et al., 2020). Recent surveys have also identified populations of *Ixodes scapularis* ticks, confirming the presence of *Borrelia burgdorferi*. There is also evidence of local Lyme disease transmission in the state. Lone Star ticks (*Amblyomma americanum*) are present in Nebraska, where they pose health risks due to their role in transmitting diseases like ehrlichiosis and tularemia. Although these ticks are more commonly found in the southeastern and south central United States, their range is expanding northward, leading to their presence in Nebraska and other northern regions. Additionally, Lone Star ticks are associated with Alpha-gal syndrome (AGS), an allergy to certain types of meat caused by tick bites (NDHHS, n.d.).

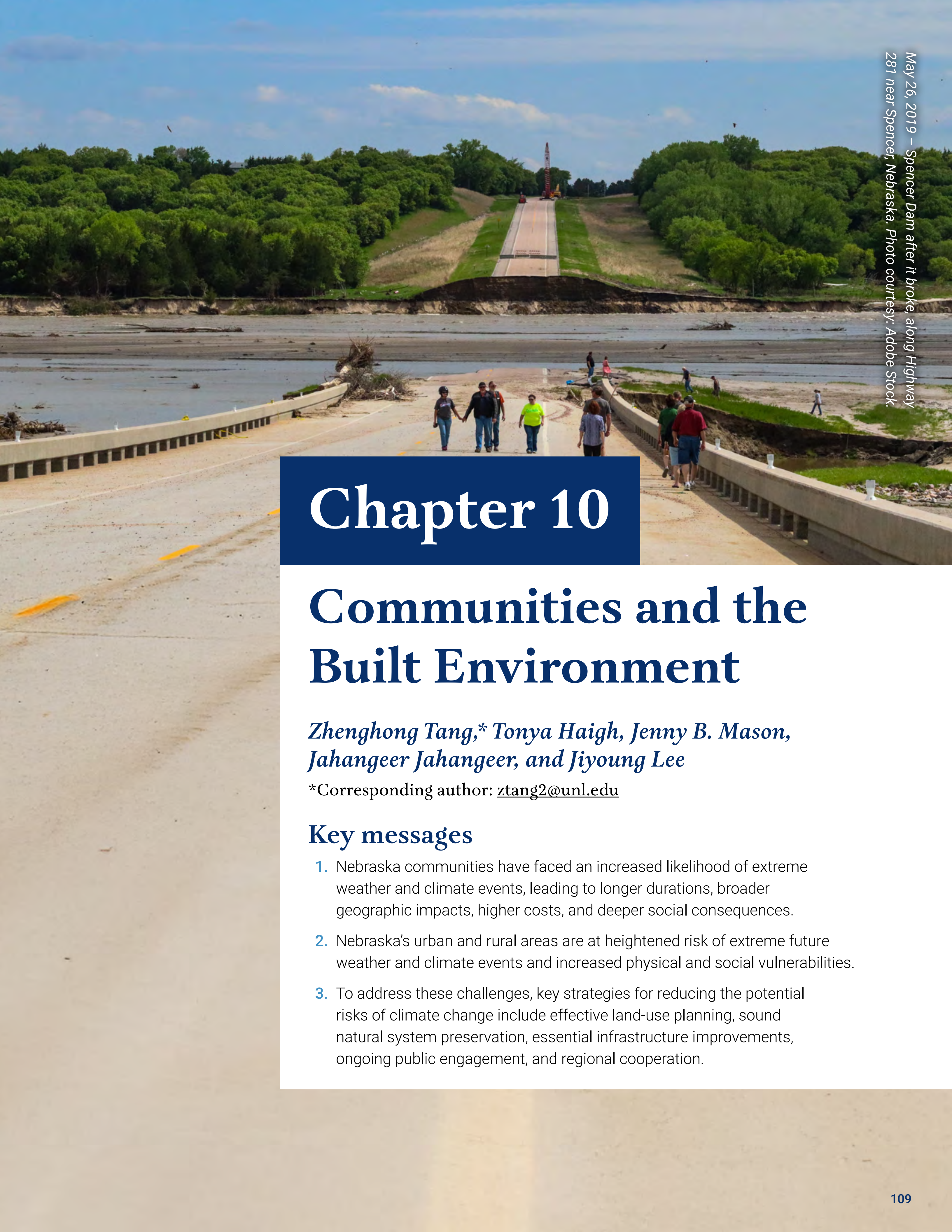
Addressing health threats in Nebraska

While these and other climate-related threats have and will continue to impact Nebraskans' health, much is being done to address these issues. Since 2022, Nebraska has been one of 33 recipients of a Centers for Disease Control and Prevention (CDC) National Environmental Public Health Tracking cooperative agreement that aims to collect, integrate, analyze, and disseminate data from various sources to monitor the burden from environmentally related health outcomes in the U.S. (CDC, n.d.) The Nebraska Tracking Program is a joint effort between the Nebraska Department of Health and Human Services (DHHS) and the University of Nebraska Medical Center (UNMC) and is using this funding to develop a Nebraska Tracking Data Portal and address environmental issues of concern to our state. Many indicators tracked by the national and state tracking programs include climate-related risks and health outcomes. On the environmental side, this includes information about extreme heat, drought, air quality, precipitation, and flooding, among others. On the health side, tracking programs monitor respiratory conditions like asthma and chronic obstructive pulmonary disease, heat-related illnesses, and cardiovascular conditions such as heart attack and stroke, among others.

The state and several metropolitan areas, including Lincoln, Omaha, and the larger Omaha–Council Bluffs Metropolitan Statistical Area, have been working to develop and build climate action and resilience plans to improve our sustainability for the future (City of Lincoln, 2021; City of Omaha, 2024). These plans inventory greenhouse gas emissions, identify focus areas for reduced emissions, and set target limits for emissions in the future. Reductions in greenhouse gas emissions will improve air quality. Many greenhouse gases are also considered air pollutants and strategies to reduce their emissions often overlap with actions to decrease other harmful air pollutants, such as particulate matter and sulfur dioxide (West et al., 2023). Therefore, mitigating climate change through greenhouse gas reduction can positively impact air quality and public health. Climate action and resilience plans also include sustainable economic development. Initiatives like this will add jobs in specific sectors and improve the local economy while focusing on the built environment and increasing green spaces and tree canopy. Many of these plans also consider healthcare systems and other impacts on human health. These efforts will have long-term implications for individuals' physical and mental health and improve overall quality of life and community resilience.

Gaps and needs

- Improved monitoring and surveillance systems to track the impacts of climate change on health in real-time.
- Research into the complex interactions between extreme heat, air pollution, and drought on physical and mental health impacts.
- Epidemiologic studies examining the short- and long-term effects of extreme weather events on health, particularly indirect health impacts, including heat waves, floods, droughts, wildfires, and severe storms.
- Development and evaluation of community-level adaptation strategies to mitigate the health risks associated with climate change.
- Assessments related to local healthcare systems resiliency and capacity to respond to climate-related events and infrastructure adaptions to withstand these events.



May 26, 2019 – Spencer Dam after it broke, along Highway 281 near Spencer, Nebraska. Photo courtesy: Adobe Stock.

Chapter 10

Communities and the Built Environment

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Key messages

1. Nebraska communities have faced an increased likelihood of extreme weather and climate events, leading to longer durations, broader geographic impacts, higher costs, and deeper social consequences.
2. Nebraska's urban and rural areas are at heightened risk of extreme future weather and climate events and increased physical and social vulnerabilities.
3. To address these challenges, key strategies for reducing the potential risks of climate change include effective land-use planning, sound natural system preservation, essential infrastructure improvements, ongoing public engagement, and regional cooperation.

Introduction

Understanding the effects of climate change on Nebraska's communities and built environment is essential for developing effective strategies to mitigate and adapt to the risks of extreme weather and climate events. Climate change has significant consequences, impacting Nebraska's ecosystems, societies, and economies. These effects include important areas such as natural resources, biodiversity, public health, agriculture, infrastructure, and overall quality of life (IPCC, 2014; USGCRP, 2017).

Whether they live in urban or rural areas, Nebraskans face inevitable challenges from climate change that affect their well-being. Climate change brings more extreme weather events, makes infrastructure more vulnerable, and increases social challenges across the state. By understanding these impacts, policymakers, communities, and individuals can create effective strategies and interventions to reduce risks, adapt to evolving conditions, and build a more resilient future for Nebraska's communities and the built environment.

Climate change has wide-ranging impacts on Nebraska's communities and the built environment. First, it poses serious risks to human well-being and livelihoods. We can see this in the escalating frequency and severity of extreme weather and climate events in recent years. Second, Nebraska's buildings, transportation systems, and vital water and power infrastructure are at risk due to climate change. Changes in rain and snow patterns, extreme temperatures, and floods can lead to costly infrastructure damage and disrupt services. Lastly, climate change makes social challenges worse, with marginalized communities bearing a disproportionate burden and existing inequalities growing. Understanding how climate change affects Nebraska's communities and infrastructure is critical to protecting our well-being, improving infrastructure resilience, and striving for social equity.

This chapter examines and evaluates the impacts of climate change on Nebraska's communities and the built environment. It reviews past studies on climate impacts on Nebraska and the scientific data from extreme weather and climate events. This chapter also discusses the current challenges in climate action and emphasizes opportunities to enhance climate resilience at the community level. By exploring the specific impacts of climate change, we hope to raise awareness of Nebraska's challenges and highlight the importance of building resilience in response to our changing climate.

Climate change impacts on Nebraska's communities

In Nebraska, the effects of extreme weather and climate disasters are becoming increasingly evident as the frequency and intensity of such events continue to rise. These events put communities at risk, affecting their physical, social, and economic well-being and overall quality of life. Over the past decade, Nebraska communities have experienced a higher likelihood of extreme events, resulting in longer durations, wider geographic impacts, more costly damages, and deeper social consequences for urban and rural areas.

Increased likelihood of extreme events

While natural hazards like floods, severe storms, winter snowstorms, tornadoes, and heat waves are a natural part of climate variability, climate change can amplify these events and their impacts on communities and the built environment. National-level research predicts more frequent flood events in Nebraska (Figure 2.12). The total U.S. population exposed to severe flooding is estimated to be 2.6 to 3.1 times higher than previous estimates, with this risk likely heightened by climate change (Wing et al., 2022). Research provides strong evidence of an increasing frequency of flooding across the central U.S. (Mallakpour & Villarini, 2015). Additionally, flood events have increased across most of the Midwest in the past 50–70 years (Neri et al., 2019). Records of Nebraska's extreme weather and climate events align with national-level predictions (Chapters 2 and 3).

According to the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information (NCEI) datasets (2024c), the frequency of billion-dollar disasters has statistically increased over the past four decades in Nebraska. Billion-dollar disasters are weather and climate events where the overall damage costs (across all affected areas) reach or exceed $1 billion, adjusted for inflation. It is essential to acknowledge that disaster impacts are a combination of risk factors (such as population growth, density, and material wealth) and the effects of climate change and variability.

From January 1, 1980, to December 31, 2024, Nebraska experienced 66 weather and climate disaster events, where total losses from each event exceeded $1 billion (NOAA NCEI, 2024c). These major extreme weather and climate events, categorized as billion-dollar disasters, included 13 droughts, 5 floods, 2 freezes, 44 severe storms, 1 wildfire, and 1 winter storm (Figure 10.1).

From 1980 to 2024, Nebraska was affected by an average of 1.5 billion-dollar events per year (NCEI, 2024c). However, the most recent five years (2019 to 2023) show an increase to an average of four events per year (NOAA NCEI, 2024c). By the decade (Figure 10.2), Nebraska was affected by 5 billion-dollar weather and climate events during the 1980s, 4 during the 1990s, 15 during the 2000s, and 20 events from 2010 to 2019 (NOAA NCEI, 2024c). From 2020 to 2024, over 20 major disaster events have affected Nebraska, with 16 of these from 2022 to 2024.

The three most frequent types of billion-dollar events affecting Nebraska from 1980 to 2024 include severe storms, drought, and flooding (NOAA NCEI, 2024c). Over the past four decades, severe storms have accounted for 66.7% of all billion-dollar events affecting Nebraska, droughts for 19.7%, and flooding for 7.6% of the total events (NOAA NCEI, 2024c). Severe storms and floods are closely related, with severe storms often leading to flood disasters.

The frequency and damage costs of extreme weather events, particularly severe storms, droughts, and floods, have increased significantly from 2020 to 2024 compared to 1980 to 1999. According to the 2021 Nebraska State Hazard Mitigation Plan (NEMA, 2021), between 1980 and 1999, 10 federal-level disaster declarations were made for severe storms. However, in the past two decades (2000 to 2019), the number of severe storms, ice storms, and floods resulting in federal disaster declarations rose to 27. These disaster declarations, made by the president based on the governor's request, activate an array of federal programs and funding to support state and local governments in responding to and recovering from major natural disasters.

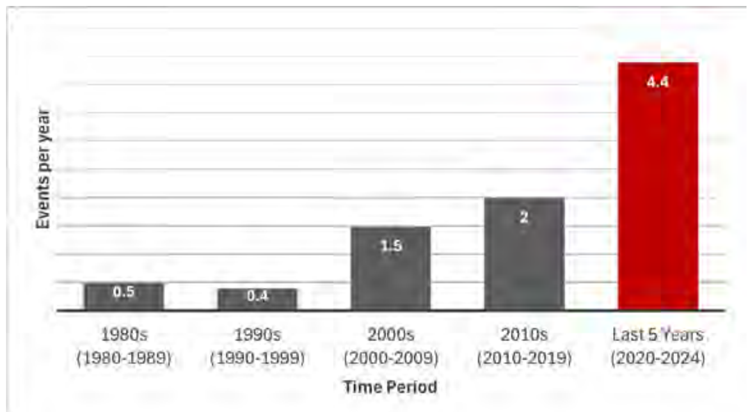


Figure 10.1. The number of events per year for the billion-dollar disaster events that affected Nebraska communities from 1980 to 2024. (Source: NOAA NCEI, 2024c, https://www.ncei.noaa.gov/access/billions/summary-stats/NE/1980-2024)

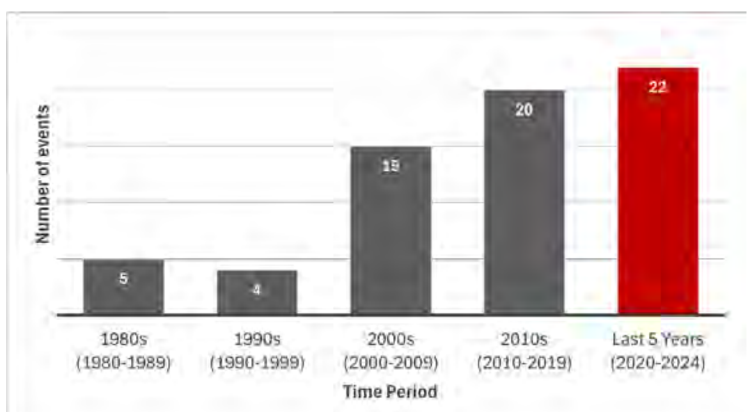


Figure 10.2. Number of billion-dollar disaster events that affected Nebraska communities from 1980 to 2024. (Source: NOAA NCEI, 2024c, https://www.ncei.noaa.gov/access/billions/summary-stats/NE/1980-2024)

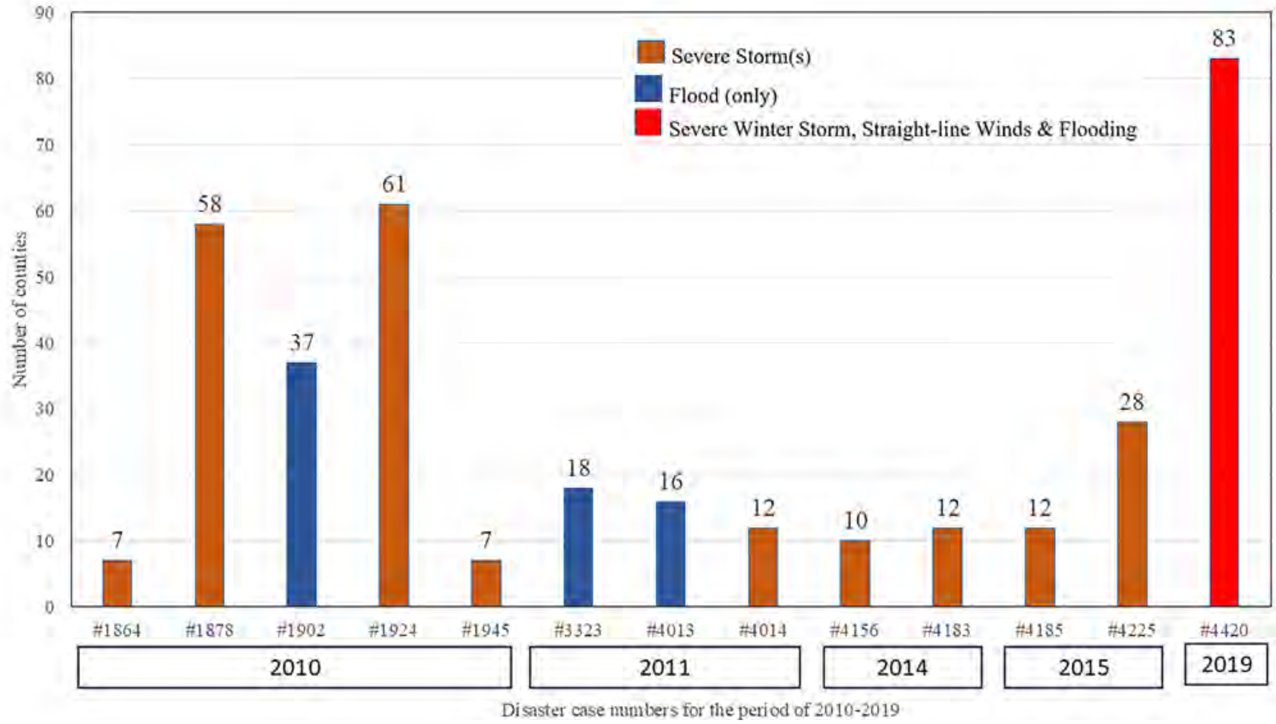


Figure 10.3. Federal major disaster declarations related to flooding in Nebraska from 2010 to 2019. (Source: NEMA, 2021)

Figure 10.3 shows the occurrence of federal disaster declarations in Nebraska communities between 2010 and 2019—nine for severe storms, three for floods, and one each for a severe winter storm, straight-line winds, and flooding-related events.

Broader geographic impacts

Extreme weather and climate disasters have significantly impacted all areas of Nebraska, affecting rural and urban regions over the past decades. The drought of 2012 affected 86 out of Nebraska's 93 counties (NEMA, 2021). Between 1980 and 2024, 13 major droughts (billion-dollar events) have widely affected Nebraska (NOAA NCEI 2024c). These droughts have widely disrupted urban and rural economic activities such as drinking water, agriculture, and recreation (NEMA, 2021).

Since 2008, Nebraska has experienced 482 tornadoes, impacting every county in the state (NEMA, 2021). These severe events also significantly impacted various communities across Nebraska.

From 1996 to 2019, flooding impacted every county in Nebraska, causing varying degrees of damage (NEMA, 2021; NeDNR, 2022). The scale of the historic flood in 2019 was vast, resulting in state or federal disaster declarations for 104 cities, 84 counties, and 5 tribal nations in Nebraska (NeDNR, 2022; State of Nebraska, 2021).

Prolonged durations

Nebraska communities have faced long-lasting impacts from extreme weather and climate disaster events. The severe drought that began in 2011 persisted through 2012 before concluding in 2013 (NDMC, 2024). The University of Nebraska–Lincoln Conservation and Survey Division (Young et al., 2018) found that it took over five years for the High Plains Aquifer's groundwater levels to return to normal, significantly affecting Nebraska's agricultural economy (Table 10.1, community highlight 1).

Another major event in Nebraska's history was the flooding disaster in March 2019. The Federal Emergency Management Agency (FEMA) defined this flood as an extended-duration event, with a 128-day FEMA Incident Period, lasting from March 9 to July 14, 2019. Encompassing winter storms, high winds, and flooding, this historic event resulted in two deaths and hundreds of air and boat rescues, as well as the failure of the Spencer Dam on the Niobrara River. Many residents were isolated from their homes and workplaces for days, and the city of Fremont was completely closed off due to flooded highways. Furthermore, the cleanup of debris and sand in affected fields has taken years to complete, with flood-recovery processes extending over years and, in some cases, up to a decade (Table 10.1, community highlight 2).

From January 2000 through June 2020, 53 counties reported 14 days of excessive heat events. During these 20 years, the state experienced 10 extreme heat events, resulting in a recurrence interval of 0.5% in any given year (NEMA, 2021). For instance, in 2018 and 2019, the city of Beatrice and three counties—Hayes, Frontier, and Hitchcock—identified extreme heat as a major hazard (NEMA, 2021). In contrast, data on extreme cold or wind chill events during the same period showed that many Nebraska communities were affected for more than 36 days (NEMA, 2021).

Higher costly damage

The costs associated with billion-dollar events affecting Nebraska from 1980 to 2024 have significantly increased (NCEI, 2024c). Figure 10.4 shows the percentage of costs for major billion-dollar disaster events that affected Nebraska communities from 1980 to 2024. From 1980 to 1989, the costs accounted for 11.9% of the total; from 1990 to 1999, they accounted for only 4.6%; from 2000 to 2009, they rose to 14.2%; and from 2010 to 2019, the costs dramatically increased to 42.7% of the total (NCEI, 2024c). The trend has continued into the 2020s, with costs from the last five years reaching 26.6% of the total and the three years (2021 to 2023) reaching 22.7% of the total costs from 1980 to 2024 (NCEI, 2024c).

The top three costliest extreme disaster types for the billion-dollar events affecting Nebraska from 1980 to 2024 are drought, severe storms, and flooding (NCEI, 2024c). Over the past four decades, drought has been the costliest disaster type in Nebraska, accounting for

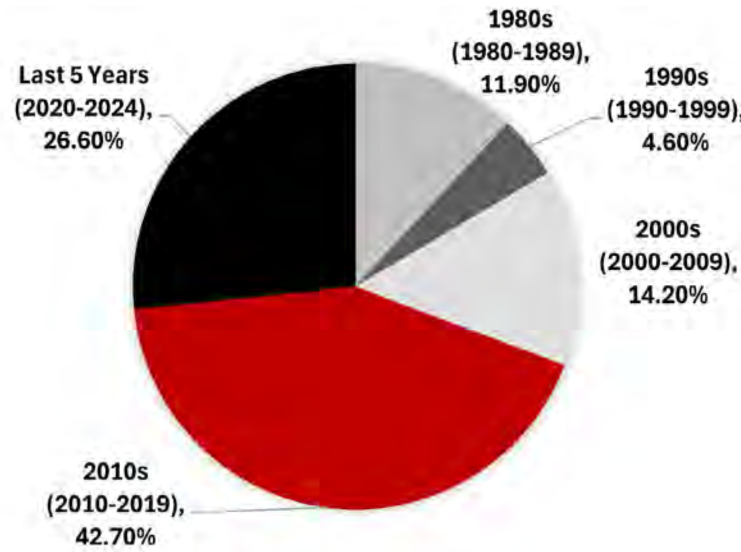


Figure 10.4. The percentage of total cost for the billion-dollar disaster events that affected Nebraska communities from 1980 to 2019. (Source: NECI, 2024c. "Select Time Period Comparisons of Nebraska Billion-Dollar Drought, Flooding, Freeze, Severe Storm, Tropical Cyclone, Wildfire, and Winter Storm Statistics [CPI-Adjusted]")

44.5% of the total costs from the billion-dollar events. Severe storms have led to 41.6% of the total costs, and flooding has accounted for 13.4% (NCEI, 2024c).

Nebraska has suffered costly damage from various natural disasters driven by extreme weather and climate disaster events. Between 2008 and 2020, the state experienced 13 federal disaster declarations, including tornadoes, resulting in over $158 million in federal public assistance (NEMA, 2021). Tragically, tornado events in Nebraska have caused 6 fatalities and 103 injuries from 2008 to 2020 (NEMA, 2021). In addition to tornadoes, severe storms and floods have inflicted significant losses on Nebraska communities. In 2024 alone, at least four major federal disaster declarations were issued for Nebraska, including severe storms or winter storms, straight-line winds, tornadoes, and flooding, occurring between April and September (Table 10.1, community highlight 3).

The public assistance funds obligated to floods in Nebraska from 2010 to 2019 are shown in Figure 10.5. In the recent three-year period from 2018 to 2020, flood-related property losses reached a staggering $623,043,000, which is 1.5 times higher than the total flood losses recorded in the previous ten-year period

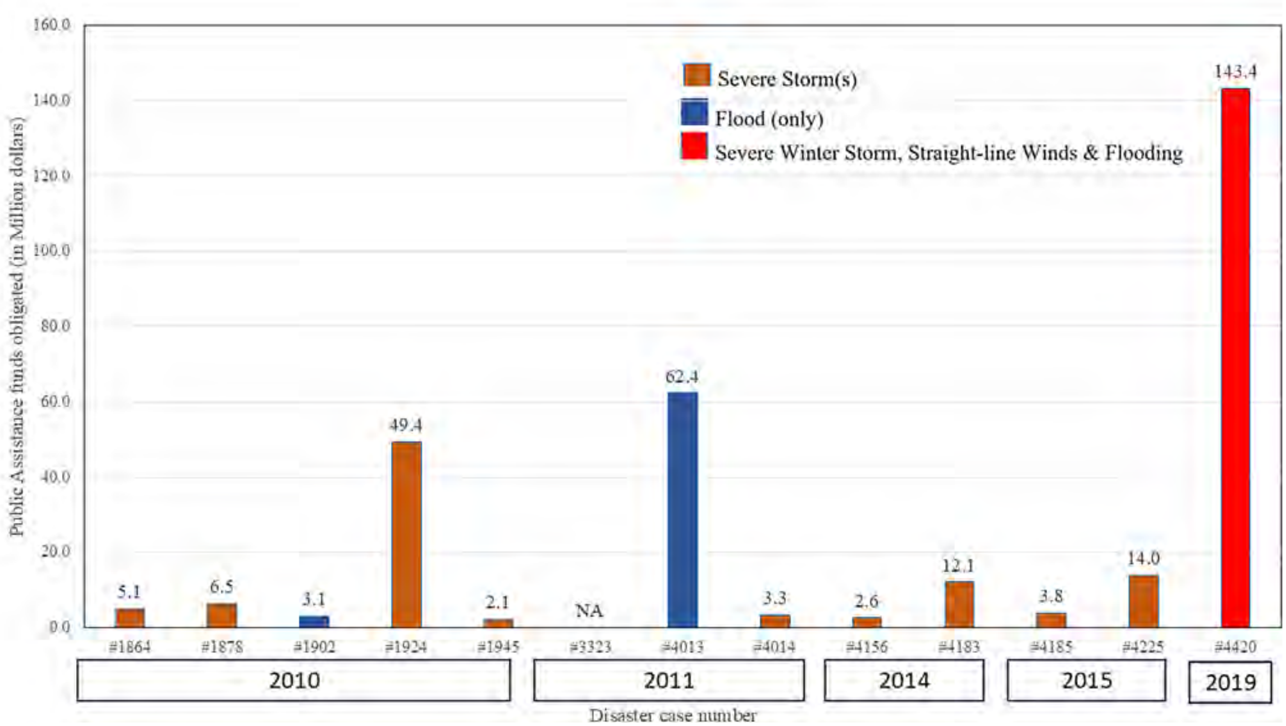


Figure 10.5. Public assistance funds obligated (in millions of dollars) related to floods in Nebraska from 2010 to 2019. (Source: NEMA, 2021) Nebraska from 2010 to 2019. (Source: NEMA, 2021)

from 1996 to 2017, totaling $543,243,600 (NEMA, 2021). Hazardous weather and climate events during 2019 were particularly devastating, claiming the lives of five individuals and injuring seven others. Data on flood losses indicate a rising trend in the number of flood events affecting the state over recent years (2019 to 2023), along with an increased vulnerability of property and the agricultural economy (NEMA, 2021). The damage caused by these events in 2019 was substantial, with property losses exceeding $640.5 million and crop damages amounting to $27.7 million (NEMA, 2021; NeDNR, 2022). Altogether, the cumulative impact of these damages reached $668.2 million, positioning Nebraska as the fourth highest-ranking state in terms of costs associated with such events in 2019 (NEMA, 2021; NeDNR, 2022). The estimated damage caused by the 2019 flooding exceeded $1.3 billion, including infrastructure losses of $449 million, crop losses of $440 million, and cattle losses of $400 million (NEMA, 2021; NeDNR, 2022; Schwartz, 2019; Wright & Brackett, 2019).

Deeper social impacts

Nebraska communities have not only faced economic losses from these extreme weather and climate events but have also endured profound social impacts. The aftermath of extreme events often involves the displacement of residents, leading to various social challenges (Table 10.1, community highlight 4).

During the historic flood in 2019, access to clean water and essential services was severely disrupted across the state. Many communities along the Missouri River, Platte River, and Elkhorn River faced mandatory or voluntary evacuations as floodwaters inundated their regions. The 2019 flood hit households hard, with 80% of the damage reported for owner-occupied units and 20% for renter-occupied units (State of Nebraska, 2021). Many residents lacked adequate insurance, with approximately 81.7% of homeowners lacking flood insurance and 23.3% lacking general home insurance (State of Nebraska, 2021). More than 95% of renters lacked flood or renter's insurance (98.2% and 97.4%, respectively). For households with flood insurance, National Flood Insurance Program (NFIP) data indicates that 1,026 claims were paid out after the 2019 disaster, with $5,994,846 in advance payments and $39,673,497 in total payments as of July 29, 2019 (State of Nebraska, 2021).

Disadvantaged communities and underserved populations are disproportionately affected by floods and severe storms. Extreme weather and climate events cause property damage, displacement, and economic burdens, particularly for vulnerable populations (Chapter 9). A 2016 report by the Nebraska Department of Natural Resources finds that Hispanic residents are disproportionately likely to live in floodplains in Nebraska communities (Table 10.1, community highlight 5). In addition, over 10,000 residents living in Nebraska floodplains rent their homes. Renters are, on average, at lower income levels than homeowners, and very few (less than 0.04%) have flood insurance, leaving them vulnerable to devastating losses when floods occur (Paine, 2016). For example, one death was reported due to excessive cold on January 22–23, 2003, when a homeless man in the Omaha area suffered severe frostbite and passed away several days later (NCEI, 2024a; NEMA, 2021). In May 2024, floods washed out an unhoused encampment in Omaha, forcing individuals to seek higher ground to escape the danger. Individuals who are disabled, elderly, have mobility issues, have limited income, or reside in low-lying areas or floodplains are among the most susceptible to extreme weather and climatic events related to climate change (Hayden et al., 2023).

Impacts of extreme weather and climate events on the built environment

Nebraska's built environment is increasingly vulnerable to extreme weather and climate events, which can be amplified by climate change. These vulnerabilities directly impact the integrity and functionality of the state's infrastructure. Addressing these infrastructure vulnerabilities and enhancing their resilience to climate change is essential, as this will contribute to the state's stability, prosperity, and security. By identifying these risks and taking action, Nebraska can better protect its urban and agricultural systems and lay the foundation for sustainable growth and prosperity in a changing climate.

Extreme weather and climate events, such as tornadoes and severe storms, subject structures to heightened wind forces, heavy rainfall, and floods (Al-Humaiqani & Al-Ghamdi, 2022). These conditions can lead to structural failures, roof damage, and the destruction of buildings. Additionally, extreme droughts can cause foundational shifts in buildings, bridges, and water lines (Robinson & Vahedifard, 2016). Roads and bridges are also at risk of erosion, landslides, and washouts caused by intense rainfall or flooding, compromising transportation and telecommunication networks and impeding connectivity within and between communities. The rising frequency and intensity of extreme weather events also contribute to higher maintenance costs for infrastructure (Venner & Zarnurs, 2012). Extreme temperatures, including heat waves and freezing conditions, accelerate material deterioration, resulting in cracks, corrosion, and a reduced lifespan for buildings, roads, bridges, equipment, and facilities.

For example, the historic 2012 drought caused significant damage to various infrastructures, including building foundations, private and municipal wells, water mains, and trails. As soils dried, they shifted and sank, damaging foundations. From May to July 2012, Omaha reported 178 water main breaks due to drought conditions (NEMA, 2021). The combination of extreme heat, drought, and increased water usage increased pressure on the city's water lines, causing some to crack. At least 81 municipal water systems in Nebraska experienced drought-related water supply issues during the 2012 drought (NEMA, 2021).

Water, energy supply, transportation, healthcare, telecommunication, and information services are essential components of Nebraska's critical infrastructure. These interconnected and interdependent systems are susceptible to disruptions caused by extreme weather and climate events. A significant example of this vulnerability is the devastating flood of 2019, which resulted in infrastructure losses estimated at $449 million (NeDNR, 2022; Schwartz, 2019; Wright & Brackett, 2019). The severe impacts affected roads, bridges, levees, water and sewer systems, electrical infrastructure, and other properties (NeDNR, 2022). The 2012 drought and 2019 flood impacted the water supply infrastructure of the city of Lincoln. These examples demonstrate how extreme weather and climate events have impacted Nebraska's built environment, notably its water, transportation, levee, and dam infrastructure.

The 2019 flooding caused severe damage to Nebraska's built environment and infrastructure, with cascading impacts across many sectors. The estimated cost to repair infrastructure is valued at over $640 million and potentially higher (State of Nebraska, 2021). For example, several fire stations were damaged during Winter Storm Ulmer, which preceded the 2019 flood event. The most notable were the Fremont Rural Fire Station and the North Bend Fire District. North Bend reported spending $30,000 on repairs, though estimated mitigation costs range from $3 to $4 million (State of Nebraska, 2021). Infrastructure remains vital as the backbone of community and commerce, connecting homes to businesses and their larger communities. Post-disaster recovery and mitigation may take years, affecting community economics.

Impacts on water, fire, and energy infrastructure

Extreme weather and climate disaster events can directly impact water and electricity infrastructure. Records from the past four decades indicate a trend toward increased frequency and intensity of rainfall events and extreme temperature days (Chapters 2 and 3), heightening water and energy infrastructure risks.

For example, flooding posed significant threats to two nuclear power plants along the Missouri River on June 20, 2011. Similarly, the March 2019 flood on the Niobrara River threatened the Cooper Nuclear Station downstream near Brownville, Nebraska (NEMA, 2021; NeDNR, 2022). Additionally, this flood directly affected drinking water infrastructure and resulted in power outages in and around the well fields of the water treatment plant near Ashland, Nebraska. The loss of water production capacity prompted the City of Lincoln to impose mandatory and voluntary water use restrictions.

Prolonged periods of lower precipitation also have significant implications for communities, leading to droughts and water scarcity and exacerbating various water-related issues. Droughts and water scarcity present formidable challenges, impacting agriculture, food production, access to clean water, sanitation, hygiene, and public health as well as amplifying social inequities. From June to August 2012, Nebraska experienced a record drought. The prolonged hot, dry weather and sporadic rainfall resulted in devastating consequences, including the Wellnitz Fire and property damage totaling $215,050,000 across 86 counties (NEMA, 2021). Multiple studies have found that climate change has already led to an increase in wildfire season length, wildfire frequency, and amount of area burned (Chapter 2). The 2012 Nebraska wildfire season was the worst on record, and 2022 was the second worst in terms of acres lost to wildfire (*El Dorado News-Times*, 2023). Dry conditions both years contributed to devastating wildfires across Nebraska. Wildfires have severely impacted Nebraska's rural communities, stressing volunteer fire departments, causing injuries and deaths among volunteer firefighters, and resulting in millions of dollars in property damage yearly (Table 10.1, community highlight 6).

The 2023–2024 drought led to water shortages in reservoirs, streams, and wells, posing risks of water emergencies. On June 1, 2023, the city of Lincoln and Lancaster County experienced exceptional drought conditions for the first time since 2020, according to the U.S. Drought Monitor (NDMC, 2024), prompting authorities to suggest voluntary water conservation.

Moreover, heat waves, extreme cold events, and windstorms can disrupt energy infrastructure, including power grids and transmission lines, due to increased strain and potential damage. These disruptions can result in power outages, further exacerbating the challenges associated with meeting energy demands during extreme weather conditions (Table 10.1, community highlight 7).

Impacts on transportation infrastructure

Climate change can significantly impact transportation systems, affecting both the functionality of transportation networks and trade-related economic activities (Liban et al., 2023). Transportation routes, including roads, rail segments, bridges, trails, and bicycle lanes, are vulnerable to flood inundation and storm damage (e.g., washed-out roadways, downed power lines, or trees), hindering the movement of goods and people. Extreme weather events such as floods, blizzards, and severe thunderstorms can damage and render roads, bridges, and railways impassable. Increased rainfall can trigger erosion, further closing transportation routes, causing delays and limited accessibility. Repairing post-disaster transportation systems, such as roads, bridges, and local trails, incurs significant costs, posing a financial burden for many local communities in Nebraska during post-disaster recovery. The interruption of transportation networks can disrupt supply chains, resulting in delivery delays and increased costs. Industries reliant on efficient transportation, such as manufacturing, agriculture, and tourism, may experience reduced productivity and economic losses.

For example, the 2019 flood event caused significant damage to transportation infrastructure across Nebraska, with the damage currently estimated at $429 million (State of Nebraska, 2021). This catastrophe affected local, state, and federal transportation networks, leading to the closure of 3,300 miles of state highways and 27 state highway bridges, roughly one-third of Nebraska's state highway system (State of Nebraska, 2021). Flooded roads and broken bridges prevented entry and exit, disrupting transportation, compromising critical emergency routes, isolating communities, and leading to travel delays. In particular, the Spencer Dam breakage destroyed three bridges, including the Highway 281 bridge over the Niobrara River (NeDNR, 2022). The damaged bridges forced drivers to take a detour of over 127 miles, significantly hampering emergency response and flood-recovery efforts in the region (NeDNR, 2022). Local bridges in the city of Fremont were also washed away, and floodwaters blocked critical emergency routes on land (NeDNR, 2022). Local jurisdictions have struggled with extensive damage to streets and culverts, which are still in various stages of repair. Significant work remains for years to fully restore the state's transportation infrastructure (State of Nebraska, 2021).

Impacts on levee and dam infrastructure

Levee and dam infrastructure are at significant risk of damage or complete destruction, exacerbating the challenges faced during flooding incidents. In the spring and summer of 2011, heavy rainfall and high water levels caused levee breaches along the Missouri River chain of reservoirs. The United States Army Corps of Engineers (USACE) responded by investing over $2 million in levee repairs in Omaha and nearly $1 million in Sarpy County (NEMA, 2021; NeDNR, 2022). In May 2015, the city of Lincoln faced a critical situation as its levees approached capacity, leading to significant water pooling in some neighborhoods along Salt Creek.

In the 2019 flood event, over 350 miles of levees on the Missouri, Platte, and Elkhorn Rivers and tributaries experienced significant flood damage due to the more than 40 breaches that occurred (NEMA, 2021; NeDNR, 2022). Levees along the Platte and Missouri Rivers received the most damage as both river systems reached record heights. Damage to levee systems forced the evacuations of tens of thousands and necessitated the rescue of hundreds of individuals by air and boat.

Repairing the damaged levees requires substantial funding to ensure resilience against future floods. The devastating levee breaches in March 2019 severely damaged communities, leading to far-reaching social, infrastructure, and economic consequences (NEMA, 2021; NeDNR, 2022). In addition to the loss of lives and damaged infrastructure, flooding across vast agricultural lands severely impacted production and compounded the already substantial economic losses incurred during the 2019 event.

Challenges facing Nebraska's communities in climate change

This section highlights the existing challenges Nebraska's communities face in addressing climate change. To account for the differing capacities of urban and rural areas, we follow the classification criteria provided by the U.S. Census Bureau (USCB), which is based on housing units or population size. According to the 2022 USCB delineation criteria, based on the 2020 census, a "rural community" is defined as one with fewer than 2,000 housing units or fewer than 5,000 residents. Conversely, an "urban community" is defined as having at least 2,000 housing units or 5,000 residents (U.S. Census Bureau, 2024).

Challenges in Nebraska's urban communities

Urban communities in Nebraska are experiencing increasing population growth, and higher population density, which can worsen the impacts of climate change through extreme weather events like droughts, floods, severe storms, and wildfires. Urban areas, characterized by gradual population growth and land development, are prone to heightened vulnerabilities (Dodman et al., 2022). Increased flood frequency and magnitude (Figure 2.12) combined with population trends, land-use development plans, and employment opportunities means that the eastern third of Nebraska will continue to bear a disproportionate burden of flood impacts compared to other parts of the state (Abedin et al., 2024). These counties and communities also face greater exposure to potential economic losses due to the region's concentration of critical infrastructure and housing developments.

Dodge County in eastern Nebraska has been identified as having a higher percentage of changes in the exposure of developed areas within flood zones from 2001 to 2011 compared to the national average (Abedin et al., 2024). Similarly, Douglas, Sarpy, Lancaster, and other eastern Nebraska counties face comparable challenges. When looking at the exposure for the most devasting floods—those with 100-year return periods, researchers (Tale et al., 2021) found that areas along the Platte, Missouri, and Elkhorn Rivers in the eastern third of the state, which contain the highest population concentrations, are especially vulnerable to extreme flood disasters.

With climate change, the frequency of heavy rainfall events is expected to increase (Chapter 4), raising the risk of flooding and potentially leading to repetitive losses as the occurrence and intensity of storms grow. The top 10 counties in Nebraska for flood insurance coverage from 1978 to 2020 were Douglas, Lancaster, Sarpy, Dodge, Cass, Saunders, Buffalo, Platte, Lincoln, and Dawson. The top 10 counties for flood insurance claims during the same period were Sarpy, Douglas, Dodge, Cass, Buffalo, Saunders, Madison, Washington, Lancaster, and Richardson.

Recent major floods, including the 2011 flood along the Missouri River and the 2019 floods along the Elkhorn and Platte Rivers, have altered river channels and floodplains, rendering existing floodplain maps inaccurate or underestimated. As a result, many communities in eastern Nebraska, such as Bellevue, Hooper, North Bend, Inglewood, King Lake, La Platte, La Vista, Valley, Venice, and Waterloo, lack adequate protection for future extreme flood events.

The increase in extreme events could result in insurers leaving the state—which has happened in California, Colorado, and Florida (Lin, 2023)—and would have cascading effects on Nebraska's economy. This includes the need to maintain infrastructure to remain eligible for federal funding and the growing recognition that wildfires are becoming more common in Nebraska.

Although the probability of an individual levee failing in a given year remains relatively low, the cumulative risk of multiple levees experiencing failure is considerable (NEMA, 2021). Large-scale events like the 2011 Missouri River flood and the 2019 flood across Nebraska have put immense strain on numerous levee systems, making simultaneous failures a possibility, which may affect urban communities. These counties will remain vulnerable to floods and related extreme weather and climate events under climate change scenarios (Chapter 4).

Challenges in Nebraska's rural communities

Rural Nebraska faces numerous challenges and obstacles in responding to climate change. These limitations stem from various factors that need to be addressed to enhance their institutional capabilities. By examining these challenges in detail and proposing potential solutions, rural communities can be empowered to tackle climate change effectively.

First, rural communities often face economic, social, and structural barriers. These include aging populations, declining numbers, and lower average incomes, which can limit their capacity to address climate change (Hu et al., 2018). Most of Nebraska is rural, and 73% of Nebraska counties lost population between 2010 and 2020 (Burkhart-Kriesel, 2022). Shrinking populations, coupled with tough economic times, have reduced the ability to take proactive actions against climate change and extreme weather and climate events. For example, the village of Winslow was completely inundated by flooding in March 2019. As a result, many residents expressed willingness to relocate the village to a higher and safer location, though some chose not to move out of the floodplain. Despite state and federal aid availability, the recovery process has taken much longer than expected. Five years later, in October 2024, the village remains in the recovery phase, leading to a loss of residents and the revenues needed to rebuild the community.

Aging infrastructure is another significant challenge, with many rural areas having outdated and deteriorating roads, bridges, water systems, and energy grids that are ill-prepared for the increasing impacts of climate change. Most dams that fail in Nebraska are small low-hazard potential dams located in rural areas (NeDNR, 2022). Many rural areas lack digital flood hazard maps or digital databases to help evaluate the potential impacts of these aging infrastructure systems on communities and agricultural lands. A lack of access to expertise and technical knowledge within rural communities poses another significant challenge, hampering their ability to implement sustainable practices and adopt climate-friendly strategies.

Limited financial and other resources also present challenges for investing in climate change initiatives in rural areas (Hu et al., 2018). Rural communities and Tribes often lack the capacity to adapt to and mitigate harm from climate change, lacking "the staffing, resources, and expertise—to apply for funding, fulfill complex reporting requirements, and design, build, and maintain infrastructure projects over the long term" (Headwaters Economics, n.d.). The research highlighted in the Fifth National Climate Assessment states that Nebraska ranks among the 10 states where the greatest share of communities have a capacity lower than the national medium, making them less competitive for assistance (Knapp et al., 2023).

Additionally, the new Federal Flood Risk Management Standard (FFRMS) may result in higher compliance costs or reduced investments, as federal funding will now be subject to stricter standards (FEMA, 2024). Many communities in Nebraska depend on federal funding to support capital improvement projects (Fischer, 2024), many of which are in flood-prone areas, including the 1% and 0.2% annual chance flood zones – also known as the 100-year and 500-year floodplains. These communities will face increased financial challenges in meeting the new standards and requirements.

Physical isolation is yet another obstacle, with geographical remoteness resulting in limited access to resources, services, and infrastructure, hindering the adoption of climate-friendly practices and technologies (Cain, 2021). Reports indicate that the remoteness of rural Nebraska communities increases their vulnerability to extreme weather and climate events. The 2020 Nebraska Rural Poll (Vogt et al., 2021) reported that over half of rural Nebraskans say their community was harmed at least moderately by extreme weather events in 2019. They reported longer distances to stores, damage to homes, and increased levels of anxiety and stress. The smallest Nebraska communities appear to be experiencing the most harm, with more than 45% of these residents reporting having to drive extra miles for shopping because of the extreme weather events in 2019. Driving extra miles for work, school, shopping, or health care is particularly difficult for rural Nebraska residents living in geographically remote regions (over a 60-minute drive) from grocery stores, gas stations, and essential health care services. According to the USDA Economic Research Service, over 95,000 Nebraska residents were geographically remote from essential services in 2010 (USDA ERS, 2024b). Moreover, rural communities often lack economic diversity, relying heavily on a single industry, primarily agriculture, making them vulnerable to climate change impacts such as extreme drought or floods.

Opportunities and policy recommendations to improve climate resilience in Nebraska's communities and built environments

Communities can take a comprehensive approach to reducing the risks associated with climate change by adopting a combination of mitigation and adaptation strategies. Integrating measures such as land-use planning and regulations, infrastructure upgrades, preservation of natural systems, and promoting education, awareness, engagement, and collaborations will contribute to building resilience and adapting to the challenges posed by weather and climate extreme events (Berke et al., 2009; Fu & Tang, 2013; Hu et al., 2018).

Several Nebraska communities have taken proactive measures to address climate change (Hu et al., 2018). The City of Lincoln has laid a solid foundation for building a more resilient city by releasing its first environmental plan, the *Lincoln Environmental Action Plan* (*LEAP*), in 2017. Building upon this, the City of Lincoln developed the *2021–2027 Climate Action Plan* in 2021, which identified 12 key areas where the city faces risks from the intersection of climate impacts with existing social and infrastructure vulnerabilities (City of Lincoln, 2021). Similarly, the Omaha City Council released a draft climate action plan that addresses climate change in 2024 and recommends solutions to mitigate climate risks in the Omaha area (City of Omaha, 2024). These plans demonstrate Lincoln's and Omaha's commitment to addressing climate change and finding practical solutions. The City of Beatrice has also implemented a buyout and relocation program to move property owners out of flood-prone areas. The City of Fremont and Dodge County have made significant non-structural mitigation efforts in the areas most at-risk for floods since the 2019 event. This proactive approach helps protect the most vulnerable residents and businesses from the impacts of flooding and promotes long-term resilience. Overall, these examples highlight the progress being made in Nebraska to enhance climate resilience and safeguard communities and their built environments. By prioritizing these efforts and seeking innovative solutions, Nebraska can better adapt to climate change and protect its residents from future weather and climate challenges.

Limited resources and capabilities mean that rural communities typically cannot develop their climate action plans. However, they can actively participate in regional planning efforts that seek regional solutions (Table 10.1, community highlight 8). Rural communities, particularly small and isolated ones, are highly encouraged to engage in regional hazard mitigation planning organized by each natural resources district. Doing so makes them eligible for potential disaster funds to combat climate-induced extreme hazards. Regional hazard mitigation planning involves identifying major weather and climate events, evaluating their impacts, and prioritizing key mitigation measures. In addition, rural communities are encouraged to collaborate with regional economic development districts to seek external funding opportunities. This collaboration can enhance economic capabilities and help address future climate risks. Furthermore, rural communities are also encouraged to partner with the University of Nebraska system to help identify key local challenges and practical solutions. The university can provide expertise in rural development and climate actions, further supporting rural communities' resilience efforts. By actively participating in regional planning, collaborating with economic development districts, and engaging with the university system, rural communities can access resources, funding, and expertise to enhance their resilience and effectively address weather and climate challenges.

Climate-informed land-use planning and design

Climate-informed land-use planning and design are essential for building climate resilience in Nebraska communities, particularly in eastern Nebraska, where land development is more prevalent. By integrating climate projections and data into planning processes, communities can identify vulnerable areas and develop mitigation strategies. This includes considering the impacts of extreme weather and climate events when designing land-use scenarios, implementing zoning regulations, and establishing building codes (Hu et al., 2018; Tang et al., 2010). Climate-informed planning promotes the development of resilient and adaptive communities better equipped to withstand and recover from climate impacts. For instance, effective land-use planning and regulations can discourage new construction in flood-prone areas and require that existing structures meet resilience standards.

Infrastructure upgrade and retrofitting

Infrastructure upgrades and retrofitting are effective approaches for enhancing climate resilience (Sandink & Binns, 2021). By assessing the vulnerabilities of existing infrastructure, communities can identify areas that require improvements or modifications to withstand the impacts of climate change. This may involve retrofitting buildings to enhance their structural integrity against strong winds, flooding, wildfire, or heat stress.

Preserving natural systems

Preserving natural ecosystems is an ecological approach to reducing the impacts of extreme climate events on communities and the built environment (Brody & Highfield, 2013). These strategies focus on minimizing damage and preserving the functionality of natural systems to mitigate climate-induced flood risks. Activities such as wetland restoration, protection and enhancement of natural floodplains, and adopting sustainable stormwater management practices are key to achieving this. Preserving and restoring natural systems can mitigate flood risks and provide additional benefits, including improved water quality and enhanced biodiversity (Table 10.1, community highlight 9).

Education, engagement, and collaborations

Education, engagement, and collaboration are crucial to addressing climate risks (Hu et al., 2018; Z. Tang et al., 2010; Woodruff & Stults, 2016). Increasing knowledge and awareness among stakeholders and the public is essential for driving concrete actions. By promoting public awareness and understanding of climate change's impacts, communities can encourage sustainable practices, informed decision-making, and active participation in resilience efforts. Collaborative decision-making processes ensure that adaptation measures are context-specific, culturally sensitive, and inclusive, enhancing their effectiveness and sustainability. Engaging community members, stakeholders, and local organizations in planning and implementation ensures that adaptation initiatives reflect the needs and priorities of the community. This participatory approach empowers individuals, fosters ownership, and garners support for adaptation initiatives. Partnerships and cooperation leverage collective wisdom and resources for effective climate adaptation strategies. Collaborating with stakeholders such as elected officials, planners, engineers, and community members is vital for successful implementation. For example, the Invitational Drought Tournament exercises organized by the National Drought Mitigation Center have proven to be an effective platform for engaging stakeholders in conflict resolution during extreme events (Hill et al., 2014; Wilhite et al., 2014). Implementing these policies requires a multi-stakeholder approach involving government agencies, urban planners, architects, developers, community organizations, and residents (Table 10.1, community highlight 10).

Conclusions

In the past decade, Nebraska has seen a rise in extreme weather and climate events. These have become more frequent, lasted longer, and affected more areas. As a result, these events increased costs and deeply impacted Nebraska's communities and infrastructure.

This chapter shows that climate change presents serious challenges for Nebraska's communities and infrastructure. The escalating frequency and intensity of extreme weather and climate disaster events, combined with infrastructure vulnerabilities and shifts in precipitation patterns, make it necessary to take proactive measures to lessen these impacts. Reducing risks, protecting lives and property, and building resilient communities requires action. This can be achieved by incorporating climate-informed land-use planning and design, upgrading infrastructure systems, promoting public awareness, engaging the community, coordinating stakeholders, and finding regional solutions. These steps will help Nebraska communities adapt and thrive in the face of climate change. Addressing the impacts of climate change on communities and the built environment requires comprehensive approaches that include adapting, building resilience, and reducing risks. By taking proactive measures, involving community members, making policy changes, and encouraging collective action, Nebraska can lower risks, protect lives and property, and promote sustainable development in the face of a changing climate.

TABLE 10.1. COMMUNITY HIGHLIGHTS.

Community Highlight 1: Drought impacts in McCook

Agricultural losses during extreme drought have ripple effects throughout local communities. The community of McCook, like many other rural Nebraska communities, experienced agricultural losses during the 2012–2013 drought event that rippled throughout local and regional economies. Multiplying the impact, McCook also faced losses to its recreational sector as both reservoir levels and pheasant populations fell due to drought. Because of dust storms, transportation was also hazardous at times (Jedd et al., 2018).

Community Highlight 2: Flooding in Rulo, Brownville, and Nebraska City

Southeast Nebraska communities experienced an extraordinary stretch of consecutive days above the flood stage in 2019. The village of Rulo endured an unprecedented 272 days above flood stage. The village of Brownville endured 271 days above the flood stage, while the city of Nebraska City experienced 270 days of flooding (NeDNR, 2022).

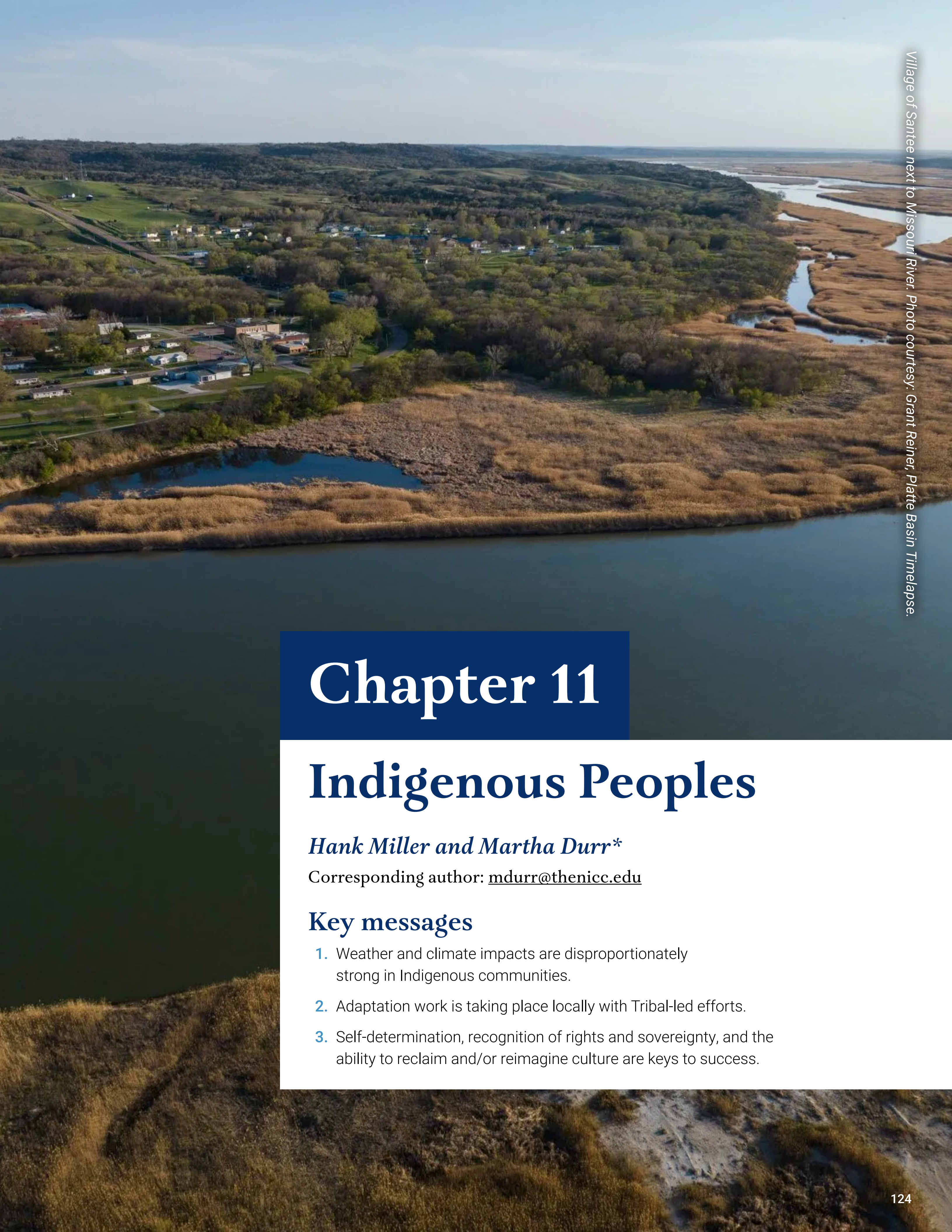
Community Highlight 3: Tornadoes in Lincoln, Elkhorn, Bennington, and Blair

From April 26 to 28, 2024, multiple severe tornado outbreaks caused extensive damage to eastern Nebraska's homes, businesses, vehicles, agriculture, and infrastructure (NOAA NCEI, 2024c). Lincoln narrowly missed a direct hit as a large tornado touched down outside the city. A local manufacturing facility on the edge of Lincoln was destroyed, and the company's employees were laid off as a result. The same storm system produced a mile-wide tornado that inflicted heavy damage on Elkhorn, Bennington, and Blair near Omaha (NOAA NCEI, 2024c). Additionally, an EF-3 tornado struck Eppley Airfield near downtown Omaha, destroying several hangars and airplanes (NOAA NCEI, 2024c).

Community Highlight 4: Flood impacts in Norfolk, Fremont, and Winslow

The 2019 flood compelled the city of Norfolk to evacuate a third of its residents, and the city of Fremont became completely isolated, relying on National Guard military convoys to provide essential supplies for several days (NeDNR, 2022). Over 1,500 homes and buildings were affected in Fremont alone, with more than 247 being unsafe for occupation due to extensive damages (NeDNR, 2022). The nearby village of Winslow remained submerged for multiple days, and the road to recovery for these communities is expected to span several years.

TABLE 10.1. COMMUNITY HIGHLIGHTS.
Community Highlight 5: Compounding flood and COVID impacts in Schuyler The March 2019 flood impacted 79 properties in Schuyler, Nebraska, where over 70% of properties are at risk of flooding and over 65% of floodplain residents identify as Hispanic (Paine 2016; First Street, n.d.). While recovering from flood impacts, the community was further economically impacted by the COVID-19 pandemic when meatpacking workers were sickened and the Cargill meatpacking plant temporarily closed (Stella, 2020).
Community Highlight 6: Wildfire impacts in Elwood, Cambridge, and Purdum The communities of Elwood, Cambridge, and Purdum all experienced deaths of volunteer firefighters in 2022, and several others were injured or faced lifelong health repercussions (*El Dorado News-Times*, 2023). These communities are among the 449 of 478 fire departments in the state that depend upon unpaid volunteer firefighters. Many rural fire departments in Nebraska are "small and underfunded" (NFS, 2023, p. 5). Recruiting and retaining volunteers is one of the top challenges facing volunteer fire departments, even as they anticipate increased future risk of fires and EMS calls caused by extreme weather, including wind and drought, according to a 2023 survey conducted by Nebraska Public Media News (Kelly & Wheaton, 2023).
Community Highlight 7: Wind impacts in Omaha Metro Area On July 9, 2021, three storms with 96 mph winds, equivalent to a Category 2 hurricane, caused significant damage to the Omaha Public Power District (OPPD), leading to widespread outages. The complex restoration process took nearly seven days to complete (American Public Power Association, 2021). A windstorm on July 31, 2024, with winds up to 100 miles per hour, resulted in the largest outage event in the Omaha Public Power District's recorded history. The extreme winds caused widespread tree damage and power outages throughout the Omaha metro area, particularly in Douglas and Sarpy Counties. OPPD reported that nearly 220,000 customers lost power that evening, more than half of the utility's 412,000 customers (American Public Power Association, 2024).
Community Highlight 8: Building Niobrara's community climate resilience The village of Niobrara is collaborating with the University of Nebraska on a project to increase the community's resilience to climate extremes. Among planning and mitigation efforts, local college student interns are surveying the community to map the assets that might be used in future emergencies, getting grants for tree planting, and gathering digital images that will help the community apply for financial assistance in the future.
Community Highlight 9: Santee Sioux Nation's climate resilience partnership In the aftermath of the March 2019 flood, the Nebraska Indian Community College and Santee Sioux Nation Office of Environmental Protection have begun leading efforts to undertake environmental projects that would improve the community's future climate resilience, like restoring native prairies, monitoring the environment (water and air quality, wildlife) and installing a weather station to improve their monitoring capabilities (Reiner, 2023).
Community Highlight 10: North Platte NRD community drought plan In 2016, the North Platte Natural Resources District (comprising Sioux, Scottsbluff, Banner, Morrill, and Garden Counties) collaborated with the National Drought Mitigation Center (NDMC) to engage local government, agriculture, education, media, and industry stakeholders in discussing challenges and opportunities for the region during drought (NDMC, 2016) and shaping a community drought plan, finalized in 2018 (North Platte NRD, 2018).



Village of Santee next to Missouri River. Photo courtesy: Grant Reiner, Platte Basin Timelapse.

Chapter 11

Indigenous Peoples

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Key messages

1. Weather and climate impacts are disproportionately strong in Indigenous communities.
2. Adaptation work is taking place locally with Tribal-led efforts.
3. Self-determination, recognition of rights and sovereignty, and the ability to reclaim and/or reimagine culture are keys to success.

Introduction

Indigenous communities located in what is currently called Nebraska include the Sovereign Nations of Isanti Dakota (Santee Sioux Nation), Ponca (Ponca Tribe), Ho-Chunk (Winnebago Tribe), Umo^{n}ho^{n} (Omaha Tribe), Sac and Fox Nation, and Ioway (Iowa Tribe of Kansas and Nebraska, 2024). Forced assimilation and relocation from traditional homelands, broken treaties, genocide, the spread of illness, boarding school atrocities, and a disproportionate percentage of missing and murdered Indigenous people have been and continue to be significant and generational stressors. The complete termination of the Ponca Tribe by the U.S. government occurred in 1966, and only in 1990 did the Tribe regain federal recognition (Grobsmith & Ritter, 1992). Ironically, Standing Bear—a Ponca—was held for trial near so-called Omaha in 1879 after trying to return his deceased son to their traditional home. He successfully argued to be recognized as a person with legal rights in his "I Am a Man" speech (Ponca Tribe of Nebraska, 2025). Communities on Indigenous lands across Nebraska are rural, generally with small populations, limited infrastructure, and an overall lack of financial resources. Tribally owned land remains fragmented (Figures 11.1 and 11.2) because of historical land allotment and land use, primarily for agricultural-related practices.

Despite such immense hardships and systemic inequities, community resilience and reclamation of culture remain strong and are growing. Self-determination and governance, momentum toward Native Nation Building principles, tribal economic development, grounding in Indigenous Knowledge and values, and local educational opportunities are building and rising. For example, efforts underway with Ho-Chunk Incorporated (2024), founded in 1994, focus on shared Tribal priorities such as housing, education, jobs, youth, and elders. Within Nebraska, higher education through accredited Tribal colleges is available at Little Priest Tribal College and Nebraska Indian Community College (NICC), where certificates, associates, and now bachelor's degrees are offered in settings with a foundation of Indigenous core values. The student population has grown significantly at NICC, and college enrollment doubled from 2019 to 2023.

Figure 11.1. Native American land cessions via treaties in what would later become Nebraska. (Source: NebraskaStudies.org, 2025)

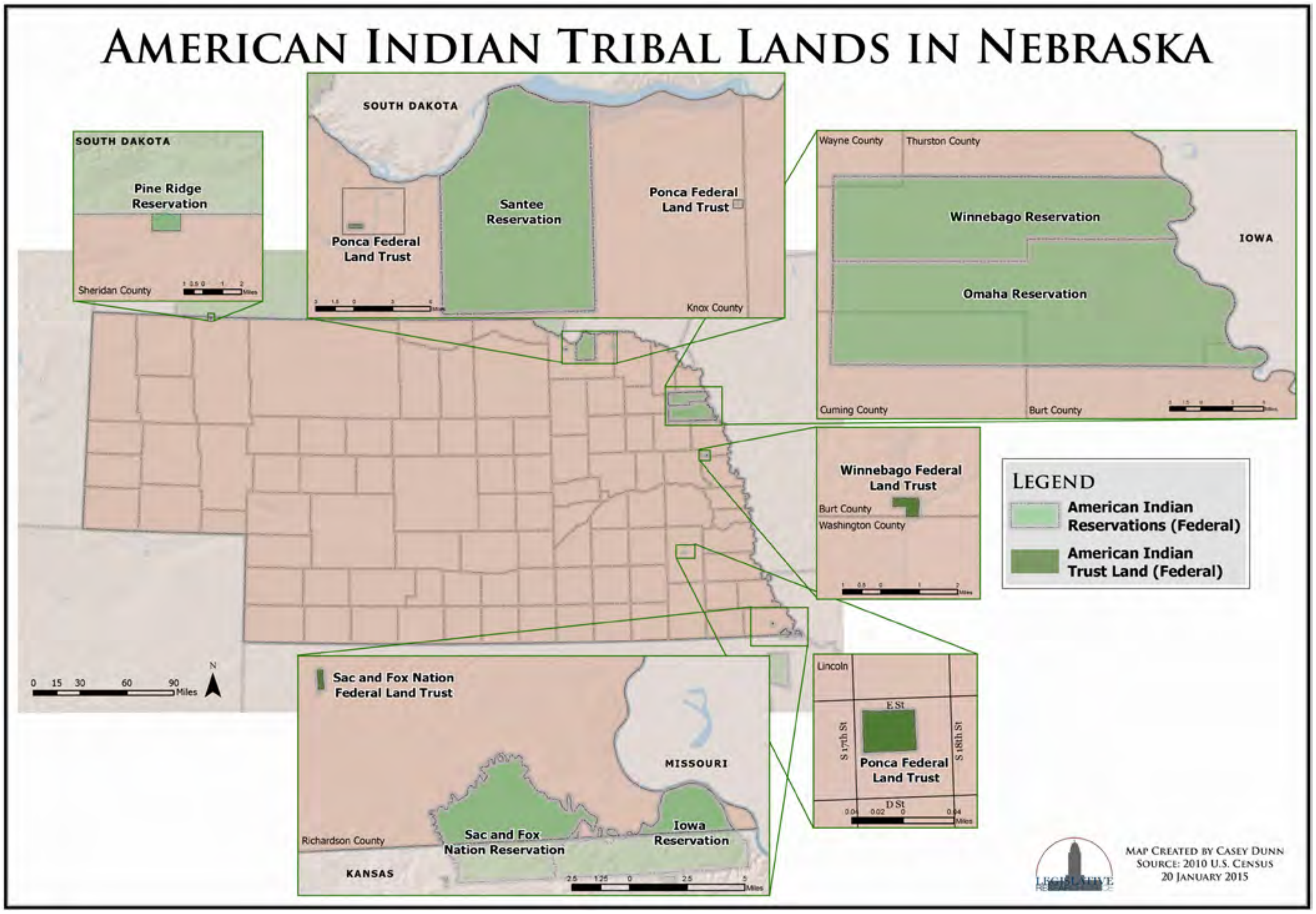

Figure 11.2. American Indian tribal lands in Nebraska. (Source: Nebraska Legislature, 2015)

Climate assessments and impacts

Our global and regional climate assessments—including physical science, societal impacts, adaptation planning, and mitigation strategies—have not always included Indigenous voices and worldviews. However, recent efforts are making considerable strides for meaningful inclusion of disenfranchised perspectives, notably the *Status of Tribes and Climate Change Report* (Status of Tribes and Climate Change Working Group, 2021). This resource describes the unique and specific impacts felt by tribes. It provides examples of community responses and actions through the lens of relationality with the natural world, respect for traditional knowledge, practices and governance, and environmental and social justice. Specific impacts and solutions are meticulously outlined in the areas of ecosystems and biodiversity, air, water, health and well-being, economic development, energy and a just transition to renewables, cultural resources, emergency management, protection-in-place and community-led relocation, solid waste, and emerging topics.

Climate and weather hazards impacting Indigenous communities in Nebraska include the rising frequency and severity of extreme events such as heat stress, heavy precipitation, drought, high winds and storms, and increased overall variability (Knapp et al., 2023). These hazards are expected to continue and magnify for the foreseeable future, regardless of the climate pathway forced upon Indigenous people by the actions or inaction of others (USGCRP, 2023). Such weather extremes pose unique challenges for small, low-resource, and generally isolated rural Indigenous communities (Whyte et al., 2023). For example, the March 2019 flood event resulted in historic and long-lasting implications for many communities across the region. The village of Santee, with a population of less than 1,000 and the critical community services for the Santee Sioux Nation, was left stranded, without access to and from town. Residents experienced power outages and no potable water long after floodwaters receded (Abourezk, 2019). Severe weather leading to heavy rain and flash flooding in May 2019 resulted in a state of emergency for the Sac and Fox Nation when their buffalo farm was completely inundated, buildings across the Reservation were flooded, and roads were closed (Chavez et al., 2023). Unusual warmth during the Ioway Powwow has resulted in health implications for community members, and highly variable temperatures during the 2022 spring severely impacted 33% of their beehives (Iowa Tribe of Kansas and Nebraska, 2024). Due to shifts in the timing of weather or biological events, ceremonial practices for Native communities are being impacted, leading to cultural disruptions. Heat and drought stress have combined to increase wildfire occurrence and potential across much of Turtle Island (North America). This leads to more days with poor air quality impacting communities (Status of Tribes and Climate Change Working Group, 2021). Tribal environmental departments are implementing air quality sensors while notifying and educating the community on risks and mitigation strategies.

The health of Indigenous people and the environment are increasingly at risk due to climate change stressors (Whyte et al., 2023). Compounding environmental hazards include underlying stressors of negative health outcomes, higher-than-average poverty, traditional and nutritious food insecurity, historical and current institutional barriers, and unsustainable environmental practices primarily for non-Tribally controlled resources. In Santee, elevated and unsafe levels of manganese (more than 50 times the safe limit) in the town's drinking water have resulted in a no-drink order for nearly five years (Herbers, 2024a). Boiling the water only results in higher concentrations of manganese. Though not directly tied to climate change or the 2019 flood, this environmental problem is caused by naturally occurring manganese in a deep aquifer, which compounds stressors from weather and climate extremes. Research has shown that nearly half of Sovereign Nation communities in the United States do not have access to clean water or sanitation. Through the Santee community's tireless efforts to shed light on this issue, progress is being made to fund the $53 million solution of a pipeline to a South Dakota water district. This increases resiliency and water security in the face of increasing extremes (Beach, 2024b).

Planning and resilience activities

Community-led and culturally focused climate resilience planning and activities are taking place. For example, the Ioway Tribe has recently developed a Pathways to Climate Resilience guide. The recommendations include eight priority areas and six climate resilience strategies (Iowa Tribe of Kansas and Nebraska, 2024). The guide's interconnected themes weave food sovereignty, public health, biodiversity, water, and a regenerative economy with elders and youth participation and arts and culture. Furthermore, the Tribe was awarded the Center of Excellence in Regenerative Native Agriculture, has established a free-trade zone in cooperation with Native-owned operating partner Ayittatoba, and has created a Tribal national park (Iowa Tribe of Kansans and Nebraska, 2024). The Santee Sioux Nation has directed the production of a comprehensive Tribal hazard mitigation plan. By outlining specific weather and climate hazards and risks, the Nation is better positioned to implement preparedness actions and apply for disaster-related funding. The Winnebago Tribe's Ho-Chunk Inc. is a leading entity in community economic development. Traditional foods are planted and harvested using culturally considerate practices. This contributes to food sovereignty, workforce development, and cultural education, leading to increased resilience.

Movements toward Indigenous land return (recognition of historical treaties and sovereignty) are growing and ultimately rooted in climate justice. In what was termed a "historic moment for the Winnebago Tribe" by Chairwoman Victoria Kitcheyan, approximately 1,600 acres of land were transferred back to the Tribe after illegal seizure by the U.S. Army Corps of Engineers in the 1970s. The Winnebago Land Transfer Act, introduced by U.S. senator Deb Fischer (R-Neb.), was signed into law in 2024 (Herbers, 2024b).

Climate mitigation often involves energy transition from fossil-based fuels to renewables, which can require land-use conversion (Chapter 6). The benefits and consequences of renewable energy sources must be considered, and implications for Indigenous Peoples must be included, a concept termed a just energy transition (Chapter 12). Tribally owned and operated energy assets exist locally, and opportunities to fund renewable projects such as solar are on the rise. In 2022, the NICC installed solar arrays at their Macy, Santee, and South Sioux City campuses using Nebraska-based GC ReVolt. The capacity meets 35% of energy requirements for colleges.

Weather and climate impacts are disproportionately strong in Indigenous communities (Whyte et al., 2023). Adaptation work is taking place locally through Tribal-led efforts. Self-determination, recognition of rights and sovereignty, and the ability to reclaim and/or reimagine culture are keys to success. Learning from Indigenous knowledge systems and co-creation of local resilience strategies built on reciprocity on offer solution pathways.

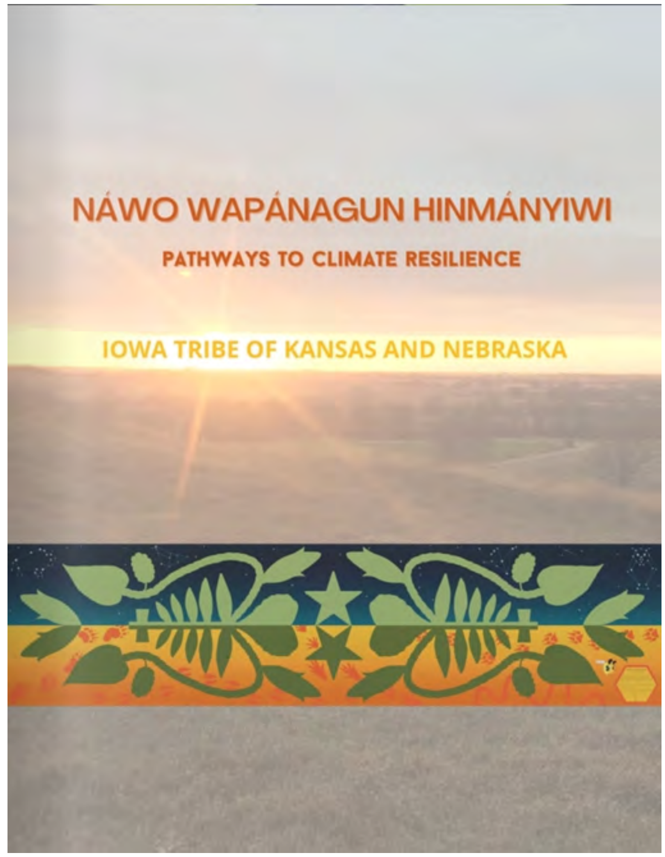

Figure 11.3. Pathways to Climate Resilience guide (Source: Iowa Tribe of Kansas and Nebraska, 2024).

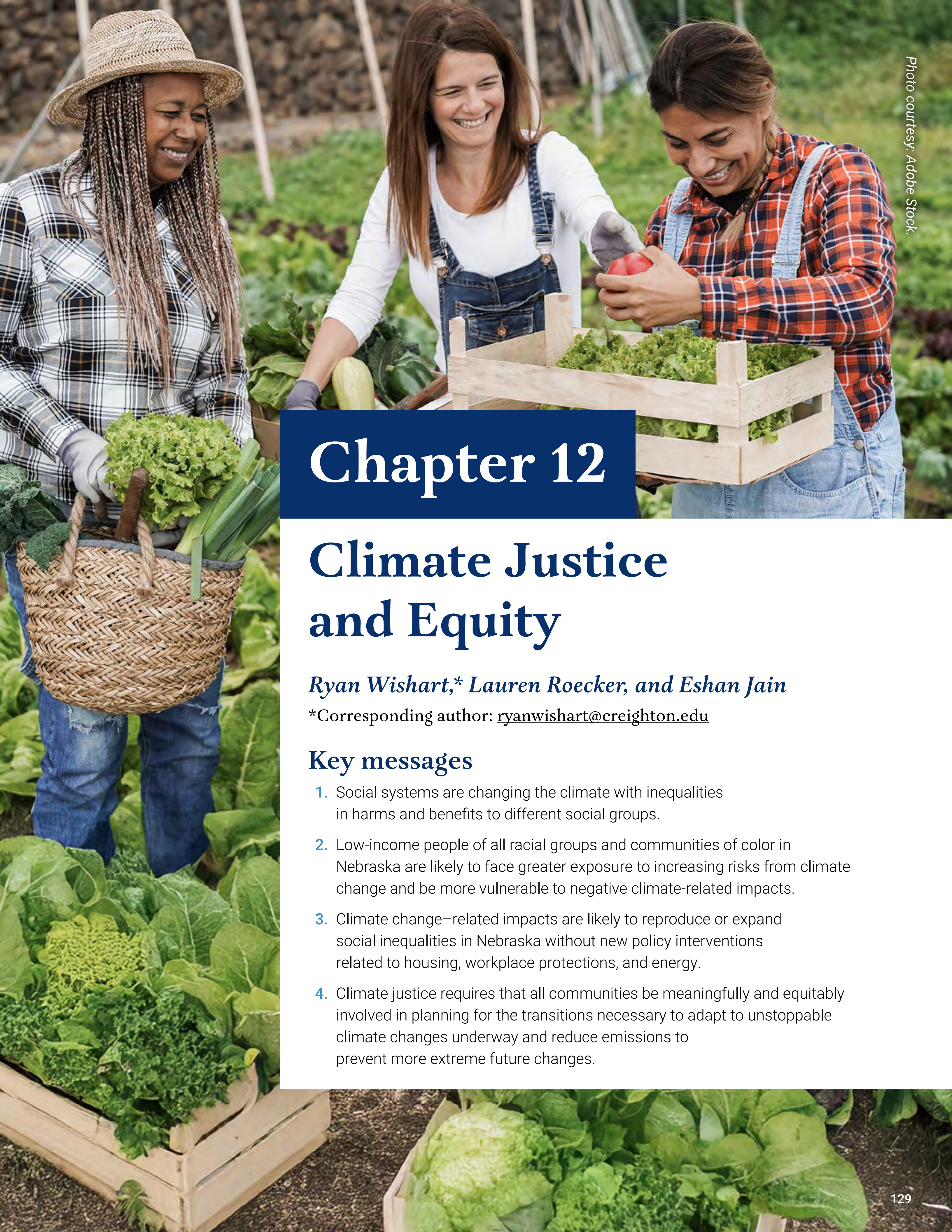

Photo courtesy: Adobe Stock.

Chapter 12

Climate Justice and Equity

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Key messages

1. Social systems are changing the climate with inequalities in harms and benefits to different social groups.
2. Low-income people of all racial groups and communities of color in Nebraska are likely to face greater exposure to increasing risks from climate change and be more vulnerable to negative climate-related impacts.
3. Climate change–related impacts are likely to reproduce or expand social inequalities in Nebraska without new policy interventions related to housing, workplace protections, and energy.
4. Climate justice requires that all communities be meaningfully and equitably involved in planning for the transitions necessary to adapt to unstoppable climate changes underway and reduce emissions to prevent more extreme future changes.

Introduction

Social systems are changing the climate and distributing the impacts inequitably, making social science and humanities research essential for understanding how different forms of adaptation and mitigation (Box 1.2) will promote or undermine climate justice. Climate justice recognizes this unequal distribution of burdens and benefits of climate change. It is based on the idea that countries and people contributing the most to climate change should help those affected the most.

The Fifth National Climate Assessment (NCA5) states that scientists have very high confidence (Box 1.3) that social systems are driving climate change, primarily through how they shape fossil fuel use (Marino et al., 2023; see also Chapter 1). Experts are confident in their understanding of how social systems distribute both the benefits of energy consumption driving climate change and the consequences of climate change in an inequitable manner within societies. Governance processes—policies and procedures—create inequalities today but can also help reduce them in the future.

Scientists also have high confidence that social systems shape how people understand and talk about climate change via their personal history, culture, education, and ethical beliefs. Differences in these understandings combined with the complexity of climate politics can create challenges for effective governance. However, research shows that including multiple forms of knowledge in climate decision-making, such as views from Indigenous communities (See Chapter 11), can help promote justice (Marino et al., 2023).

Climate justice is important for Nebraska policymakers both for normative (deciding what ought to be done) and practical (what can be done) reasons. If we don't actively address existing social inequalities, climate change adaption and mitigation efforts will likely be less successful. Climate justice is relevant for both the drivers and the impacts of climate change within Nebraska and for the connections between drivers within the state and climate impacts to communities outside the state and across the world. In other words, climate justice concerns how Nebraska's role in causing climate change affects both its residents and communities outside its borders. For instance, greenhouse gas emissions from Nebraska's agriculture and energy industries contribute to rising global temperatures, which can worsen droughts in distant countries already facing water shortages.

Well-established evidence shows that developed nations, particularly the U.S., have historically contributed the most to climate change (Marvel et al., 2023). A range of global policy agreements recognize that, based on those contributions and their greater capacity to act, climate justice requires developed nations to contribute more to climate change mitigation and adaptation efforts (United Nations, n.d.). These principles of "common but differentiated responsibilities" can also be applied to communities within a developed nation like the U.S. For example, those communities, corporations, or sectors that are more responsible and capable also have greater responsibility to act.

Limited peer-reviewed research specifically addresses climate justice in Nebraska. However, findings from studies across the country and worldwide offer important lessons about likely threats to climate justice within Nebraska and stemming from it, as well as actions that help promote greater justice.[1] Communities that have contributed the least to climate change often suffer the most negative human and ecological health impacts from its effects (Schaefer Caniglia et al., 2021). These climate impacts can interact with and worsen existing social inequalities related to race, class, gender, sexual orientation, age, and religious or ethnic background (Marino et al., 2023).

Principles of climate justice

The Intergovernmental Panel on Climate Change (IPCC) (Chapter 1, Box 1.1) describes climate justice as justice "that links development and human rights to achieve a human-centered approach to addressing

[1] The Keystone XL Pipeline has been the most common focus of research using a climate justice lens (Derman 2020; Ordner 2018).

climate change, safeguarding the rights of the most vulnerable people and sharing the burdens and benefits of climate change and its impacts equitably and fairly" (IPCC, 2023b, p. 2913).

The IPCC's Sixth Assessment Report and the Fifth National Climate Assessment (NCA5) address how different responses to climate change align with the three principles of justice: distributional justice (who gets what and how much?), procedural justice (who decides and how?), and recognitional justice (why does it matter?) and how this impacts the effectiveness of mitigation and adaptation (do they work?). Climate justice involves "the recognition of diverse values and past harms, equitable distribution of benefits and risks, and the procedural inclusion of affected communities in decision-making processes" (Marino et al., 2023, p. 14).

Climate justice builds upon the broader concept of "environmental justice," focusing specifically on the causes and consequences of climate change. The field of environmental justice originated from social science scholarship in response to the social movement advocating these issues.

Distributional justice

Distributional justice examines how the benefits and harms of different environmental processes affect different social groups. These processes can include intentional discrimination and unintentional inequalities caused by existing structures and systems. This aspect considers fairness among individuals, communities, states, and future generations.[2]

A related principle is "common but differentiated responsibilities," which appears in all major international climate negotiations and treaties. This principle recognizes that all nations are responsible for acting on climate change. However, those who have contributed more to the problem and possess greater resources should assume a larger share of the responsibility. This principle highlights that the "uneven distribution of wealth and power between (and within) countries is a key driver of climate injustice" (IPCC, 2023b, p. 160). This relationship can be applied within the U.S. and in Nebraska.

Procedural justice

Procedural justice examines whether affected groups have meaningful participation in decisions that affect the environment. Achieving procedural justice requires not only avoiding discrimination but also addressing the capabilities and vulnerabilities of marginalized groups. This ensures that they have access to the appropriate resources and decision-making processes that allow them to shape collective political processes and outcomes effectively.

According to the IPCC (2023c, p.1368),

> **Consensus-building institutions should avoid reducing normative questions to technical ones, recognizing that values, interests, and behaviors are all shaped by ongoing climate governance. Additionally, communities affected by low-carbon transition may face challenges in articulating their understandings and experiences, which need to be addressed in the design of climate institutions.**

In other words, groups such as community planning councils, government committees, and organizations tasked with addressing complex policy issues such as climate change should assist communities in discussing which values and practices are threatened or protected by climate impacts or responses. For example, planning for energy infrastructure with procedural justice would include not only technical questions of emissions or costs but what impacted communities consider to be fair or just, and what kinds of benefits (e.g., new jobs or reduced illness) or drawbacks (e.g., lost jobs or changes to the landscape or type of livelihood) concern them most. There are often multiple technical pathways to achieving a goal, and communities' attitudes about them can change upon reflection and consideration of what they value. Meaningful participation allows for both to occur.

[2] *Other species or ecosystems themselves are also part of distributional considerations under some cultural and political frameworks, such as in many Indigenous societies or "rights of nature" legal frameworks adopted in some nations.*

Recognitional justice

Recognitional justice asks whether impacted groups' perspectives, values, and cultures are represented in policymaking, particularly during agenda setting at the start of policymaking processes. Although this aspect is less prominent in the climate literature, scientists warn that without recognitional justice, "actors may not benefit from the two other aspects of justice" (IPCC, 2023b, p.160).

Indigenous and local knowledge are crucial for understanding and adapting to climate risks. Therefore, it is important to include these perspectives when setting climate action goals rather than just gathering input after goals have been established (IPCC, 2023b). In contrast to these scientific findings, many state governments oppose using Indigenous Knowledge and environmental justice in environmental regulation (U.S. District Court, 2024).

Distributional, procedural, and recognitional justice must be considered together. Recognitional and procedural processes are key in determining distributional outcomes. Policymaking and implementation frameworks that address only two of the three dimensions without explicitly recognizing limitations or connections can be ineffective (Baker et al., 2023). "Critically, social systems define who is seen as deserving of local, state, and federal interventions to address climate impacts" (Marino et al., 2023, p. 4).

For instance, the Environmental Protection Agency (EPA) uses a measure known as the social cost of carbon to estimate the economic damage resulting from climate change. Because this measure is tied to gross domestic product per capita, it places different monetary values on lives in different countries. Using this assessment, each U.S. life is equal to about nine lives in India, but only half as much as a life in Qatar. This approach affects the amount of spending justified to protect different communities from harms related to environmental carbon emissions (Hersher, 2023). Although this practice follows a common method used in environmental economics, it also reflects political and social value decisions that shape the selection of that method. As noted in the NCA5, "If climate change is understood as an outcome of socioeconomic and ethical arrangements that resulted in exploitation and discrimination, then reexamining those arrangements also becomes necessary" (Marino et al., 2023, pp. 9–10).

Unequal drivers and consequences

Globally, scientists have high confidence that prioritizing climate justice and implementing just transition processes improves mitigation and adaptation outcomes. Viable options exist for improving social well-being and resilience while reducing emissions (Calvin et al., 2023; Marino et al., 2023). To achieve climate justice, we must first recognize and address the uneven distribution of decision-making power and responsibility for emissions that drive climate change. Also, we must understand how these emissions' benefits and negative impacts are spread unevenly across society.

Social drivers of climate change

Responsibility for emissions can be assessed from the production or consumption side of the same interconnected processes. Production-based and consumption-based accounting are two different ways of accounting for responsibility for the same emissions. Globally, 70% of historical production-side carbon dioxide emissions have been traced to just 78 contemporary corporate and state-owned entities, with Chevron and ExxonMobil leading among investor-owned entities (Carbon Majors, 2024).

When looking at individuals or households, studies generally find that the responsibility for emissions is concentrated among the upper class. This is mainly due to their disproportionate influence on production through ownership and leadership roles and their higher consumption-related emissions from their lifestyles. In the U.S., 40% of emissions are associated with the income sources of the richest tenth of households. The richest 1% contributes to 15% to 17% of total emissions—more than the bottom 50% of households combined—mainly due to the emissions from their investment income (Starr et al., 2023). One analysis shows that "15 days of income for a top 0.1% household generates as much carbon pollution as a lifetime of income for a household in the bottom 10%.

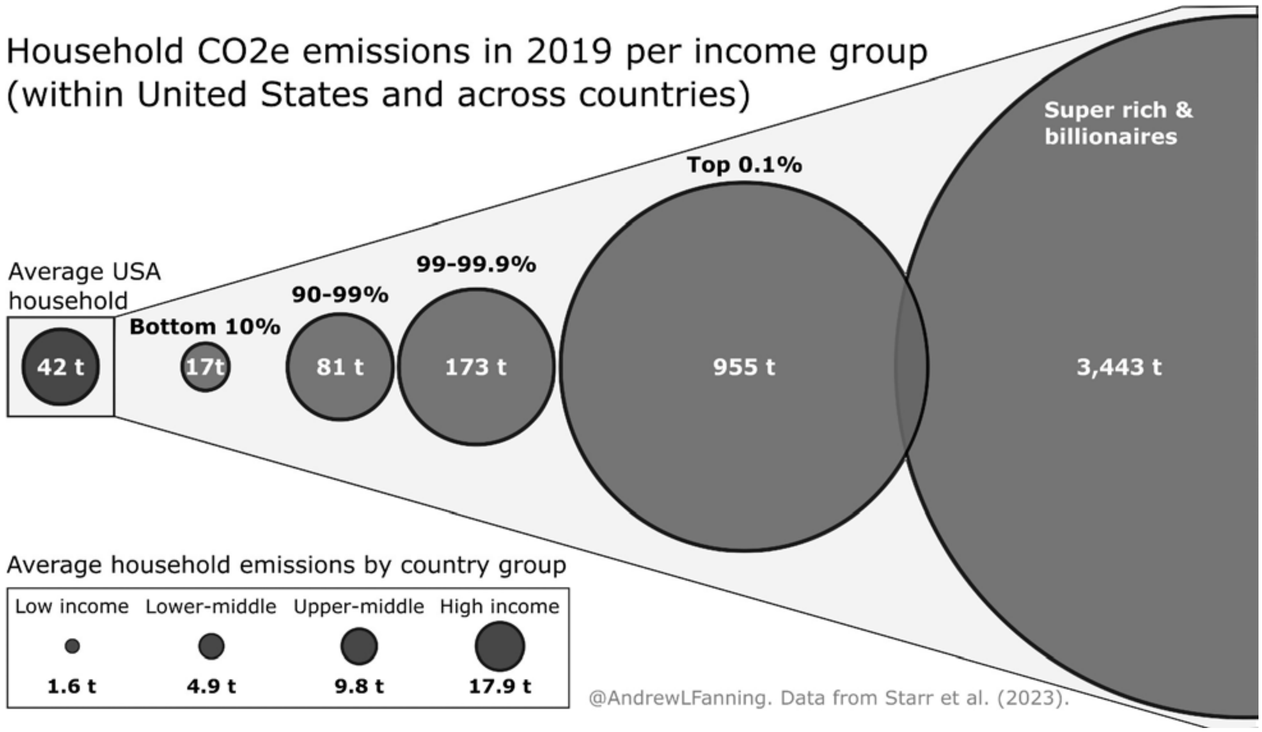


Figure 12.1. Household CO2 emissions in 2019 per income group, within the United States and across countries. The circles are scaled by household emissions, with larger circles representing more emissions. Based on data from Starr et al. (2023; Table 4). (Credit: Andrew Fanning. CC-BY)

An income-based lens highlights who is profiting the most from climate-changing carbon pollution and designs policies to shift their behavior" (Miller, 2023).

Figure 12.1 shows the differences in average emissions based on income groups in the U.S. compared to averages from other countries.[3] The top 1% of earners in the U.S. have increased their emissions, while most other households have reduced theirs. Racial disparities are also evident. White non-Hispanic households have emissions linked to their income that are 1.3 to 1.7 times higher than that of other racial groups (Starr et al., 2023).

Research indicates that increasing social inequality is associated with increasing emissions. U.S. states with increasing concentrations of income among the top 10% of earners also have higher overall emissions (Jorgenson et al., 2017). Nebraska has a lower level of income inequality when compared to the national average. However, the gap between the rich and the poor is widening, placing it among the top three states with the most increase in income inequality in recent years (Useful Stats, 2024). Nebraska also has higher-than-average wealth inequality (Suss et al., 2024). Despite having low unemployment and lower-than-average income inequality, Nebraska has high rates of the working poor (Nixon, 2023). These individuals often work long hours and multiple jobs to meet basic needs (Lozano, 2024). Research links longer working hours to higher emissions (Fitzgerald, 2022), distinct from working hours' influence on household income. Therefore, understanding the links between inequality, working hours, and emissions could be significant for policy in Nebraska.

Consumption-based calculations attribute emissions from the goods and services to those who consume them rather than produce them. For example, a production-side accounting of a hamburger would attribute associated emissions to the financiers, farmers, processing facilities, retailers, and so on, who produced the commodity. In contrast, a consumption-side accounting attributes them to the individual

[3] The poorest 10% of the population in the U.S. has a slightly lower income-based footprint than the average for all income groups across other high-income countries (in contrast to consumption-based footprints discussed below), while the top 1% in the U.S. have a footprint roughly 10 times larger than the average of other high-income countries.

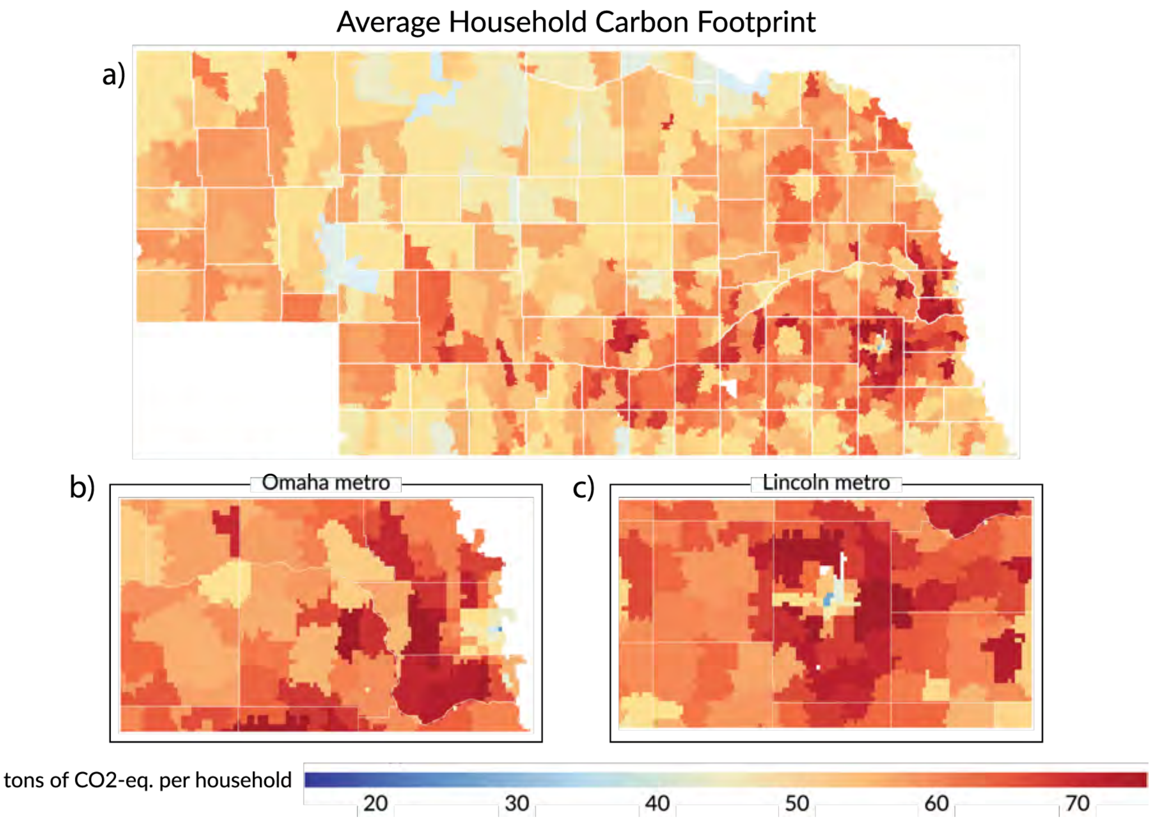


Figure 12.2. Average household consumption-based emission footprints for (a) the state of Nebraska, (b) the Omaha metro area, and (c) the Lincoln metro area. (Source: U.C. Berkeley Network, 2013)

or household that purchases the burger. These measures show similar but less extreme patterns of inequality to production-side calculations.

In the U.S., households earning over $200,000 a year have an average consumption footprint about 2.6 times larger than those earning less than $15,000 (Feng et al., 2021). "Most contributors of high carbon footprints across income groups in the U.S. are heating, cooling, and private transport, which reflects U.S. settlement structures and lifestyles, heavily reliant as they are on cars and living in large houses" (IPCC, 2023c, p. 1747). For instance, households in denser urban areas of Nebraska have lower average emissions than those in suburbs and exurbs, as shown in Figure 12.2. Even the lowest-income group in the U.S. (earning less than $15,000) has a carbon footprint higher than those in other wealthy countries—more than double the global average. Due to U.S. energy and transportation policies and investments, they also spend a larger share of their income on modes of daily living that are more polluting than global averages (Feng et al., 2021). Without attention to these inequalities, policies risk failing to change the behavior of the most influential people and undermining the support and legitimacy for climate action. As the most recent IPCC concludes:

> **Redistributive policies across sectors and regions that shield the poor and vulnerable, social safety nets, equity, inclusion, and just transitions at all scales can enable deeper societal ambitions and resolve tradeoffs with sustainable development goals. Attention to equity and broad and meaningful participation of all relevant actors in decision-making at all scales can build social trust, which builds on equitable sharing of benefits and burdens of mitigation that deepen and widen support for transformative changes. . .**
>
> **The design of regulatory instruments, economic instruments, and consumption-based approaches can advance equity. Individuals with high socioeconomic status contribute disproportionately to emissions and have the highest potential for emissions reductions. Many options are available for reducing emission-intensive consumption while improving societal well-being. Sociocultural options,**

> **behavior, and lifestyle changes supported by policies, infrastructure, and technology can help end-users shift to low-emissions-intensive consumption, with multiple co-benefits. (Calvin et al., 2023, p. 31)**

Social consequences of climate change

Unequal exposure and impacts of heat and extreme weather

Increased exposure to extreme weather is shaped by social inequalities within and between communities (Chapters 9, 10, and 11). For example, low socioeconomic status groups are more likely to be exposed by living in floodplains, urban heat island zones, or working in outdoor occupations. Social inequalities also result in different climate change impacts on individuals and households, even when they face similar exposure to climate-related dangers. For example, within floodplain and urban heat island neighborhoods, some people are more severely impacted by the same flood or heat wave due to social factors such as lack of savings or air conditioning and healthcare access. Assessing climate vulnerability effectively requires understanding how environmental and social systems interact. In the U.S., certain groups—like racial minorities, low-income families, rural communities, people with limited English-language skills, the unhoused, and agricultural workers—are more affected by environmental hazards and climate change (Marino et al., 2023). Some households and individuals may face multiple, overlapping forms of vulnerability. For example, in Nebraska, low-income immigrant families —particularly those from racial minority groups with limited English skills—may experience intersecting and compounding forms of unequal exposure to climate change and greater vulnerability to its impacts.

Academic researchers and federal authorities have made efforts to prioritize vulnerable communities in Nebraska due to past governmental neglect, exposure to pollution, and social disruption from energy transitions. For example, the priority climate action plans for the state of Nebraska and the Omaha Metro area were developed using maps of low-income and disadvantaged communities. Federal designations such as "Energy Communities" (energycommunities.gov, 2024) and "Disadvantaged Communities," as identified by the Environmental and Climate Justice Program allowed Nebraskans access to targeted funding and technical assistance for these plans (US EPA, 2024d).[4]

Improving how we measure community risks and needs, together with community members, is a priority for social scientists, community organizations, and policymakers (National Academies of Sciences, Engineering, and Medicine, 2024). This ensures that distributional justice (are outcomes fair?) is understood while also promoting the local community involvement needed for achieving procedural and recognitional justice (do impacted people have a meaningful say in what "fair" means?). For example, New York State's Climate Act created a climate justice group that brought together researchers and environmental justice organizations to create mapping criteria for disadvantaged communities (New York State, 2024). This group included community organizations from across the state to better understand what aspects of climate justice issues their data models captured well, what these models missed, and how they could be improved. Applying similar methods in Nebraska could help highlight the unique climate challenges and opportunities faced by rural and urban communities. Additionally, rural communities may face greater procedural justice challenges due to a lack of existing community organizations and capacity.

Heat Inequalities

Nationally, more than 2,300 deaths from heat-related illnesses occurred in 2023—three times previous annual averages (Davenport & Weiland, 2024). In Nebraska, increased temperatures are one of the main threats posed by climate change (Chapters 3 and 4). The risk and impacts of heat exposure are not evenly distributed along the lines of class, race, gender, age, and (dis)ability. Between 2018 and 2022, Nebraska saw over 2,000 emergency room visits and nearly 200 hospitalizations due to heat-related illness (Chapter 9).

[4] The Trump administration rescinded many executive orders relating to environmental and climate justice in early 2025. However, many of these tools and databases are being preserved by other institutions for continued reference, see https://eelp.law.harvard.edu/tracker/ceqs-climate-economic-justice-screening-tool-removed.

Heat and workplaces

Extreme heat disproportionately affects laborers in working-class jobs, workers of color, and immigrants. These groups are more likely to work outdoors or indoors without adequate cooling, leading to higher rates of heat exposure. For example, laborers on farms, construction sites, warehouses, commercial kitchens, and meatpacking plants are particularly vulnerable. Low-income workers are also more likely to suffer from chronic health conditions that can increase the impact of exposure. Chapter 9 covers heat-related health impacts and vulnerabilities.

Nationally, there are insufficient policies in place to protect workers and vulnerable groups from heat-related risks, and existing regulations often lack effective enforcement. In Nebraska, the federal Occupational Safety and Health Administration (OSHA) oversees the protection of private sector and federal employees. Recently, OSHA proposed updated heat protection measures for workers. However, the State of Nebraska does not appear to have any specific environmental heat-related protections in place for its workers. Representatives from the Nebraska Department of Labor and public employee union representatives, who were contacted for this report, were unaware of any temperature-specific protections for state employees. Some states have responded to the rise in extreme heat with laws to protect workers. California, Washington, and Colorado protect outdoor workers, while Minnesota's laws focuses on protecting indoor workers. Oregon's regulations protect both. Maryland and Nevada are also developing heat protection regulations. These regulations generally require that workers have access to shade, cool water, and rest breaks to prevent heat illness (LGEAN, n.d.).

New and existing temperature-related worker protection policies are being opposed by business groups (particularly in agriculture and construction), as well as by some political leaders despite research findings and a widely agreed upon undercounting of heat-related injuries and deaths. Nebraska has many counties with large agricultural and construction workforces exposed to weeks of high heat index days (Phillips et al., 2024). Furthermore, a history of violating existing law has led to serious heat-related injuries and deaths among vulnerable workforces (Shipley, 2021). In Nebraska, more than 30% of Black and an even greater percentage of Hispanic/Latinx workers are estimated to be in occupations with risks associated with climate change (Christman, 2023). Increased heat conditions can cause additional and disproportionate occurrences of injury and death on working class and minority populations. Increased heat conditions can reduce labor productivity and threaten livelihoods (Adrienne-Arsht Rockefeller Foundation Resilience Center, 2021; Behrer et al., 2021). The limitations of adapting outdoor labor, through strategies such as adjusting work hours or providing cooling mechanisms in extreme heat, emphasize the need for effective mitigation strategies to address climate-change-induced warming (Licker et al., 2022).

In addition to a lack of heat protection from current policies in Nebraska, other state laws may further decrease climate resilience among workers. Unionized workplaces typically provide a safer environment, with some benefits extending to non-unionized workers in the same sector. Additionally, right-to-work states such as Nebraska (with a private sector unionization rate of 7%) have higher worker injury rates. Workers face greater risks due to job instability and often struggle to understand, negotiate, and enforce protections; and more vulnerability via social determinants of health are linked to lower wages and benefits (American Public Health Association, 2023; Han et al., 2024; Johnson, 2020; Leigh & Chakalov, 2021; Zoorob, 2018).

Homes and housing

Many issues affecting climate justice stem from racial and social class inequalities in housing location and quality. For example, the historical practice of explicit racial discrimination in housing, known as redlining, has been shown to predict current health vulnerabilities to pollution and increased heat impacts caused by climate change. Ongoing forms of racial inequality in housing access also contribute to these vulnerabilities (Graetz & Esposito, 2023; Greiner & McKane, 2022; Manware et al., 2022). Homes belonging to minorities are often more exposed to pollution and heat island effects from transportation infrastructure decisions that have disproportionately benefited White communities, as seen in Omaha (Greenberg et al., 2024).

Additionally, older populations are especially vulnerable to heat and, nationwide, have seen increased mortality over the past decade. Social isolation or lack of social support can increase these risks, especially among marginalized groups and those in rural areas (Chapters 9 and 10).

Energy burdens on low-income households depend on three key factors: income relative to energy costs, the efficiency of household systems, and household energy needs. In Nebraska, climate change is causing households to need more cooling but less heating, which might lower overall energy demand. However, efforts to mitigate and adapt to climate change could also raise energy prices, increasing uncertainty in how these changes will affect households' energy burdens. Consequently, improving energy efficiency for vulnerable households is a priority for achieving distributional justice (fair distribution of harms and benefits).[5]

Households are considered energy burdened if they spend more than 6% of their income on energy costs, like electricity and natural gas bills. Those that spend more than 10% are deemed extremely burdened (Graff et al., 2021; Sovacool et al., 2024). Racial minorities often face discriminatory housing and lending practices, resulting in higher average energy burdens compared to White households with similar incomes (Brown et al., 2020). Energy-burdened households are also at a greater risk for food insecurity and health issues due to poor home conditions. These challenges can also harm mental health and contribute to economic disadvantages (Drehobl et al., 2020; Jessel et al., 2019).

On average, Nebraska households that earn less than 60% of the median income are energy burdened. The U.S. Department of Energy (DOE) estimates that nearly 182,000 Nebraska households are energy burdened, with approximately 89,000 of these households severely burdened (DOE LEAD Tool, n.d.). To help these vulnerable households, various programs have been set up across the country authorizing or requiring governments and utilities to act.

Nebraska could implement similar initiatives through action by its legislature or public utility districts. Nebraska's federally funded Weatherization Assistance Program (WAP) provides efficiency upgrades to low-income households. The state also authorizes public utilities to assist with home efficiency upgrades. These improvements reduce pollution from power production, contributing to climate change, and lower residents' utility bills and demand-related costs.

Nationally, households that are energy insecure, have lower income, are neither White nor Asian, or are renters pay higher energy bills (20 cents or more per square foot of the residence, compared to other demographic groups) (EIA, 2023b). This is due to barriers to obtaining and maintaining energy-efficient homes and appliances. Research shows that low-income and minority populations have less access to energy-efficient options. For example, energy-efficient lightbulbs are more expensive and less available in high-poverty areas than in more affluent neighborhoods, and African American female-headed households appear to face greater barriers in accessing the benefits of energy efficiency (Adua et al., 2022).

Other federally funded programs, such as the Low-Income Home Energy Assistance Program (LIHEAP), local programs like the Omaha Public Power District (OPPD) Customer Assistance Program, or charities help low-income households pay their energy bills or repair their heating or cooling systems in emergencies. While these payment assistant programs are important, they do not address underlying causes of energy burden in the way that efficiency programs do.[6]

Nebraska residents receiving LIHEAP struggle with much higher energy burdens than the average household. On average, these residents spend about 20.5% of their income on energy bills before assistance, the third highest in the nation, and 14% after receiving aid, the fifth highest in the nation. Unfortunately, only 20.4% of those eligible for LIHEAP receive it (Cleveland & Wang, 2022). Figure 12.3 contrasts the extent of low-income energy efficiency assistance and the amount of households in need by displaying the number of households reported assisted by the state WAP from 2018 to 2024 (dark

[5] Climate projections in Nebraska show increases primarily in cooling needs, but more periods of volatile weather and energy costs, such as extreme cold associated with polar vortex behavior (see Chapters 2 and 3) could interact with changing heating sources and costs as well (e.g., heat pumps inefficient in extreme cold or methane gas price volatility).

[6] Nebraska state agencies have struggled to implement a directive to use LIHEAP funds for home efficiency improvements (Legislative Performance Audit Committee, 2023).

green, bottom bar) with DOE estimates of energy-burdened households in each WAP service area (Figure 12.4) who earned below 200% of the federal poverty line, the eligibility threshold for WAP assistance in 2022 (red, top bar).[7] The ratio of energy-burdened households in 2022 to households assisted by WAP over six years runs from a low of 22 burdened households per home assisted in the Northwest Community Action Partnership region to a high of 149 in Douglas County.

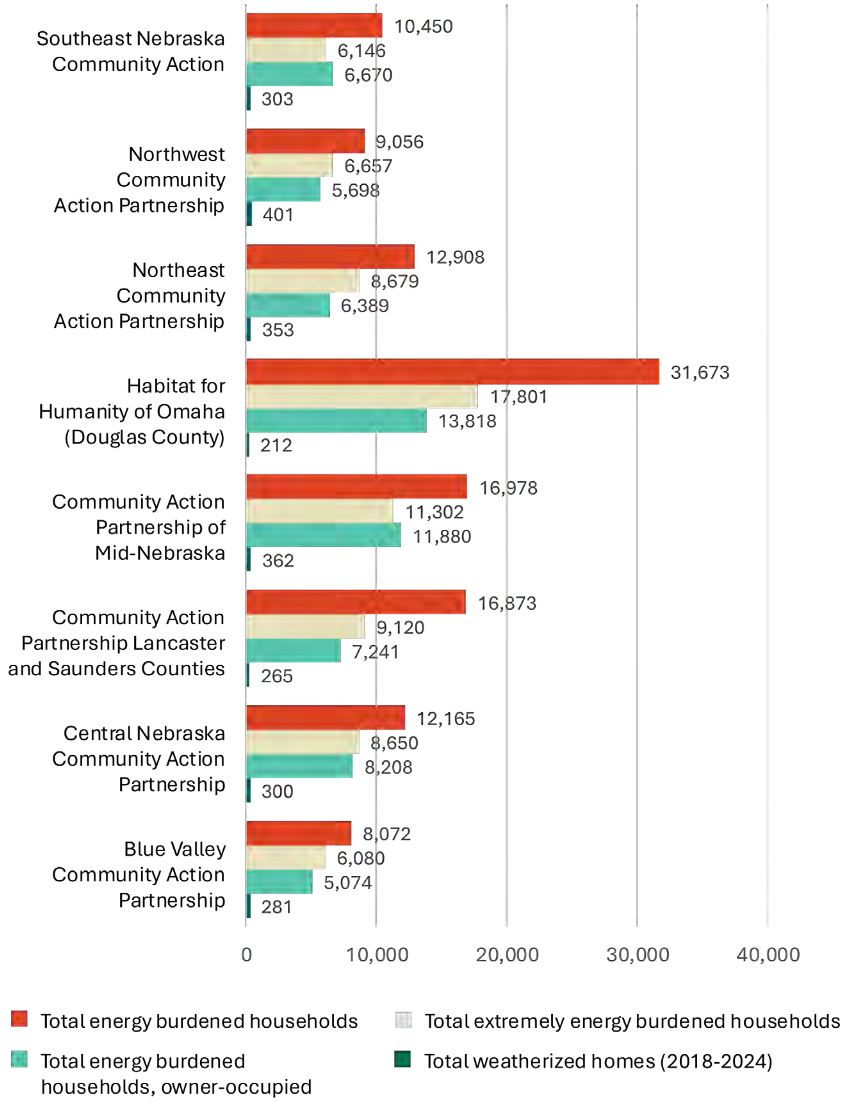


Figure 12.3. The number of weatherized homes (dark green bars) from 2018–2024 compared with the number of income-eligible, energy-burdened households in 2022 (red, tan, and light green bars). Data are presented by weatherization assistance service area (Source: DOE LEAD Tool, n.d.)

Climate-driven increases in energy bills and housing costs can compound the affordable housing crisis. When considering investments in energy efficiency for existing and new housing, evaluating these costs against the lifetime energy expenses for residents and the overall life-cycle costs to the public is essential. Despite having favorable public utility structures and recent updates to efficiency building codes, Nebraska lacks statewide energy efficiency mandates (MEEA, n.d.). Additionally, some municipalities have weakened the new state code through amendments. Utility efforts have been limited, spending only $3.20 per residential customer on electrical efficiency and nothing on gas efficiency in 2021 (MEEA, n.d.). In 2022, OPPD estimated that existing federal, state, and local programs addressed only 25% of residents' electrical energy burden needs (i.e., excluding gas) in their 13-county district. They aim to increase this percentage to 31% by 2026. Increased fixed utilities fees in Nebraska have disproportionately raised energy bills for low-income customers (Sanderford, 2019), making it more difficult for them to reduce their energy burden through conservation and efficiency efforts (OPPD, 2021a; OPPD Board of Directors, 2021b).

Figure 12.5. shows the regional proportion of WAP spending (dark green), households assisted (light green), and households in need (tan, orange, and red bars). Douglas County has the highest number of households in need, especially among non-White households (dark red bars). However, it receives a somewhat lower share of funding and assists significantly fewer households. Figures 12.3 and 12.5 suggest two main points. First, state weatherization assistance programs are vastly smaller than the need

[7] Not all energy-burdened households would meet other non-income-based criteria for WAP eligibility or necessarily have energy burdens caused by lack of home weatherization. However, such a comparison is a valuable starting place.

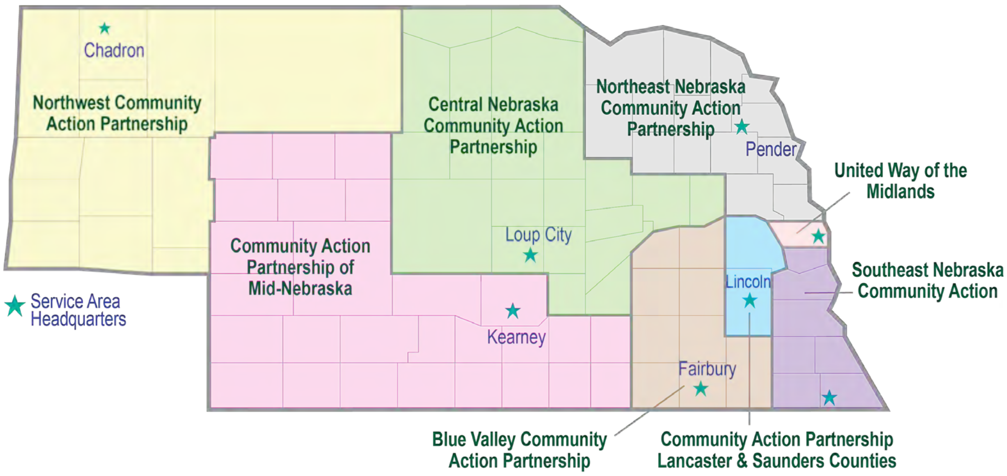


Figure 12.4. Weatherization service areas in Nebraska. (Source: NDEE, 2024e)

across the state, and second, assistance may be disproportionately distributed relative to household need and potential benefits from weatherization, including along racial lines.

Further research is needed to assess how the WAP program aligns with energy and climate justice principles, the role of current state policies, and factors related to service providers' capacity. For example, cost limitations may negatively impact urban areas where wages and expenses exceed state averages. Additionally, stricter building codes, which are important for climate resilience, may raise costs for home upgrades. Language barriers could also hinder participation in diverse communities, especially where program materials and staff may not speak the necessary languages. Analysis of the demographics of WAP and related program recipients in comparison with the populations vulnerable to energy burdens is essential to evaluate distributive justice outcomes.[8]

[8] Current state policies prioritize funding allocation between regions by, in order of importance, counties' share of Nebraska's elderly, impoverished, low income, and total population. Funding priorities are, first, households with elderly members, followed by disabled individuals, children under six, and finally households with higher-than-average energy bills or a higher-than-average energy burden. It is likely better metrics for household vulnerability and potential benefit from weatherization service could be developed (ACEEE, 2023).

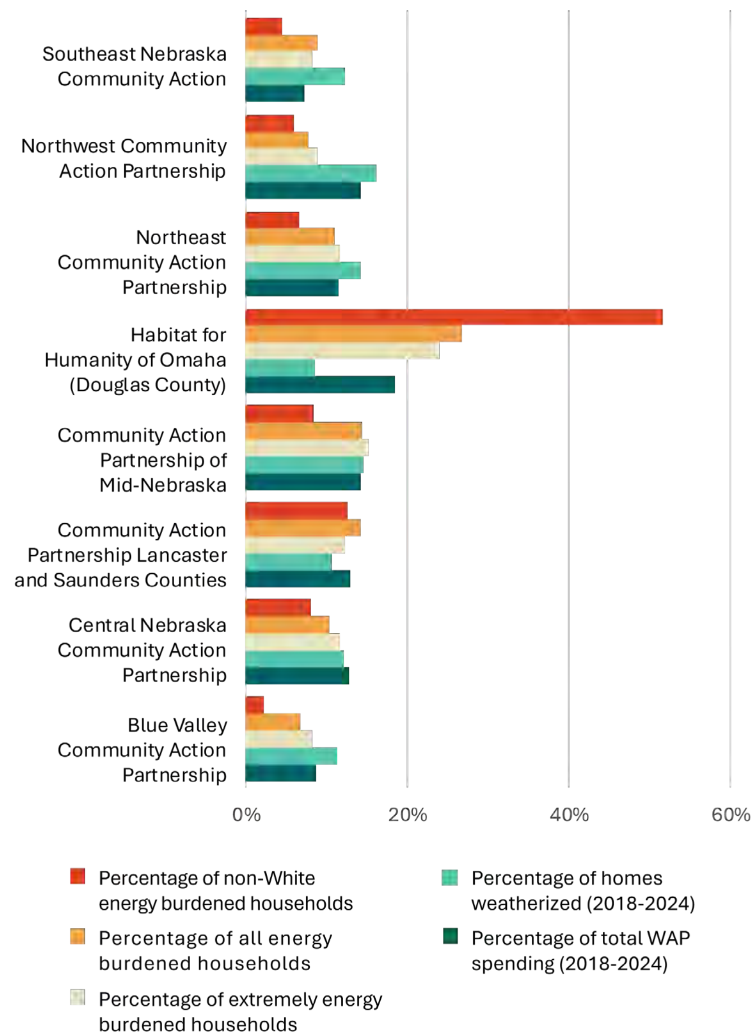


Figure 12.5. The regional percentage of total WAP spending (dark green bars) from 2019–2024. The percentage of income-eligible homes weatherized (light green bars), categories of need (orange and tan bars), and percentage of non-White energy burdened households (red bars). Data are presented by weatherization assistance service area (Source: DOE LEAD Tool, n.d.)

Renters face increased climate-related vulnerabilities that differ from homeowners. A key issue is the "split incentive" problem, where landlords lack financial incentives to invest in energy-efficient upgrades, even though these upgrades could lower utility bills and improve tenants' health (Melvin, 2018). Although renters are eligible for state WAP and OPPD efficiency programs designed for low-income households, these households are more difficult to reach due to the split incentive problem and the technical challenges of upgrading multifamily housing. Data show (Figure 12.3) that Nebraska has a higher total number of energy-burdened households when accounting for renters, as opposed to just burdened homeowners.

Additionally, landlords might use climate-related investments as an opportunity or pretext to increase rent or displace tenants. Renters often lack the ability to pay upfront costs needed to invest in efficiency improvements themselves or face retaliation from landlords for asking for improvements or enforcement of regulations.

New policies can help ensure that renters benefit from government funding and regulations aimed at reducing emissions through efficiency improvements (Gourevitch, 2024). Some federal funding sources have required states to adopt such policies to qualify for assistance (energycommunities.gov, 2024). Furthermore, existing rules that require landlords to provide heating but not cooling or that limit utility shutoffs in cold weather but not during extreme heat may not properly address the climate-driven health risks renters face. In Nebraska, state-level protections exist against gas shutoffs during the winter for private utilities. However, for public utilities, shutoff protection policies related to public health risks, such as extreme temperatures, are set by individual utilities.

Expansion of green space and tree cover can help reduce vulnerable populations' exposure to extreme temperatures, among other benefits. This approach is part of the proposed strategy in the Draft Climate Action and Resiliency Plan for the city of Omaha (City of Omaha, 2024, pp.57–60). However, research also indicates that intentional policy design is needed to prevent increases in green amenities from displacing low-income residents. Entities such as the Nebraska Department of Environment and Energy (NDEE) can create implementation plans for federal funds to address these threats and achieve decarbonization without displacement or green gentrification (Gourevitch, 2024; Rice et al., 2020).

As the projected electrification of homes increases, fixed costs are likely to increase for those still using methane gas. This situation poses a risk that vulnerable households will disproportionately bear the rising cost of gas infrastructure (Davis & Hausman, 2022). Proposed policy responses include halting the expansion of new methane infrastructure and geographically prioritizing electrification (Gold-Parker et al., 2024) with attention to low-income households. However, Nebraska gas utilities are not pursuing these policies, and state laws now prevent local governments from implementing methane infrastructure restrictions that other regions have adopted. This leaves the responsibility of coordinating efforts to avoid higher overall costs and disproportionate impacts on vulnerable populations primarily with the state or utility boards, despite the lack of current climate policies to facilitate these actions.

While public utility commissions in other states are addressing these issues, in Nebraska, the responsibility largely falls to elected public utility boards. Coordination between gas and electric utilities is crucial for success. Currently, only electric utilities actively pursue beneficial electrification (LES, 2024b), while some gas utilities work against these efforts by offering ratepayer-funded rebates to switch from electric to gas appliances without regard for efficiency or climate impacts (MUD, 2024).[9]

Implementing energy efficiency policies in new and existing buildings can improve climate resilience, reduce energy consumption, and address social inequalities related to housing and energy costs. Policymakers should be cautious of

[9] *For example, Metropolitan Utilities District's rebate offers contractors $100 to replace a heat pump with an air conditioner, removing it as a heat source competing with methane. The contractor is incentivized to recommend replacement without regard to efficiency. The homeowner is eligible for a $100 rebate when a low-efficiency furnace is replaced with a higher-efficiency one in the process.*

adaptation strategies that undermine emissions reductions and increase risks for others.

For example, while air conditioning is a seemingly simple adaptation strategy for coping with extreme heat, it should not be viewed as a substitute for reducing emissions. Air conditioning increases energy demand and can strain power grids, making it harder to transition to lower-carbon energy sources and reduce greenhouse gas emissions. Air conditioners contribute to urban heat island effects by expelling warm air outdoors, further increasing the demand for cooling. Its potential to leak refrigerants, which have a high global warming potential, leads to more warming. Finally, air conditioning is not equally accessible to all, with low-income and vulnerable populations around the world often lacking access due to cost. Air conditioning is also not a solution for those who work outdoors, where people are at a higher risk of heat-related illness and death.

Prisoners

Research shows that racial minorities and low-income populations are not only facing greater climate-related threats at work, school, and home, but they are also more likely to be incarcerated. Within prisons, these individuals may face additional climate-related threats such as pollution, vulnerability to disasters like flooding, water contamination, and extreme heat (Gribble & Pellow, 2022). Nebraska prisons have a history of water quality violations, overcrowding, and lack of adequate healthcare, leading to legal actions and federal investigations (Nebraska Advisory Committee to the U.S. Commission on Civil Rights, 2020). Climate change may compound these health risks for prisoners. More research is needed to evaluate these risks.

Extreme weather and flooding

Planning and policy

In disasters like the 2019 floods (Chapters 2, 10, and 11), the impact on residents facing displacement due to evacuation orders and damage to homes and infrastructure varied according to social factors and government policy. Apart from how social class and disability affect the ability to evacuate, residents' ability to navigate requirements for aid, access savings and credit while waiting for aid and reimbursement, and social support impacted their ability to meet basic needs immediately after a disaster.

In the 2019 floods, rural and Tribal communities faced more severe impacts due to their distance from key services (see Chapters 10 and 11). Strains on marginalized communities within rural areas can be worsened by poorly aligned policies.

Government policy can reduce or increase social inequalities. For example, when cost-benefit analyses prioritize more population-dense and high-value housing in allocating hazard mitigation funding before and rebuilding assistance after disasters can increase inequalities. NCA5 points out the need to develop new methods for calculating costs and benefits. These new approaches should consider the unique lifestyles and community values at stake while also addressing the historical devaluation of property in marginalized communities. As noted, “Even when all citizens are treated the same under the law, differential outcomes may result if the law ignores structural inequalities” (Marino et al., 2023, p.7; Graetz & Esposito, 2023).

Climate justice is crucial when it comes to investing in flood prevention and managed retreat, which means relocating people from new flood zones caused by climate change, as the city of Beatrice has done. On a national scale, some natural disaster risk-reduction strategies can unintentionally increase disaster risks, and disaster relief can lead local governments to make poor land-use decisions (Marino et al., 2023). In Nebraska, the eastern third of the state faces the highest flood risk (Figure 2.12), making it important to include both recognitional (perspectives of the most vulnerable are included) and procedural (inclusiveness in the decision-making process) justice in local government planning. This includes focusing on risk management strategies like zoning and infrastructure investments in this part of the state. Hispanic and Latinx communities in Nebraska are especially vulnerable in many communities (Chapter 10).

Planning for climate justice requires collecting data relevant to disparate impacts and exposure to better predict how policies will affect social inequalities. Rural communities are more at risk because they often depend on a single economic sector, have aging infrastructure, and lack financial resources and expertise for climate planning. Surveys show that those employed in agriculture have seen their income decrease due to extreme weather (see Chapter 14). In addition, higher levels of skepticism regarding climate change in these areas may mean more resources are needed for effective communication and planning to ensure equal protection for those populations from increasing climate impacts (Chapter 14).

Insurance

Extreme weather events are driving up home insurance costs in Nebraska (Flavelle & Rojanasakul, 2024; Gentzler, 2023). Severe storms that bring hail and high winds are causing more damage but have been considered by the insurance industry as "secondary perils," along with wildfires and floods, in contrast to catastrophic events like hurricanes. However, parts of Nebraska face overlapping risks from these types of perils (Chapters 2 and 3), and insurers and reinsurers are expanding their modeling of such risks. As has been done for Minnesota, analysis of overlapping risks and their effects on social inequalities could help Nebraska (Birss et al., 2024). Rising home insurance costs can worsen the affordable housing crisis by driving up home and rental prices. Without state regulation vulnerable communities in Nebraska are likely to face higher costs as insurers seek profits.

The 2014 Nebraska state climate assessment expressed hopes that the insurance sector could promote adaptation to climate change (Bathke et al., 2014). However, higher prices may not lead people to leave dangerous areas. Instead, they could result in a higher rate of uninsured properties, unless the government intervenes. Assuming people will relocate to places with a low risk of climate disaster is incorrect (Seebauer & Winkler, 2020). Also, there is little evidence that insurance premium prices are correlated with disaster risk as a signal to residents. Finally, communities that face the greatest number and severity of climate risks tend to have fewer resources to adapt or relocate (Birss et al., 2024).

Lack of adequate planning can increase the exposure of low-income residents to overvalued floodplain properties, where insurance may be unaffordable or unavailable. Around 10,000 Nebraska renters live in floodplains and typically do not have flood insurance (Liska & Holley, 2014). Evidence from states like Florida suggests private insurers' speculative activities are abetted by poorly designed public programs and regulations and, more broadly, failing to produce risk reduction. When major disasters strike, uninsured and underinsured residents look to state and federal disaster relief programs for help. The costs are shared in unplanned irrational ways reflecting and reinforcing social inequalities, rather than being managed through state-coordinated risk prevention measures (Birss et al., 2024).

Higher insurance costs can lead landlords to increase rents for tenants and limit the resources available for investing in risk reduction through retrofits. These higher insurance costs also strain the financing for new affordable housing. Manufactured homes built before the passage of federal regulations enacted in 1976 are particularly vulnerable to extreme weather. While new federal efforts are improving manufactured housing's energy efficiency and resilience, all manufactured homes are more vulnerable to damage from high winds. Proper anchoring can help reduce some of this risk.

Nebraska has 394 mobile home parks, and manufactured homes account for 1.4% of the housing stock (Edgell & Thayer, 2024). Mobile and manufactured homes often face higher flood risks but have limited insurance protection since they are classified as personal property located on land not owned by the resident.

Lower-quality housing may be harder to insure or repair, which can increase impacts for low-income households. However, it is unclear if building more disaster-resistant homes will result in lower insurance costs without state intervention (Chen, 2024; Flitter, 2024). In some cases, the most effective climate adaptation measures, such as stormwater management, can only be undertaken through collective action. Aggressive climate change mitigation is the most effective way to reduce long-term risk.

Because states are primarily responsible for insurance regulation, and state and local authorities are most closely linked to policymaking relevant to reducing climate risk, some researchers propose establishing a state housing resiliency agency. This agency would prioritize and implement local risk reduction activities using state-level funding resources and public disaster insurance to provide fairer and more equitable protection (Birss et al., 2024). Expanding Nebraska's existing Fair Access to Insurance Requirements provision plans may help create a more robust and comprehensive public disaster insurance program that pools risk effectively and prevents private insurers from taking only the most profitable policies.

Human migration

The impacts of climate change will affect human migration patterns at national and regional levels. Some parts of Nebraska could benefit from gaining migrants, while other areas may face social stresses resulting from population decline due to environmental and economic pressures. Nationally, population migrations caused by rising sea level are likely to have direct and indirect effects on Nebraska counties (Robinson et al., 2020). Migration-related population growth is higher in low-risk than high-risk areas of the Midwest, likely for economic reasons, with Nebraska among the highest-risk states in the region (Indaco & Ortega, 2024). This trend raises questions for future research as to whether more vulnerable populations, such as the elderly, remain at higher rates in high-risk areas (e.g., the more rural western areas of the state).

A recent study of rural outmigration in Nebraska found dissatisfaction with environmental conditions (e.g., pollution, green spaces) to be one of the most significant predictors of residents' desire to leave rural areas, similar in effect to satisfaction with job opportunities and larger than satisfaction with medical facilities (Decker et al., 2024). Negative local environmental impacts, like air and water pollution, often accompany the release of greenhouse gases. On the other hand, improvements like increased green spaces provide opportunities for climate change mitigation and adaptation. Reducing pollution that harms rural residents and enhancing environmental amenities can strengthen climate resilience and support adaptive migration on broader scales.

Just transitions

The concept of a "just transition" toward environmental sustainability began in the labor movement during the 1980s. At the time, it focused on protecting workers impacted by changing energy systems. Today, scientists and policymakers use this concept to include equitably sharing the new benefits of the broader environmental and social transition that climate action entails while also protecting or enhancing the well-being of those economically relying on fossil sectors.

> **The transition to low-carbon development is wired in issues of justice and equity: how do you align carbon reductions to meet the needs of humanity? Distributive justice calls for a fairer sharing of the benefits and burdens of the transition process, while procedural justice is essentially about ensuring that the demands of vulnerable groups are not ignored in the pull to the transition. The impacts of climate change and the mitigation burdens are experienced differently by different social actors, with Indigenous communities facing multiple threats and being subjected to unequal power dynamics. (IPCC, 2023b, p.1746)**

National climate justice policy, such as the Justice40 initiative, reflected just transition goals. This initiative prioritized benefits for communities that have historically experienced harm, have been underinvested in for benefits, or were threatened by transitions related to climate change. Justice40 priorities also included decreasing the energy burden and pollution for disadvantaged communities and increased access to clean energy and related jobs, energy democracy, and ownership (White House, n.d.; see footnote 4 on p. 137). Note: The Justice40 initiative was rescinded by the Trump administration's Executive Order 14148, "Initial Rescissions of Harmful Executive Orders and Actions," issued on January 20, 2021.

To achieve these goals, state and local policymakers were required to address equity issues when applying for many types of federal funding. This includes opportunities such as the Nebraska Priority Climate Action Plans, developed by NDEE (2024b), and the Omaha Metro for Environmental Protection Agency (EPA) funding or various grants pursued by Nebraska's public power districts. Seven states have created policies and tasked agencies with just transition planning (NCEL, 2023).

Just transition planning requires attention to three components of environmental justice (Figure 12.6). First, distributional justice requires identifying which groups have been disproportionately harmed by the existing systems that produce climate pollution. This includes considering how those current and past harms can be redressed or minimized and how benefits from new systems can be distributed equally to these groups. Distributional justice also requires recognizing which groups could face disproportionate negative impacts—economically, culturally, or environmentally—due to the shift toward cleaner production systems and helps determine how to avoid these negative impacts. Second, recognitional justice requires plans for how communities' values and priorities will effectively shape the goals and strategies of the climate transition. Third, procedural justice ensures stakeholders with different capacities can participate equitably in the planning process.

Figure 12.6. The three core components of a just transition framework. Just transition planning requires consideration of: (1) Who receives what and in what amount? (distributional justice), (2) Why does it matter? (recognitional justice), and (3) Who makes decisions and through what processes? (procedural justice).

To achieve just transitions, it is important to consider the environmental goods and amenities created by mitigation and adaptation, such as green space, and the environmental risks or harms, such as pollution. Several frameworks and toolkits have been developed for distributive justice concerns in just transition planning. Energy and just transition policies focus on three key areas: health impacts (positive or negative), access (who can benefit), and livelihoods (growing or declining economic opportunities) (Kime et al., 2023).

Tools, such as green infrastructure equity indices or the Climate and Economic Justice Screening Tool (2022), have been created to assist in assessing and pursuing distributional justice (Marino et al., 2023). These types of tools can assist in identifying important groups to consider in the recognitional and procedural justice process. They can be improved through community feedback from stakeholders. Increased public funding for analysis and planning is widely recognized as necessary to achieve just transitions.[10]

Just transitions in Nebraska

Much of the just transition research has focused on the energy sector. Although Nebraska has comparatively low employment in fossil fuel production, measures of employment carbon footprints indicate the need for just transition planning in many parts of the state with currently carbon-intensive production—for example, in manufacturing and agriculture, as well as fossil-fueled electricity production (Graham & Knittel, 2024). Researchers find that "all low-carbon energy technologies create more jobs per unit of energy than their coal and natural gas counterparts." However, the new jobs are not necessarily in the same geography or with similar quality or wages as fossil jobs (Kime et al., 2023, p. 13). Thus, policy interventions are necessary to achieve climate justice by equitably sharing the benefits of the transition to low-carbon economies.

Fossil and clean energy and efficiency

In 2022, the energy sector in Nebraska provided 56,351 total jobs, which was 5.7% of the state's total employment. Of these jobs, 58% were in the clean

[10] "The implications for a Just Transition in climate finance are clear: expanding equitable and greater access to climate finance for vulnerable countries, communities and sectors, not just for the most profitable private investment opportunities, and a larger role for public finance in fulfilling existing finance commitments" (IPCC 2023c, p. 1559).

energy sector (including electrical transmission and corn ethanol).[11] The largest area of employment in the clean energy sector was energy efficiency, with 13,345 workers. Other areas included renewable energy (3,189), clean transportation (2,178), electric grid and storage (560), and clean fuels (211). Some jobs in polluting energy-related jobs can transition to clean energy jobs, such as moving away from making and repairing gasoline vehicles to electric vehicles. This transition requires training and investment for workers and communities.

The electrical power sector employed 7,894 workers in Nebraska in 2022, with 567 jobs in coal-fired generation and 497 in gas generation, 1,902 in solar, 750 in nuclear, and 676 in wind. Fuels-related employment was dominated by corn ethanol with 2,299 jobs, followed by natural gas with 762, petroleum with 732, and 24 in coal. Motor vehicles accounted for 18,100 jobs in 2022, with 7,387 in repair and maintenance and 6,011 in manufacturing (USEER, 2023). Nebraska's expected growth in clean energy jobs in areas such as energy efficiency and electric utility generation and transmission was below the national average. Future research could identify policy differences with other states contributing to this slower growth.[12]

According to scientific consensus, phasing out coal use in the power sector is widely considered the top priority for climate action (Clarke et al., 2022). Coal is the most carbon-intensive fossil fuel, and rapidly reducing its use is critical to mitigating climate change. Nebraska does not produce coal but imports it for its eight coal-fired electrical power plants, several of which are the largest generation sources in the state (Chapter 6). Nebraska ranks 13th nationally in carbon intensity of electrical generation and 8th in share of electricity from coal. It is one of only 15 states where coal remains the dominant electrical source (EIA, 2024).

Greenhouse gas emissions threaten life and health as well as threatening global climate justice goals. The EPA's Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool estimates that eliminating fossil fuel electrical generation air pollution would prevent 15-23 deaths annually in Nebraska, and prevent $230 to 360 million dollars in negative health effects (including the statistical value of lives lost). These health costs are not accounted for in the low comparative price of electricity in Nebraska but are important to consider when making energy transition policies.

Nebraska's sizeable agricultural industry contributes to the state having the nation's third-largest share of industrial electricity consumers (Chapter 6). We rank sixth in per capita electrical use, driven by both industrial demand and residential consumption. Nebraskans use more residential electricity per capita than all but 16 other states (EIA, 2024). The state benefits from the fifth-lowest electrical prices, partly due to our unique nonprofit public power system that provides cheaper and more reliable power than investor-owned utilities. However, these low prices also come at the expense of environmental and health costs related to energy production (Epstein et al., 2011; Sovacool et al., 2021).

Reducing energy demand through efficiency has already become the largest green job sector in the state. Given Nebraska's relatively high per-capita consumption, targeted policies and investments to expand efficiency and conservation could create good jobs and lessen energy burdens in disadvantaged communities. Most energy efficiency jobs are currently found in the construction industry, which highlights the connection to building codes and affordable housing policy, as well as efforts to retrofit existing buildings.

The growing electrical demand in Nebraska, driven by beneficial electrification that displaces dirtier fossil fuel energy sources, and new industrial growth, creates opportunities for re-employing current fossil fuel workers and new jobs for communities historically burdened by pollution from energy production. However, policies are needed to ensure that clean energy jobs are of good quality.

Fewer than 14% of hiring energy sector employers in Nebraska reported no difficulty in hiring, while almost 37% reported hiring to be very difficult (USEER, 2023). Policies that support and expand Nebraska's unionized

[11] Transmission and distribution jobs include workers across current energy sources, and corn ethanol, woody biomass, large hydropower, and nuclear but are excluded for reasons of environmental pollution by some analysts such as Clean Jobs America (E2, 2024).

[12] For example, Nebraska does not supplement federal energy efficiency funds with other state funding sources as Colorado does.

public power jobs could facilitate a just energy transition. Nationally, 48% of non-union firms reported that hiring was very difficult compared to only 29% of unionized firms. Unions also increased the likelihood of recruitment of women by 50% and people of color by 200% (USEER, 2023).[13] Union support for apprenticeship and other training programs is a potential explanatory factor that can contribute to these outcomes.

Publicly owned utilities are more likely to implement policies focused on equity and the environment (Homsy, 2020). Nebraska's public power model is well-positioned to pursue just transition goals by creating good jobs within public utilities, setting fair terms in project labor agreements, and ensuring proper wages and working conditions in contracts with private sector partners.

Public power may also provide advantages in expanding renewable energy, grid infrastructure, and energy storage. Procedural justice requires meaningful community involvement in the siting of energy infrastructure. Distributional justice requires that communities be fairly compensated for negative impacts and share in energy projects' benefits. Examples of this can be seen in the workforce and community benefits agreements (DOE, n.d.) that are shaped through inclusive and deliberative processes.[14] Recognitional justice requires that communities are able to determine their priorities for such agreements. Procedural justice ensures that they have access to expertise to represent those priorities. For example, the Omaha and Iowa Tribes likely have specific sovereign interests related to utility policies and planning.

Studies show that opposition to wind and solar energy development projects tends to diminish when there is some form of community ownership and with perceived fairness and equity (particularly in local decision-making processes) (Caggiano et al., 2024; Stokes et al., 2023).

Nebraska's public power system offers forms of community ownership and democratic decision-making. However, due to historical tax-based incentives, the predominant approach to renewable energy has been private development, ownership, and operation through power-purchase agreements. Nebraska utilities could take a more proactive role in the development process by helping create community benefit and project labor agreements with private developers or using new federal financing programs to develop and own projects themselves. The latter may pose procedural justice benefits, but to meet distributive justice goals policymakers should ensure the structure of Payments in Lieu of Taxes allow tax-exempt public power districts to provide appropriate community benefits.

In contrast to evidence on the location of polluting energy sources, analysis of wind energy placement shows little evidence of distributional injustice via higher placement in disadvantaged counties (Mueller & Brooks, 2020). However, the authors note that within individual counties, communities with higher income, employment, population density, and levels of education tend to have lower rates of wind energy development. This suggests that further research is needed to determine the distribution of burdens and benefits (Mueller & Brooks, 2020). Nationally, analysis also shows

> **small groups of wealthier and Whiter wind energy opponents in North America are slowing down the transition to clean energy by opposing wind projects in their backyards. This opposition represents a form of energy privilege that has dramatic air pollution impacts on low-income communities and communities of color. . . as it slows down the transition away from fossil fuel electricity sources overwhelmingly placed in their backyards. (Stokes et al., 2023, p. 6)**

Aesthetics tied to project size, visibility, and noise are the most common drivers of wind project opposition nationally. Further research is needed to understand opposition sources to renewable energy development, particularly in Nebraska, and their

[13] Nebraska has the second-fewest minorities employed in the clean energy sector of 12 midwestern states (77.6% White, regional average 74.2%) (Clean Jobs Midwest, 2023).

[14] The webpage for the DOE resources cited has been deleted but an archive of the CBA toolkit is available here https://web.archive.org/web/20231004122057/https://www.energy.gov/diversity/community-benefit-agreement-cba-toolkit.

procedural and distributional justice implications.[15]

Policymakers could pursue procedural justice through decision-making processes that ensure distributional and recognitional justice in infrastructure planning while preventing vocal minorities (often funded by fossil fuel interests) from perpetuating broader distributional injustices (Crawford et al., 2022).

Biofuels and regenerative agriculture

Corn ethanol is a major economic industry in Nebraska, but its implications for climate justice remain unclear. Improving access to renewable energy and adopting regenerative agriculture could improve livelihoods while reducing climate emissions and providing co-benefits. These co-benefits include reducing negative health impacts, such as cancer risks related to groundwater quality stemming from current agricultural practices (Kulcsar et al., 2016; Ouattara et al., 2022; Xu, 2022).

The state's recently awarded EPA Priority Climate Action Plan grant (NDEE, 2024b) emphasizes measuring and reducing emissions linked to commodity agriculture, biofuel production, and expanding new technologies and regenerative agriculture. Farmers may encounter policy-related barriers to adopting these practices. For example, crop insurance policies can fail to benefit climate-adaptive farms and even penalize farmers for adopting climate-friendly strategies (Evaretnam, 2024).

Currently, ethanol is mainly used as an additive in gasoline. A shift toward electric vehicles and alternative transportation options (Chapter 6) will likely reduce that source of demand. Changes in the industry's climate impact will shape other potential future ethanol uses, such as aviation fuel.

Many federal agencies and researchers have found that ethanol's life-cycle emissions are lower than gasoline's. However, the impact of land-use changes due to the ethanol policies is still being debated, with some studies suggesting that ethanol is more carbon-intensive than gasoline (Alarcon Falconi et al., 2022; Hill, 2022; Scully et al., 2021a, 2021b; Spawn-Lee et al., 2021).[16] Studies generally agree that U.S. ethanol policies increase global food prices, domestic agricultural pollution, and habitat loss (Chen et al., 2021; Smith et al., 2023).

Continued research into the life-cycle emissions of various forms of ethanol production, whether corn-based or other cellulosic sources, will likely influence policy debates to ensure climate justice. In addition to efforts to reduce emissions from current agricultural practices, diversifying the economy could help rural areas adapt to changes in biofuel markets and support just transitions.

Renewable energy offers rural communities a way to diversify their economy while lowering life-cycle emissions from agricultural products. For example, an acre of photovoltaic electrical panels (Mathewson & Bosch, 2023) provides more than 60 (potentially up to hundreds of times) vehicle miles as an acre used for corn ethanol. Research is also exploring "agrivoltaics" to combine solar energy production with farming to boost land productivity.

While using corn as a fuel source seems to be a path toward renewable energy, research shows that it is relatively inefficient as an energy source (Richardson & Kumar, 2017; Hill, 2022). Research shows that increasing both food and energy production on existing agricultural lands is possible, with increased economic benefits for landowners (Turnley et al., 2024). For instance, one proposed solar project in York County was projected to generate over $5,000 more revenue per acre than growing corn and soybeans. This project could result in a net impact of $12,000 in labor income for every 100 acres converted and create one additional job for every 500 acres converted (Thompson, 2022).

Effective just transition planning requires consideration of how these benefits may be distributed among various actors within and outside the community and how they interact with existing social inequalities. For example, good community standards, such

[15] Previous research on community perceptions of economic benefits with environmental costs around the biofuel industry as a green energy source in the Midwest have found that environmental harms were typically discounted and economic benefits overestimated (Kulcsar et al., 2016). Research on how perceptions related to electric renewable energy infrastructure in the region are similar or different would be valuable.

[16] Another key question is how much domestic ethanol production reduces fossil fuel consumption, versus displacing production to the export market.

as community benefit agreements and plans with renewable energy companies (DOE, n.d.), could help ensure that local workers reliant on rented land affected by these projects benefit from energy projects.

The NDEE has proposed strategies for more sustainable agricultural production to lower carbon emissions from crops and biofuels (NDEE, 2024b). For these strategies to be effective, it is essential to increase clean energy production to lower the emissions from farming inputs and biofuel plants. More research and practical guidance are also needed on precision and regenerative agricultural practices. Studies that include just social impacts like economic, food security, and sovereignty and their broader ecosystem benefits are crucial to ensure the adoption of these practices and help maximize their positive impacts on society.

Similarly, plans to reduce the climate impacts of animal agriculture, such as using biodigesters linked to confined feeding operations or animal processing operations, should also consider ways to reduce the negative health and social impacts unequally distributed along lines of socioeconomic status and race/ethnicity (Donham et al., 2007; Son & Bell, 2024; Son et al., 2024).[17] Though these health and social issues are well-documented, they are less understood. Climate justice in Nebraska's agricultural communities is linked with energy justice in decision-making and outcomes for new infrastructure.

Distributional, procedural, and recognitional justice in energy infrastructure

Climate responses and energy transitions in Nebraska are leading to increased proposals for large-scale infrastructure projects across the state. These projects include renewable energy installations, electric transmission lines, and carbon dioxide pipelines that aim to reduce or eliminate emissions from industrial processes. Procedural justice is important when siting all forms of energy infrastructure.

Recognitional justice requires that communities have a say in the types of development they want, not just under what terms they will accept a predetermined outcome. Distributional justice involves evaluating who benefits and who is harmed by proposed infrastructure changes. Increasing state and local capacity for energy and climate infrastructure planning that meets all three aspects of environmental justice is an urgent priority for achieving climate justice. Multiple organizations have created policy guides and recommendations on just and sustainable energy infrastructure to assist communities and policy makers. Examples include guidance from the Center for Rural Affairs (2024) and legislation from other states (NCEL, n.d.).

More research on past Nebraska energy infrastructure decision making could benefit climate justice efforts in the future. The political conflict surrounding the Keystone XL pipeline captured international attention as Indigenous nations and local communities in Nebraska raised concerns about recognitional and procedural justice related to treaty rights. Local White residents also raised concerns about potential threats to their local environments and property rights (Derman, 2020; Ordner, 2018). Analyzing the state and local processes and outcomes in the pipeline decision could provide valuable insights into how to enable impacted communities, including Native tribes, to meaningfully deliberate and consider their rights to a healthy environment, property rights and the equitable distributions of benefits and costs related to Nebraska's energy and climate-related infrastructure.

[17] *Further research on how cattle animal agriculture may be distinct from impacts associated with swine and poultry could be helpful for Nebraska policy-making. For example, an analysis of Tyson's environmental impacts found Nebraska to be most impacted, with Winnebago and Omaha Tribes downstream from the largest source of pollution (Goswami & Woods, 2024).*

Conclusion

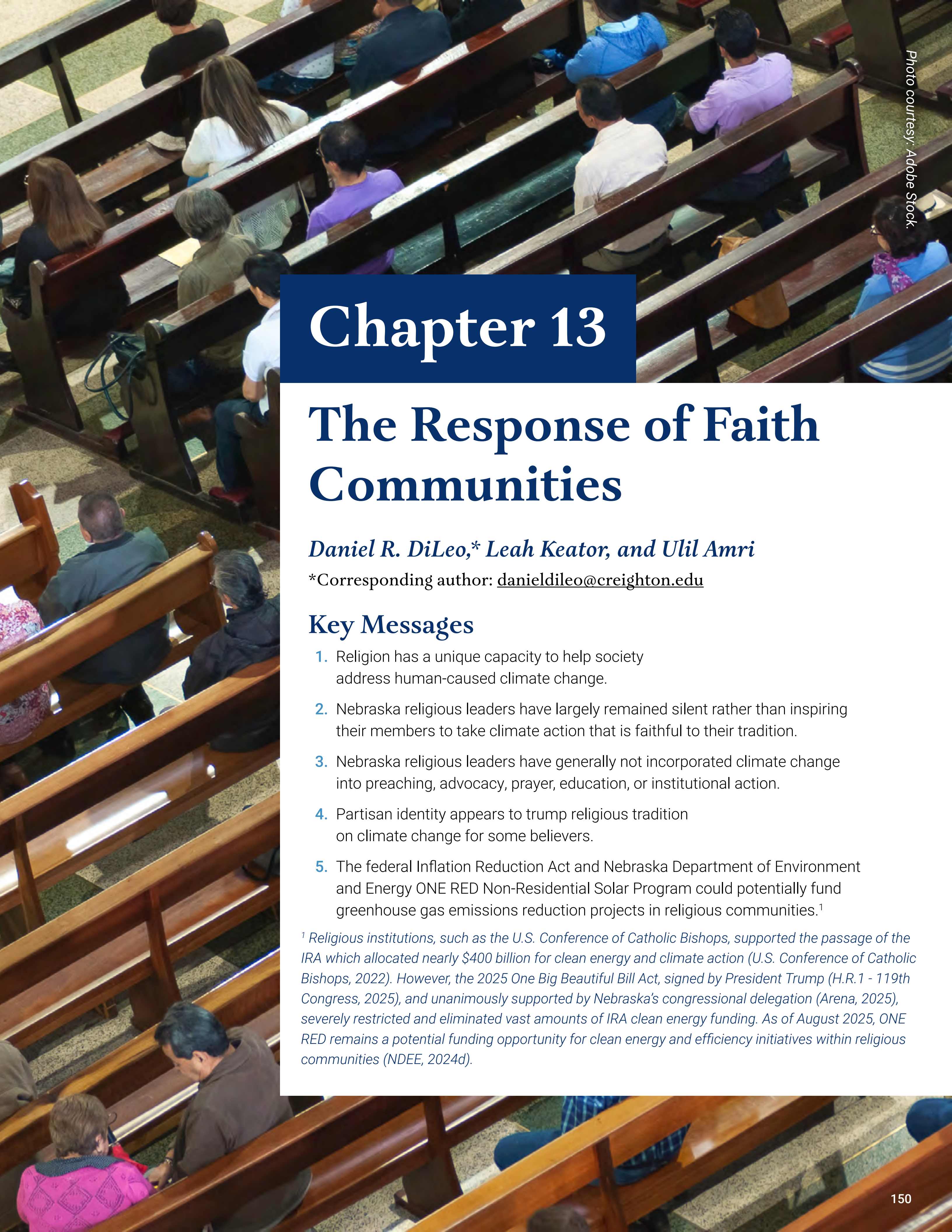
Existing inequalities in Nebraska are at risk of worsening due to climate change. However, climate action can create opportunities to reduce these inequalities. For example, creating good jobs, retrofitting, and building new efficient and climate-resilient housing can help improve income and housing inequalities. Vulnerable populations who can benefit from climate action and new opportunities for just transitions exist throughout the state, both in rural and urban communities. The success of climate adaptation and mitigation efforts in these communities is interconnected. Steps taken help build communities' capacity to participate in the decisions that affect them across many issues and foster social connections and trust. Nebraska has benefited from national resources dedicated to pursuing climate justice goals and can continue to do so. Nebraska can accelerate its progress by learning from other states and communities that have already developed useful tools and policies.

Gaps and needs

» Research to fill in gaps in our understanding of climate threats to vulnerable populations, including those in the workforce, criminal justice system, and minority and rural communities in Nebraska.

» Research quantifying climate justice outcomes of different regenerative agricultural practices and climate-related energy infrastructure, including how communities perceive and understand the distribution of benefits and harms, could inform improvements in recognitional and procedural justice.

» Research that systematically analyzes how established climate and environmental justice concepts and principles are incorporated into Nebraska's existing climate and energy policy. For example, evaluate distributional justice outcomes in state programs (such as WAP) and collect and analyze data on public participation in policy planning and implementation in other climate-related programs. Determining whether vulnerable communities identified by social science research are effectively included in the decision-making process is essential.



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Chapter 13

The Response of Faith Communities

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Key Messages

1. Religion has a unique capacity to help society address human-caused climate change.
2. Nebraska religious leaders have largely remained silent rather than inspiring their members to take climate action that is faithful to their tradition.
3. Nebraska religious leaders have generally not incorporated climate change into preaching, advocacy, prayer, education, or institutional action.
4. Partisan identity appears to trump religious tradition on climate change for some believers.
5. The federal Inflation Reduction Act and Nebraska Department of Environment and Energy ONE RED Non-Residential Solar Program could potentially fund greenhouse gas emissions reduction projects in religious communities.[1]

[1] Religious institutions, such as the U.S. Conference of Catholic Bishops, supported the passage of the IRA which allocated nearly $400 billion for clean energy and climate action (U.S. Conference of Catholic Bishops, 2022). However, the 2025 One Big Beautiful Bill Act, signed by President Trump (H.R.1 - 119th Congress, 2025), and unanimously supported by Nebraska's congressional delegation (Arena, 2025), severely restricted and eliminated vast amounts of IRA clean energy funding. As of August 2025, ONE RED remains a potential funding opportunity for clean energy and efficiency initiatives within religious communities (NDEE, 2024d).

Introduction

Religion has a unique capacity to help society address human-caused climate change. Throughout this chapter, "climate change" means human-caused, that is, anthropogenic. Many religious traditions recognize climate change as a moral issue and call for science-based action (Wells, 2023). This research shows that over the past 10 years, religious leaders in Nebraska and across the country have generally remained silent rather than inspiring their members to take climate action that is faithful to their tradition.

Since 79% of Nebraskans identify with a religious tradition (Table 13.1), mainly Christianity, Nebraska's faith leaders can play a crucial role in framing and motivating climate action (Salter & Wilkinson, 2024).

In this chapter, we highlight religious teachings that recognize a moral responsibility to address climate change and note opportunities for religious leaders to educate, implement their own teachings, and inspire their communities to act. Finally, we present findings from survey results designed to explore whether and why Nebraska religious leaders have or have not pursued these opportunities

Table 13.1. Religious Composition of Adults in Nebraska. (Source: Pew Research Center, 2014a)

CHRISTIAN	**75%**
Evangelical Protestant	25%
Mainline Protestant	24%
Catholic	23%
Historically Black Protestant	2%
Mormon	1%
Orthodox Christian	<1%
Jehovah's Witness	<1%
Other Christian	<1%
NON-CHRISTIAN FAITHS	**4%**
Buddhist	1%
Hindu	1%
Other Faiths	1%
Jewish	<1%
Muslim	<1%
Other World Religions	<1%
UNAFFILIATED (RELIGIOUS "NONES")	**20%**
Nothing in particular	15%
Agnostic	4%
Atheist	1%
DON'T KNOW	**1%**

Background

Nearly all religious traditions teach about the need to care for God's creation. Many have formal, authoritative teachings that recognize a moral responsibility to address human-caused climate change. These often recognize that the effects of climate change harm neighbors whom believers are called to love—especially and disproportionately the poor, vulnerable, and marginalized for whom most religious traditions have special concern (IPCC, 2023a, p. 1172).

The unequal impact of climate change on the poor is especially unjust since wealthy people and communities are most responsible for the problem. The U.S. has the largest economy by GDP and just 4% of global population but is responsible for 20% of historic carbon pollution (1850–2022)—more than China, India, and the 45 least developed countries combined (United Nations Environment Program, 2024, p. xiii). U.S. (18 tCO_2e) were 64% higher than in China (11

tCO_2e) and six times higher than in India (2.9 tCO_2e) (United Nations Environment Program, 2024, p. xiii).

Some of the many teachings about climate change from world religions include:

- **Mainline Protestant:**
    - "Global warming threatens the very fabric of God's creation and will hit those who are least able to adapt—both human and nonhuman—the hardest. Because the Christian community is called to justice, to be good 'neighbors' with our brothers and sisters across the globe, and to steward God's creation, addressing global warming is a moral imperative and a Christian call" (National Council of Churches of Christ in the USA, 2006).
    - "An accounting of climate change that has credibility and integrity must name the neglect and carelessness of private industry and the failure of government leadership that have contributed to these changes. However, it also must include repentance for our own participation as individual consumers and investors in economies that make intensive and insistent demands for energy" (Evangelical Lutheran Church in America, 2015).
- **Evangelical Protestant:** "As followers of Jesus, we need to respond to the suffering of those most directly affected by the degradation of God's creation . . . climate change interacts with other challenges people face" (National Association of Evangelicals, 2022, p. 19).
- **Historically Black Protestant:** "We stand together with many other leaders of faith who are calling for urgent action on climate change on behalf of the world's poor and God's creation" (African Methodist Episcopal Church, 2016).
- **Catholic:** "[The] 'greenhouse effect' has now reached crisis proportions as a consequence of industrial growth, massive urban concentrations and vastly increased energy needs . . . I wish to repeat that *the ecological crisis is a moral issue*" (St. John Paul II, 1990, nos. 6, 15, emphasis in original).
- **Orthodox Christian:** "For human beings to degrade the integrity of the earth by causing changes in its climate . . . these are sins" (Ecumenical Patriarch Bartholomew I, 2012, p. 99).
- **Jewish:** "The Torah portion of Noach details a terrible environmental disaster—God's punishment for humankind's despicable behavior. Today, as our reckless actions drive climate change, we are once again experiencing widespread destruction of the Earth. . . . When climate change irreparably damages our world—God's world, the world of future generations—it will be too late" (Coalition on the Environment and Jewish Life, 2024).
- **Muslim:** "The same fossil fuels that helped us achieve most of the prosperity we see today are the main cause of climate change. Excessive pollution from fossil fuels threatens to destroy the gifts bestowed on us by God" (Islamic Leaders, 2015).
- **Buddhist:** "There is still time to slow the pace of climate change and limit its impacts, but to do so . . . [leaders] will need to put us on a path to phase out fossil fuels. We must ensure the protection of the most vulnerable, through visionary and comprehensive mitigation and adaptation measures" (Buddhist Leaders, 2015).

In 2021, nearly 40 global religious leaders signed a joint Appeal to the United Nations (Vatican, 2021). The statement called the world to "achieve net zero carbon emissions as soon as possible" and committed the represented religious communities to a variety of corresponding activities. For example, the leaders committed to facilitating "ecological conversion" through religious education and "participating actively and appropriately in the public and political discourse on environmental issues."

Although they recognized the importance of civic action, the leaders stressed "the importance of taking far-reaching environmental action within our own institutions and communities, informed by science and based on religious wisdom. While calling on governments and international organizations to be ambitious, they also recognized the major role we play."

To ensure faithfulness to their traditions and preserve their credibility to advocate in society, the leaders committed their religious communities to take concrete internal actions like "supporting actions to reduce carbon emissions . . . working to make bold plans to achieve *full sustainability in our buildings* . . . striving to align our financial investments with environmentally and socially responsible standards . . . [and] evaluating all the goods we purchase and the services we hire with the same ethical lens" (emphasis in original).

Opportunities

Backed by such consistent and authoritative teachings, religious leaders in Nebraska can inspire members of their communities to address climate change through preaching, communal prayer, bulletin inserts, and other aspects of worship services (Antal, 2023). And leaders can incorporate climate change teachings into faith formation programs, school curricula, and other religious community education pathways.

Leaders can also assess the current emissions from their buildings, schools, and other facilities and then commit to fundraising for and implementing comprehensive science-based reductions. Religious communities have accessed federal funding through the 2022 Inflation Reduction Act. For example, Horizons Community United Methodist Church in Lincoln, installed solar panels with a $21,600 IRA federal tax credit and a grant from Nebraska Interfaith Power and Light (Israel, 2024). The project will save the church $3,000 per year on its utility bill, pay for itself in 12 years, and yield subsequent annual savings it can earmark to support additional ministries.

These direct mitigation activities may inspire other religious and secular institutions to reduce emissions. Leaders can advocate for public policies to address climate change as individuals and on behalf of their religious community (Pope Benedict XVI, 2009). Their moral authority can persuade elected officials to better care for creation and inspire community members to similarly engage in faithful citizenship on behalf of our common home.

In this chapter, we conducted two studies to explore whether and why Nebraska religious leaders have or have taken such steps in the past decade. The first surveyed local religious community leaders in Nebraska. The second surveyed Nebraskans who are not likely local religious community leaders. Together, these studies revealed the same reality: Nebraska's religious leaders have largely remained silent and inactive rather than inspiring and helping society to address human-caused climate change.

Surveys of Nebraska's faith communities

Survey 1: Religious Leaders

The first study fielded an online survey sent to leaders of local religious communities, such as congregations, parishes, synagogues, mosques, or other groupings of persons within a larger faith tradition (Table 13.2). This survey included demographic questions, questions about belief in and potential actions to address human-caused climate change, and questions about why respondents had or had not taken the identified potential actions. A complete list of the questions can be found in Appendix B.

The survey was open from February 14 to March 13, 2024, and distributed twice through a dataset of 1,782 email addresses. The dataset was constructed using public directories and includes general email addresses for local religious communities and direct email addresses for local religious community leaders. The first email was sent to the complete list on February 14, 2024, and yielded 203 "undeliverable" bounce-back messages. A reminder survey email was sent on March 1, 2024.

Table 13.2: Survey 1 email dataset.

RELIGIOUS TRADITION	NUMBER OF DATASET EMAIL ADDRESSES
Mainline Protestant: American Baptist Churches, Episcopal, Evangelical Lutheran Church in America, Friends General Conference, Presbyterian Church USA, United Church of Christ, and United Methodist Church	713
Evangelical Protestant: Adventist, Assemblies of God, Church of God, Church of the Brethren, Church of the Nazarene, Evangelical Free Church of America, Free Methodist Church, Lutheran Church–Missouri Synod, Mennonite, Pentecostal, Presbyterian Church in America, Reformed, and Southern Baptist	406
Unknown—from list of churches (ExpertGPS, 2024) with duplicate email addresses removed).	375
Catholic	323
Orthodox Christian	17
Buddhist	12
Muslim	12
Jewish	8
Hindu	6
Mormon	0 (none publicly available)

To complete the survey, respondents had to indicate that they had not previously completed the survey, were at least 19 years of age, and were either the most senior appointed/ordained leader in their local religious community completed if the respondent answered all required questions. A total of 99 surveys were completed for a 6% response rate among the 1,579 deliverable email addresses (Table 13.3).

Table 13.3. Survey 1 responses.

RELIGIOUS TRADITION	NUMBER OF COMPLETED SURVEYS
Mainline Protestant)	51
Evangelical Protestant	22
Catholic	14
Other	10
Buddhist	1
Muslim	1
Total	**99**

A content analysis (Guest, 2023; Reid et al., 2017) did not yield findings that are statistically representative of Nebraska's religious leaders. However, this analysis reveals important patterns related to faith and climate change in Nebraska's faith communities and highlights differences among them.

Survey 2: 2024 Nebraska Annual Social Indicators Survey

To complement Survey 1 of religious leaders, Survey 2 (Table 13.4) was sent to individuals who do not serve as leaders of local religious communities. It is possible but unlikely that a limited number of respondents were such leaders. For that reason, this chapter refers to Survey 2 respondents as "laity."

This study used the 2024 Nebraska Annual Social Indicators Survey (NASIS 2024), a biannual survey that represents Nebraskan's views and experiences (Bureau of Sociological Research, 2019). The Bureau of Sociological Research (BOSR) at the University of Nebraska–Lincoln conducted this survey, which included core demographic questions and additional questions submitted by researchers, including seven specifically used in this chapter.

The NASIS 2024 survey was distributed through the mail to a representative sample of 10,000 Nebraska households between July 12, 2024, and October 25, 2024. In total, 2,232 surveys were completed, 902 of which were filled out online (via a link in the letter) and 1,330 via mail-in, resulting in a response rate of 23.2%.

This chapter analyzes the 1,004 respondents who identified as Protestant, Catholic, Jewish, Muslim, Mormon/Latter-day Saints, nothing in particular, or other. It focuses on those who reported attending religious services several times a week, once a week, nearly every week, or about once a month. Respondents who reported attending religious services several times a year, less than once a year, never, or did not indicate frequency of religious service attendance were excluded from this analysis. The chapter excludes the respondents who identified as Atheist or Agnostic, and those who did not answer the question about religious identity.

Instead of Mainline or Evangelical, the NASIS survey asked Protestant respondents to identify as either "Not Evangelical or born again" or "Evangelical or born again." This chapter will present "Not Evangelical or Born Again" as Mainline and "Evangelical or Born Again" as Evangelical to facilitate readers' comparison of tables from Survey 1 and Survey 2.

Table 13.4. Survey 2 responses from those who attend religious services several times a week, once a week, nearly every week, or about once a month.

RELIGIOUS TRADITION	NUMBER OF COMPLETED SURVEYS
Mainline Protestant	312
Evangelical Protestant	313
Catholic	299
Other	53
Nothing in particular	14
Mormon/Latter-day Saints	7
Jewish	4
Muslim	2
Total	**1,004**

Although the NASIS survey is representative of all Nebraskans, the findings are not statistically representative of religious believers since the survey did not oversample for religious identity. However, as with Survey 1, the findings expose notable patterns of how Nebraskans from different traditions experience climate change engagement in their local religious communities.

Quantitative findings[19]

Belief in climate change

Only about half of survey respondents believe in human-caused climate change (Figures 13.1 and 13.2). For Mainline Protestants and Catholics, local religious community leaders were more likely than laity to believe in human-caused climate change.

Survey 2 revealed sharp disparities along political party lines (Figure 13.3). In total and across all denominations, Republicans were significantly less likely than Democrats to believe in human-caused climate change.

These findings are unsurprising and mirror national trends. In the U.S., political identity and ideology are the strongest predictors of a person's stance on human-caused climate change (Hornsey et al., 2016; Kahan et al., 2012; Leiserowitz et al., 2018). Republicans and conservatives are more skeptical of human-caused climate change and less supportive of action to address its reality (Funk and Hefferon, 2019). This is often true even when one's religious tradition explicitly challenges partisan skepticism and hostility toward human-caused climate change.

For example, after Pope Francis published his 2015 ecological encyclical *Laudato Si',* which emphasized that human-caused climate change is an urgent moral issue based on 25 years of Catholic teaching (Pope Francis, 2015), research demonstrated that in the U.S., many "conservative Catholics devalued the Pope's credibility on climate change" rather than reconsider the climate change stance of their party (N. Li et al., 2016, p. 367). Given that nearly half of Nebraska voters are registered Republicans, it is not surprising that local religious leaders in Nebraska showed relatively weak responses to human-caused climate change (Independent Voter Project, 2023), as shown in Figure 13.3. This is especially true since 88% of Christians in Nebraska are Republican or lean Republican (Pew Research Center, 2014b).

Leaders speaking about climate change

In both studies, roughly half of respondents said that at least one of their local religious community leaders has never spoken publicly to their people in the past 10 years about the importance of climate action (Figures 13.4 and 13.5). In total and among both Mainline Protestants and Catholics, leaders reported lower percentages of "never" than laity. Additionally, Mainline Protestant leaders reported higher percentages of "often" and "sometimes" than Mainline Protestant laity. These patterns could be because leaders recalled giving at least one public address on climate change while the laity either did not hear their own leader do so or missed a time when they did due to less than weekly service attendance.

Leaders speaking about climate change policies

In both studies, at least half of respondents indicated that their local religious community leader has never spoken publicly in the past 10 years about the importance of public policies to address climate change (Figures 13.6 and 13.7). Both Mainline Protestant and Catholic leaders reported lower percentages of "never" than the laity. Additionally, Mainline Protestant leaders reported a higher percentage of "often" and "sometimes" than Mainline Protestants. These patterns could arise because religious leaders recall giving at least one public address on climate change policy. At the same time, members of the laity might not have heard it or could have missed it due to attending services less than weekly.

Relatedly, the Nebraska Catholic Conference did not prioritized climate change between 2017 and 2025 (Nebraska Catholic Conference, 2024a, 2024b,2024c,2024d, 2025).

[19] *Percentages may sum to 100% +/- 1 due to rounding. Full survey questions and results can be found in Appendix B.*

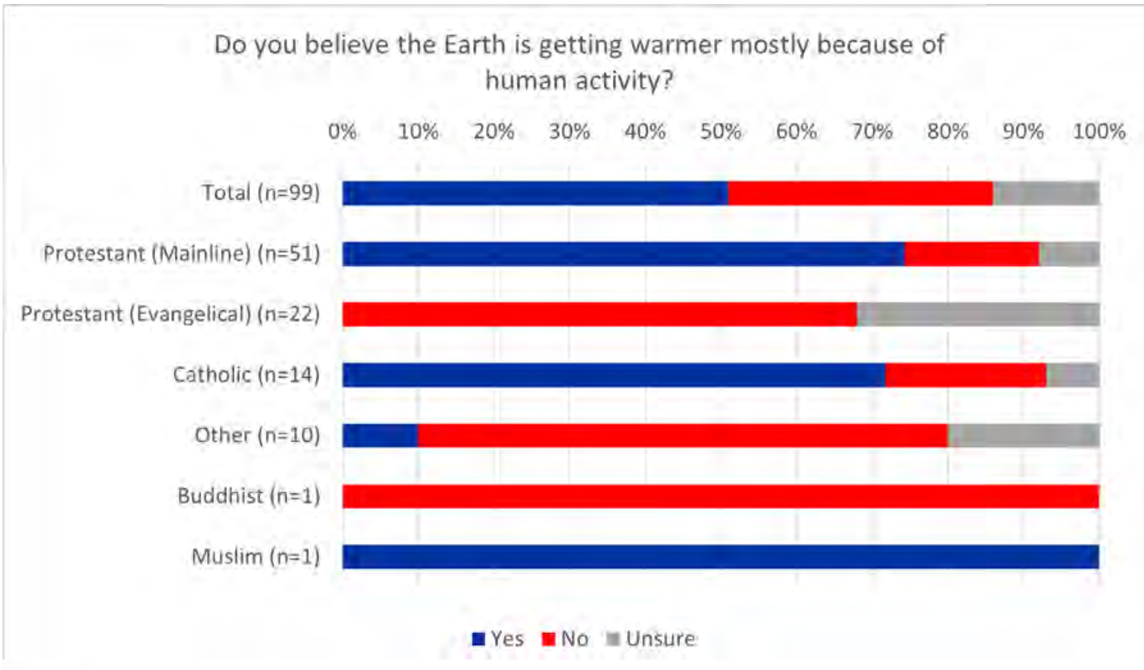


Figure 13.1. Responses from religious leaders, survey 1.

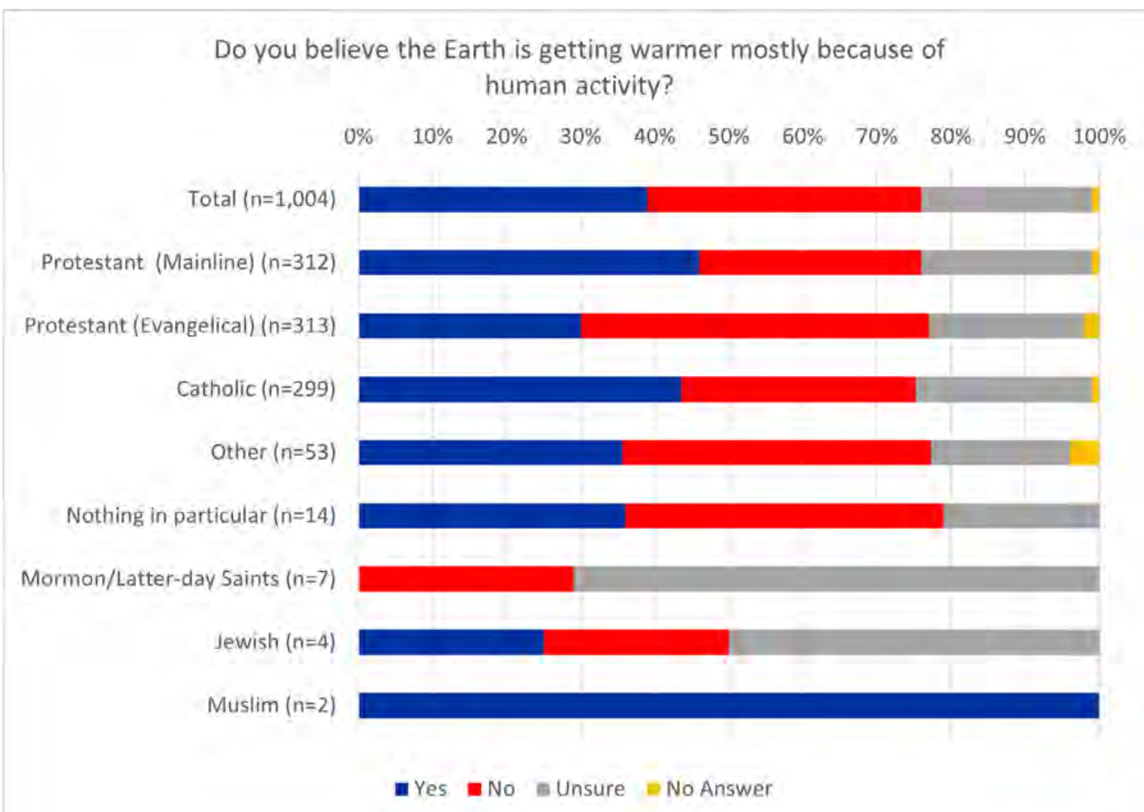


Figure 13.2. Laity, survey 2.

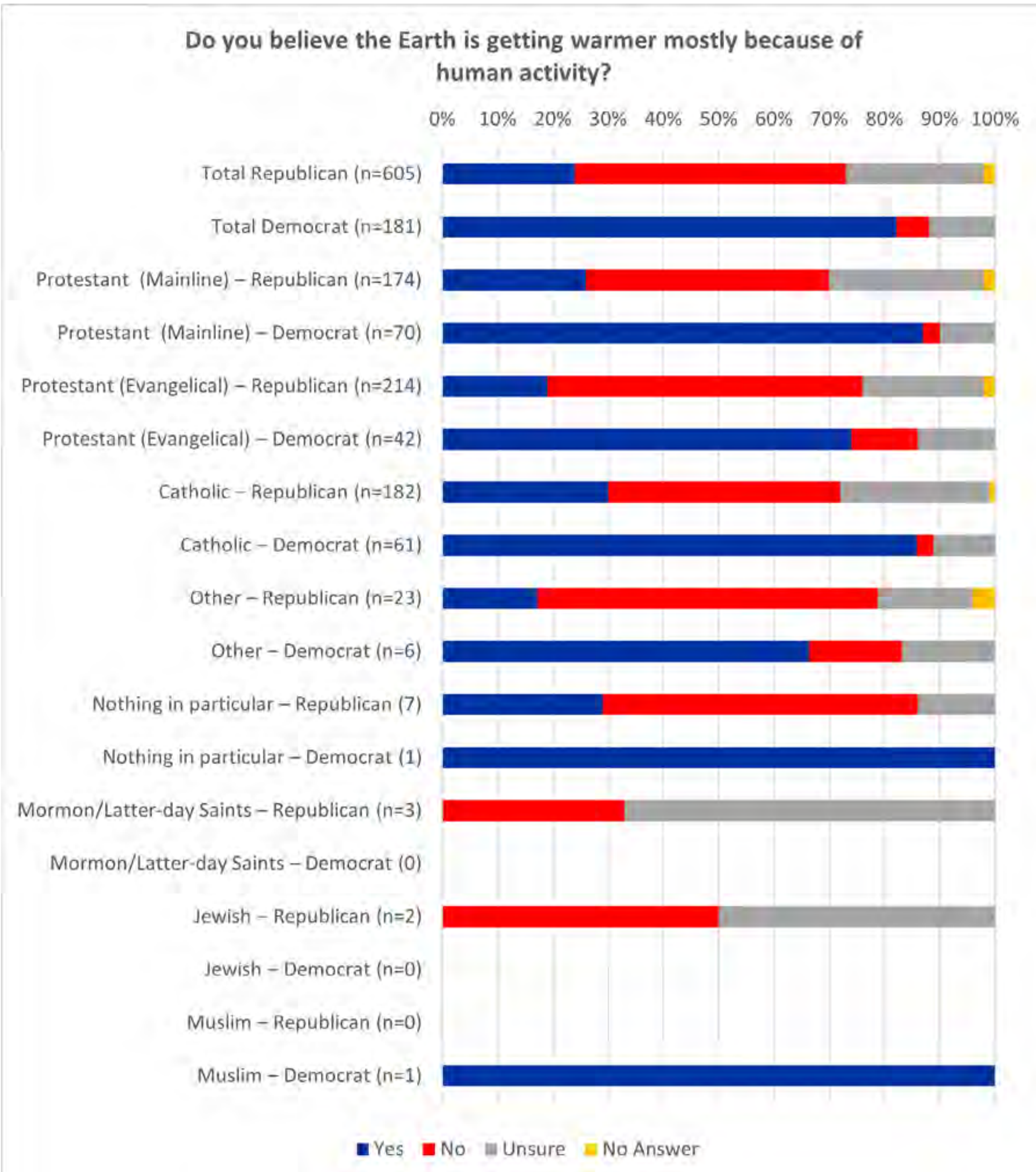


Figure 13.3 Laity, survey 2.

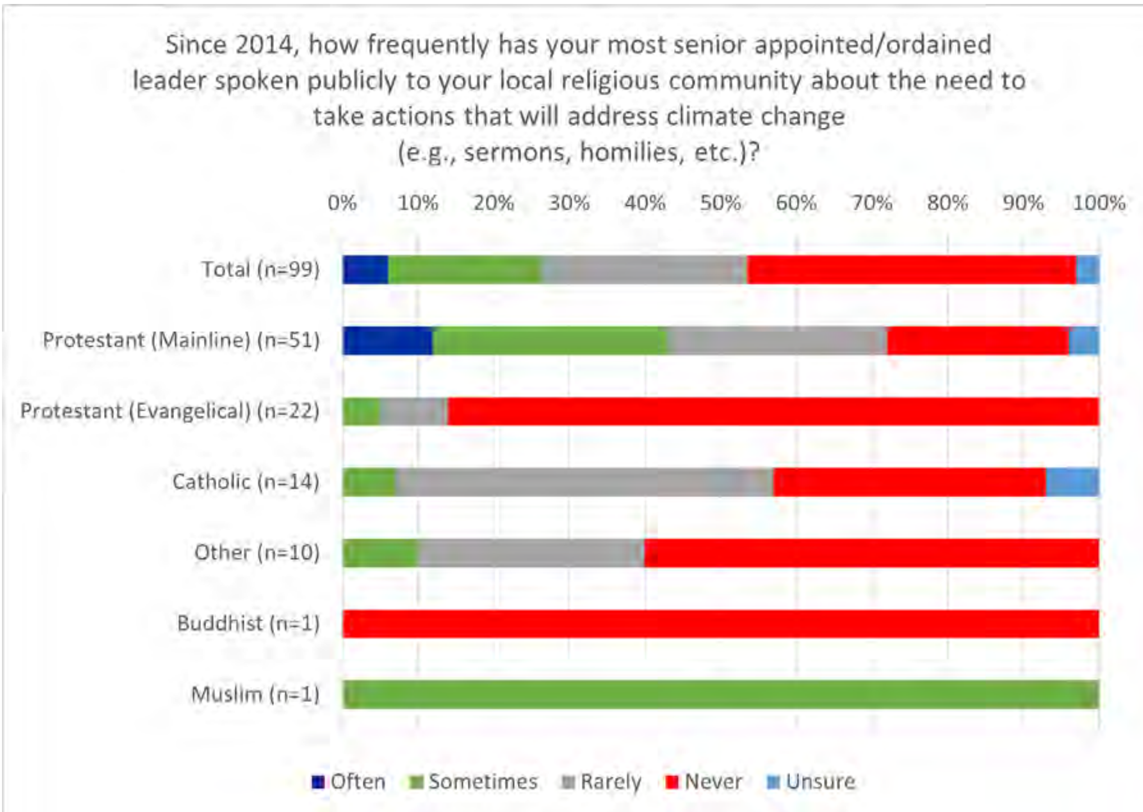


Figure 13.4: Religious Leaders, survey 1.

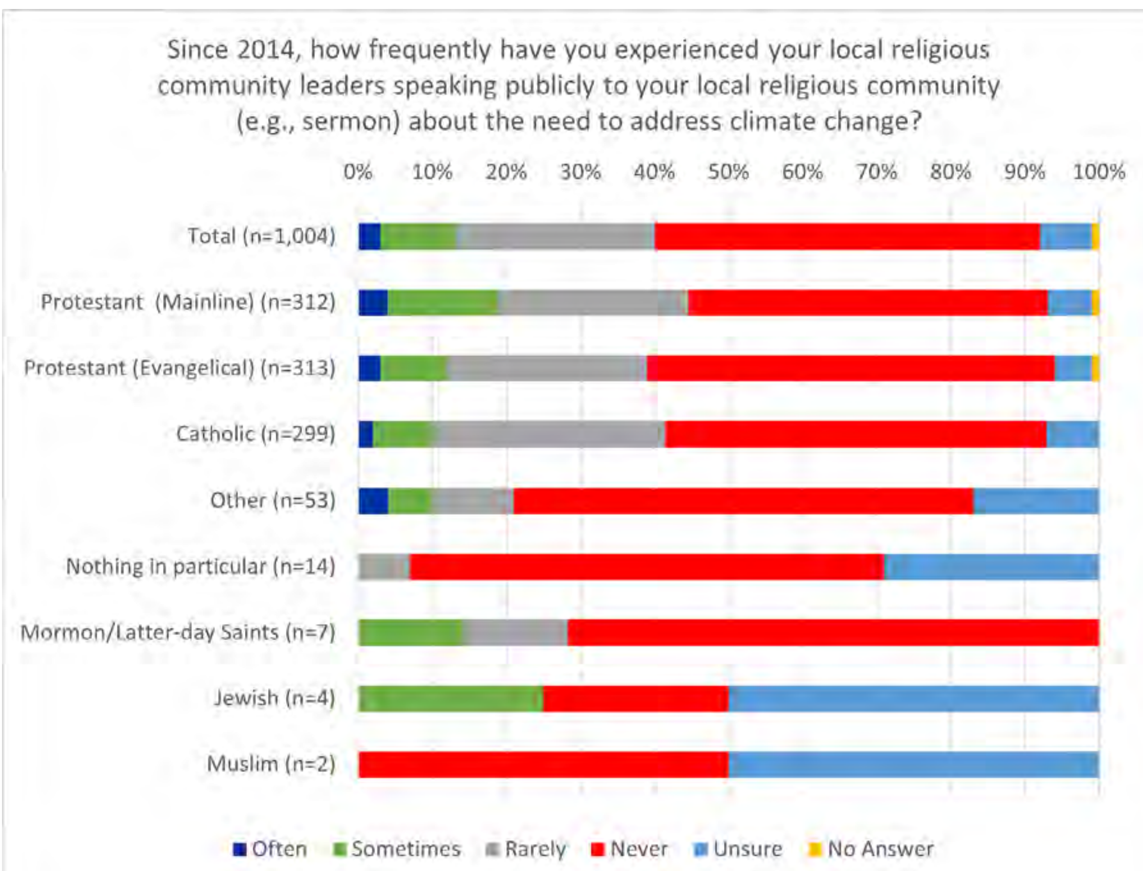


Figure 13.5: Laity, survey 2.

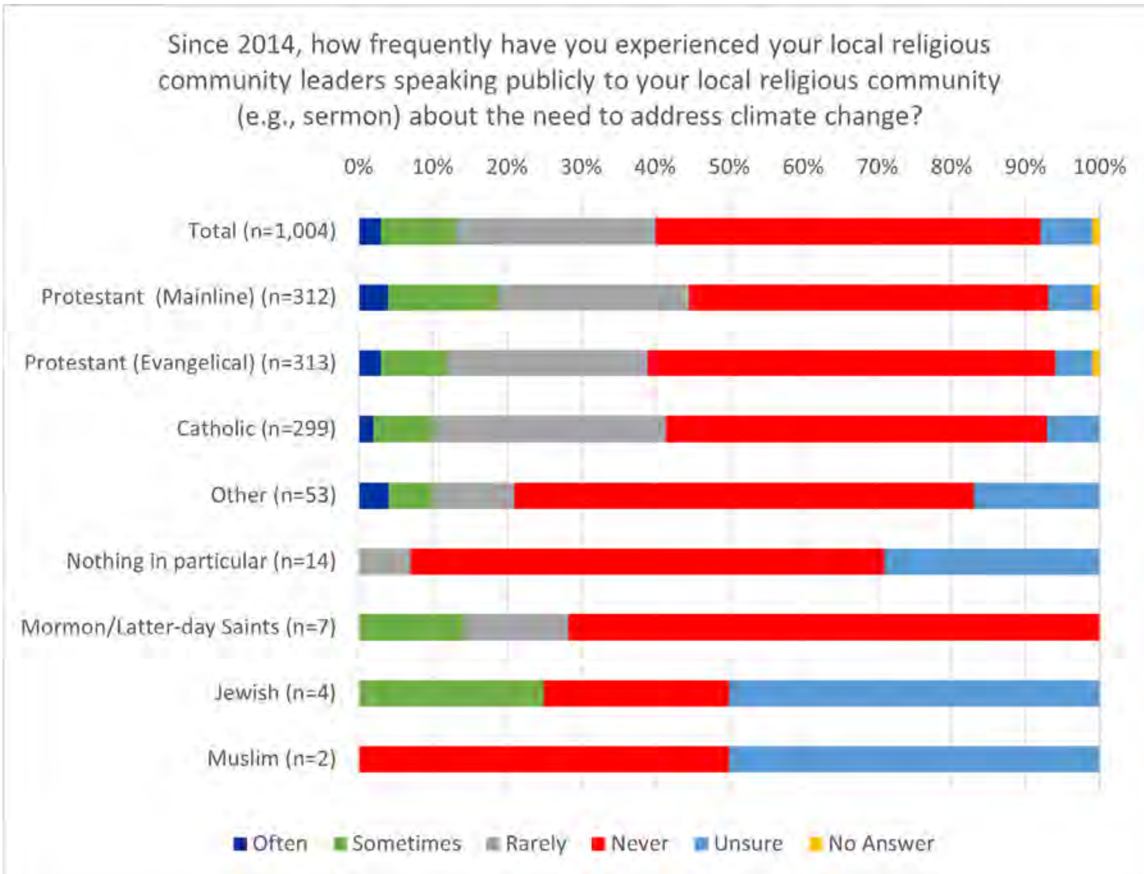


Figure 13.6. Religious leaders, survey 1.

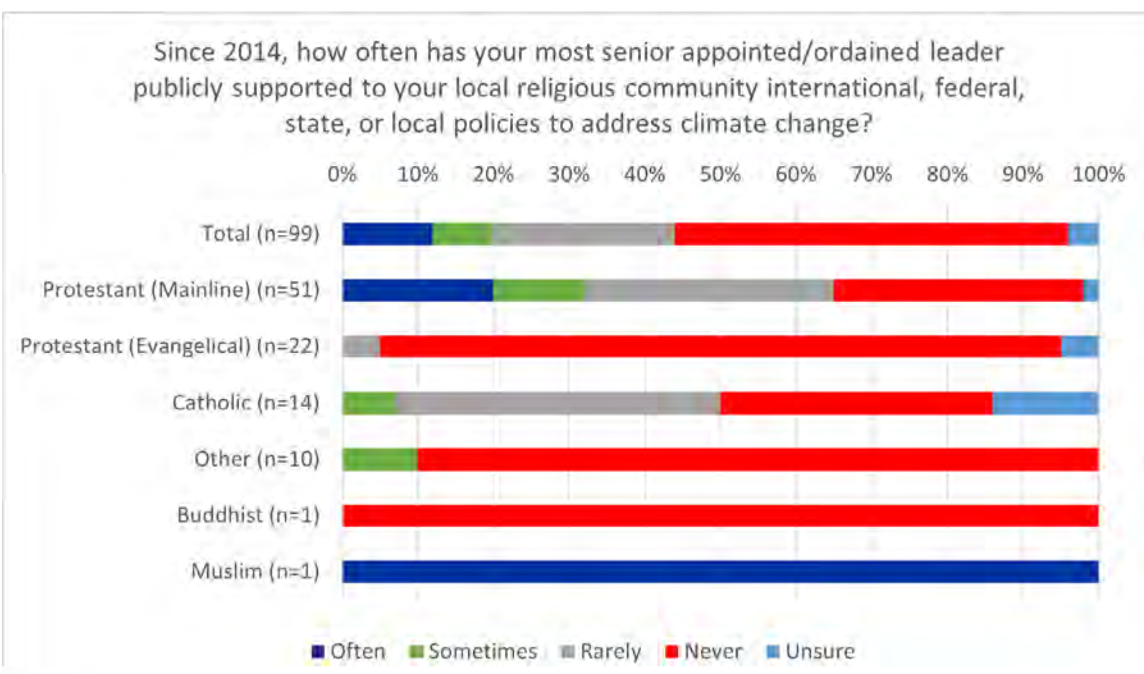


Figure 13.7. Laity, survey 2.

The Catholic Church is divided into geographic regions called dioceses, and each is led by a bishop. In the U.S., 45 states and the District of Columbia have a Catholic conference that advocates for public policies at the state level. These conferences represent all the dioceses in a state and act "at the direction of that state's bishops," providing unique, unified official advocacy on behalf of a religious denomination (National Association of State Catholic Conference Directors, 2024).

The mission of the Nebraska Catholic Conference is to "advocate for the public policy priorities of the Catholic Church" in Nebraska. It represents the state's three dioceses—Omaha, Lincoln, and Grand Island—and acts at the direction of Nebraska's three Catholic bishops (Nebraska Catholic Conference, 2024a).

For Nebraska's 109th Legislature (2025–2026), the Nebraska Catholic Conference identified five areas of advocacy and 16 priority issues (Nebraska Catholic Conference, 2025). As of February 2, 2025, these were publicly available on the NCC website. Neither climate change specifically nor anything related to the environment broadly are listed.

- **Life and Human Dignity:** Advancing the right to life of the unborn, supporting pregnant women and mothers, defending religious liberty, and promoting a true and person-centered bioethics.
- **Marriage, Family, and Human Sexuality:** Upholding the sanctity of marriage and family life, protecting the rights of parents and children, and affirming a healthy vision of human sexuality.
- **Education:** Supporting Catholics schools, furthering school choice, and developing just education policies for students and staff.
- **Social and Human Development:** Promoting economic justice, advancing restorative justice, welcoming immigrants and refugees, and combatting human trafficking.
- **Church as Institution:** Strengthening the Church's place and role in society to evangelize the Gospel of our Lord, Jesus Christ, and undertake the spiritual and corporal works of mercy.

For Nebraska's 108th Legislature (2023–2024), the Nebraska Catholic Conference identified four areas of advocacy and 23 priority issues (Nebraska Catholic Conference, 2024a). As of December 1, 2024, this information was publicly available on the NCC website. Neither climate change specifically nor any environmental issues were included in these priorities:

- **Life and Human Dignity:** Right to life of the unborn, pregnancy resources, bioethics, end of life issues, human trafficking, religious liberty.
- **Education:** School choice, matters impacting Catholic schools, NSAA regulations, federal education issues.
- **Marriage and Family:** Marriage, children's issues, human sexuality, adoption, foster care.
- **Social and Human Development:** Public assistance programs, housing, economic justice, just wage, human trafficking, immigration, restorative justice, predatory lending.

Before this, the areas and issues identified as legislative priorities by the Nebraska Catholic Conference remained consistent, covering the 107th (2021–2022), 106th (2019–2020), and 105th (2017–2018) Legislatures. This means that for nearly a decade, approximately 23% of Nebraska adults who identify as Catholic, which amounts to more than 300,000 people, have never heard climate change prioritized by their state conference.

These facts also suggest that the Nebraska Catholic Conference has not prioritized climate change in its direct advocacy efforts. This is confirmed by the positions taken on various bills and resolutions in the 105th to 108th Legislatures, as the Nebraska Catholic Conference does not list any action on any of the 14 introduced bills or resolutions related to climate change or renewable energy:

- 108th Legislature (2023–2024): LB255, LB399, and LB1370
- 107th Legislature (2021–2022): LB228, LB266, LB483, and LR102
- 106th Legislature (2019–2020): LB23, LB155, LB283, and LB704
- 105th Legislature (2017–2018): LB625, LB646, and LR46

This lack of action has occurred despite the Catholic Church's overt calls for environmental advocacy. As Pope Benedict XVI asserted, "*The Church has a* *responsibility towards creation*, and she considers it her duty to exercise that responsibility in public life, in order to protect earth, water and air as gifts of God the Creator meant for everyone, and above all to save mankind from the danger of self-destruction" (2010, emphasis in original). Lack of NCC climate advocacy also stands in contrast to the U.S. Conference of Catholic Bishops (USCCB), which represents the bishops nationally and has repeatedly advocated on climate change (2024). For example, the USCCB has declared that "decarbonization of the economy—through the replacement of fossil fuels with secure, reliable, affordable, and clean energy—is the preeminent environmental challenge faced by all nations" (U.S. Conference of Catholic Bishops, 2023).

Prayer about climate change

In both studies, nearly half of respondents said their local religious community has never prayed together about climate change in the past 10 years (Figures 13.8 and 13.9). Among respondents from both Protestant (Mainline/not Evangelical or born again) and Catholic backgrounds, those in Survey 1 (religious leaders) reported lower percentages of "never" than those in Survey 2 (the laity). Additionally, Mainline Protestant and Evangelical Protestant leaders reported higher percentages of "often" and "sometimes" compared to Mainline Protestant and Evangelical Protestant respondents.

As before, these patterns could be because the leaders recalled communally praying about climate change at least once while the laity either did not hear their community do so or missed a time when they did due to less than weekly service attendance.

Education about climate change

In both studies, roughly half of respondents said their local religious community has not incorporated climate change into religious education in the past 10 years (Figures 13.10 and 13.11). For all but Muslim respondents, the percentages of the laity who were unsure about their community's education efforts were higher among laity (Survey 2) than religious leaders (Survey 1). This is likely because leaders were generally more familiar than laity with the educational offerings of local religious communities.

Comprehensive science-based emissions reduction targets

In both studies, most respondents indicated that their local religious community has not committed to a comprehensive greenhouse gas reduction target of net zero carbon or zero greenhouse gas emissions (Figures 13.12 and 13.13). Overall, across all denominations, a larger percentage of laity reported being unsure about their community's commitments (Survey 2) compared to religious leaders (Survey 1). As with previous questions, this discrepancy is likely because leaders were generally more familiar with the master planning of local religious communities than the laity.

Actions to reduce emissions

In addition to not committing to a comprehensive, science-based emissions reduction target, more than half of survey respondents said their local religious community has not taken any new actions to reduce greenhouse gas emissions from their operations (Figures 13.14 and 13.15). Again, across all denominations, a greater percentage of laity expressed uncertainty about their community's actions (Survey 2) when compared to religious leaders (Survey 1). As with previous questions, this discrepancy likely stems from leaders being more familiar with the operational aspects of local religious communities than the laity.

In summary, religious leaders and laity indicated that attention to climate change in local religious communities across Nebraska is vastly incommensurate with religious traditions' emphasis on this issue and their opportunity to help society address it.

Qualitative findings

Survey 1 revealed a wide range of beliefs and attitudes about climate change among the leaders of local religious communities. Many respondents believe the climate has changed due to human activities, while others do not believe in climate change or do not attribute it to human activity. In addition, some respondents were unsure whether climate change has occurred or could not identify its cause.

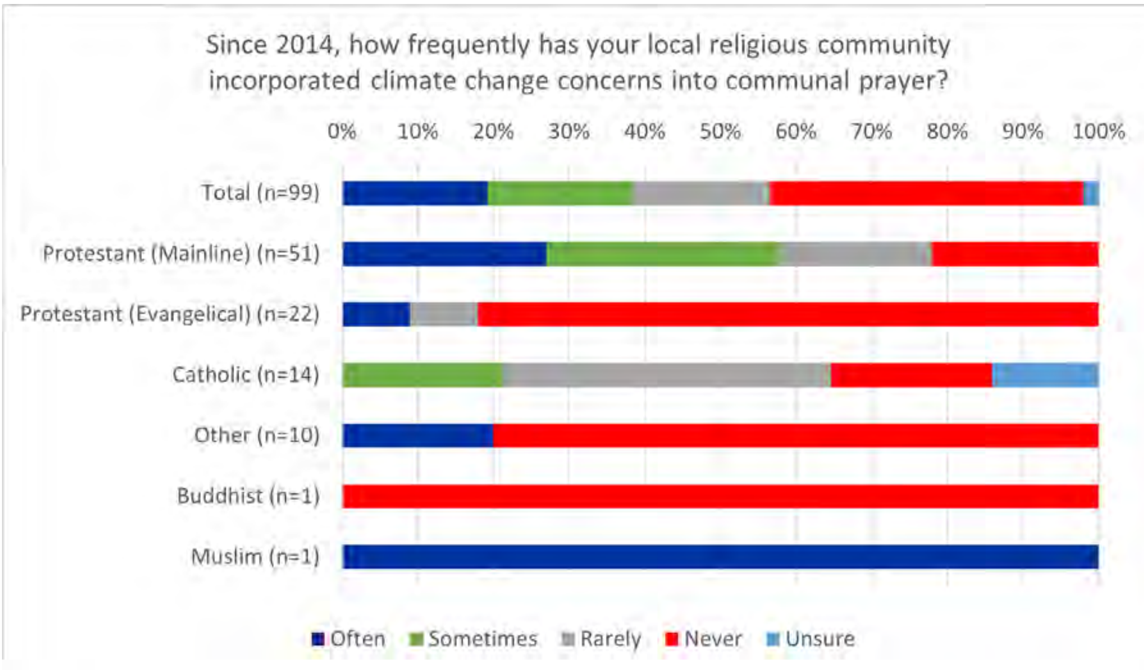


Figure 13.8. Religious leaders, survey 1.

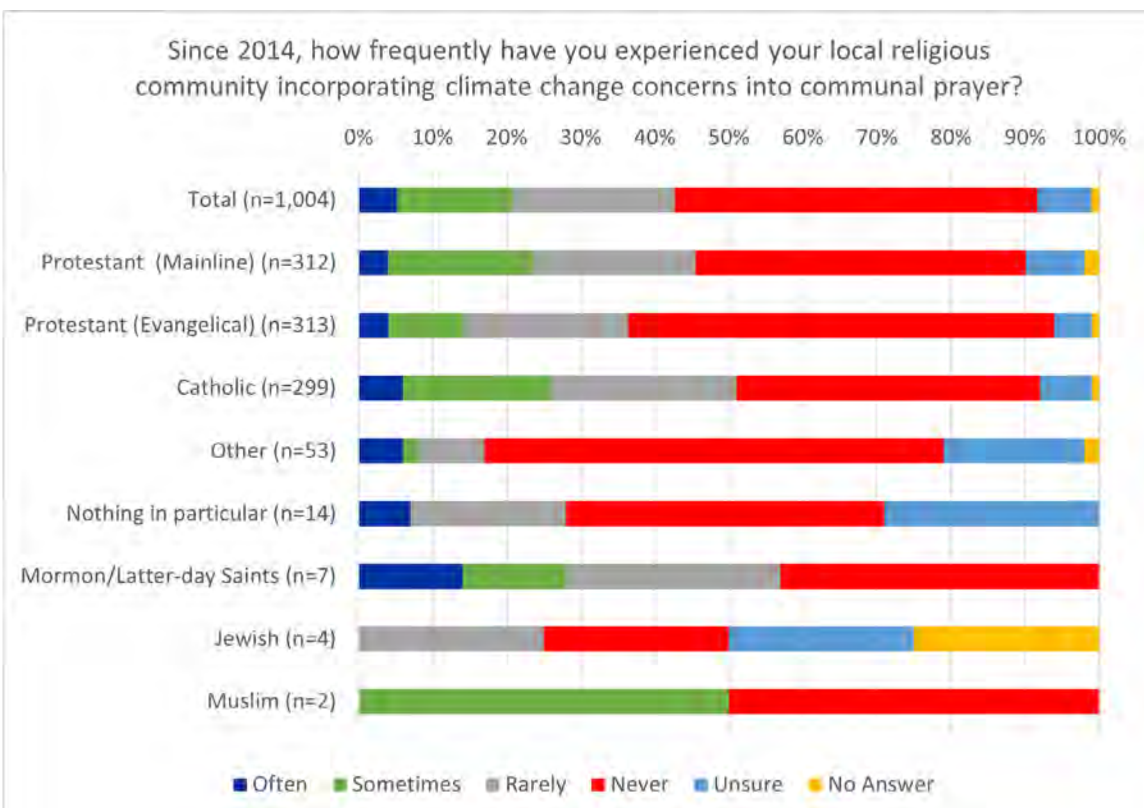


Figure 13.9. Laity, survey 2.

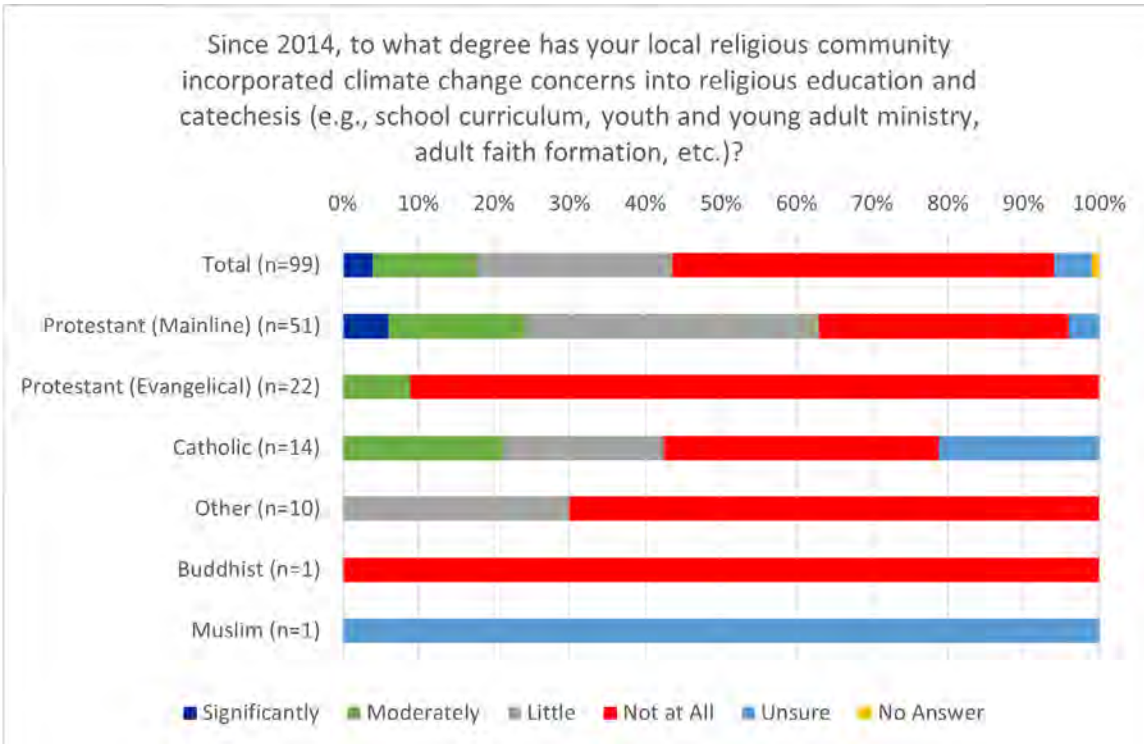


Figure 13.10. Religious leaders, survey 1.

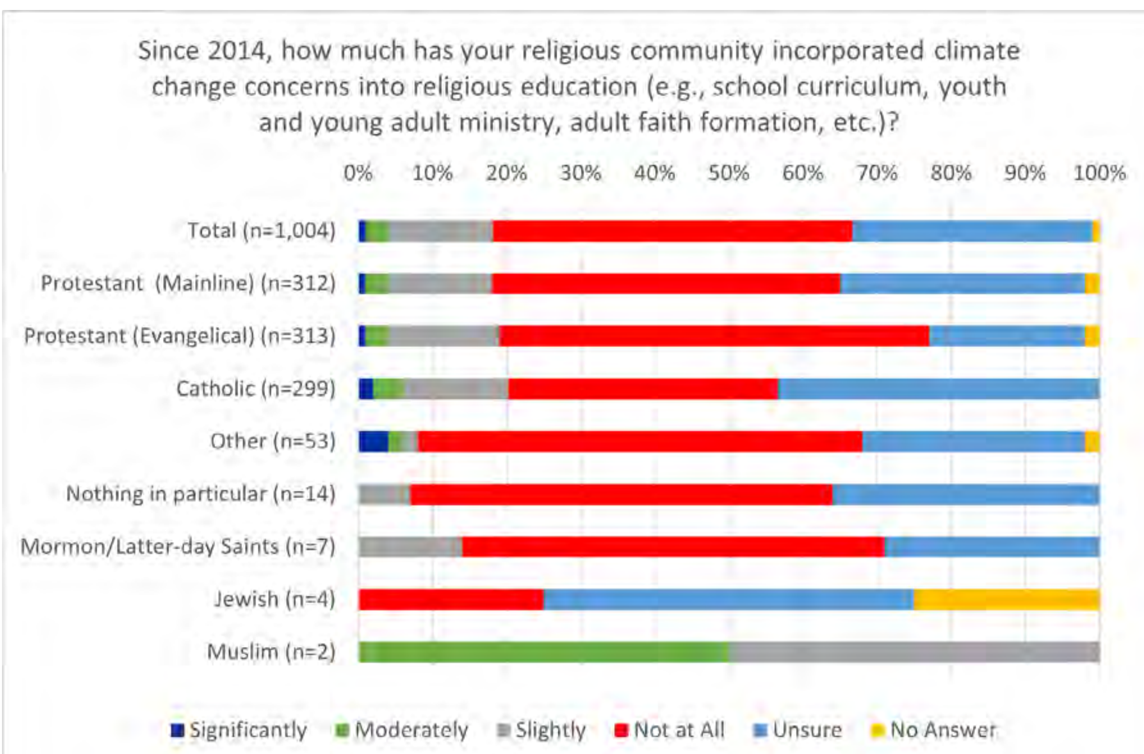


Figure 13.11. Laity, survey 2.

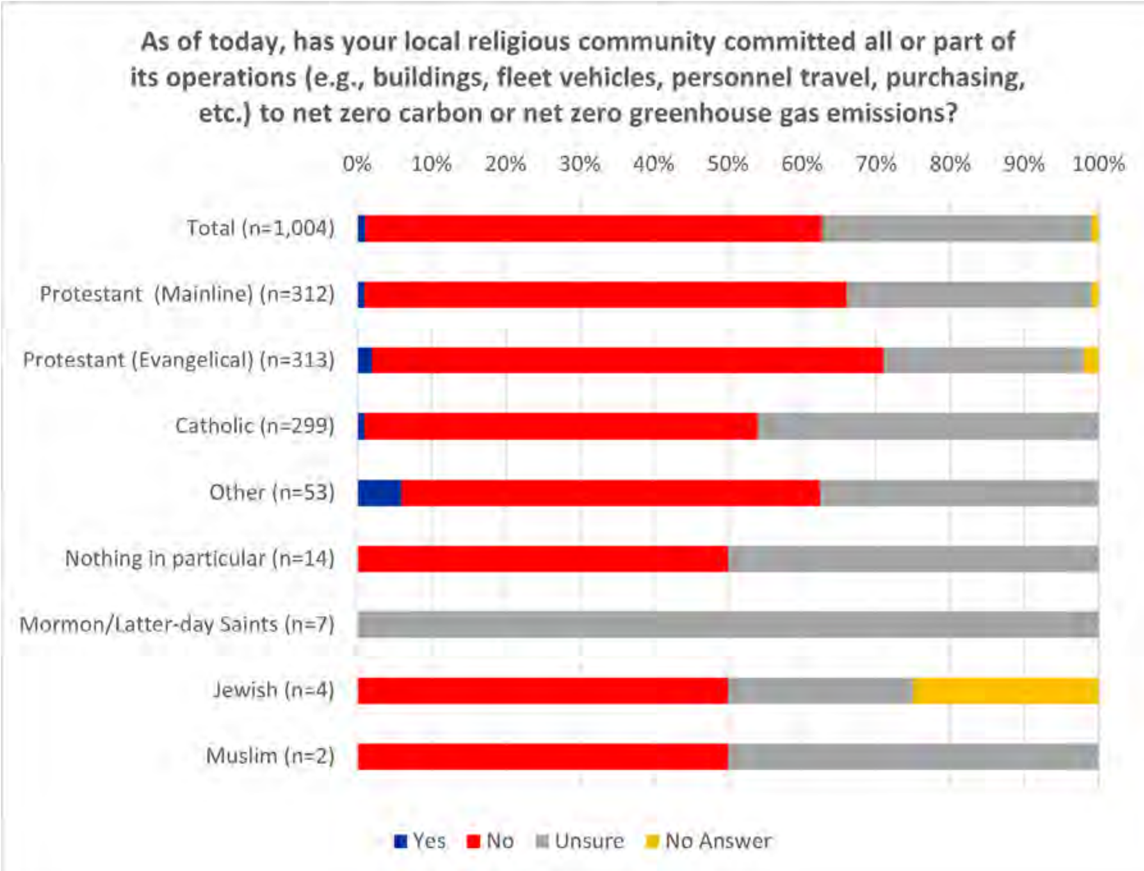


Figure 13.12. Religious leaders, survey 1.

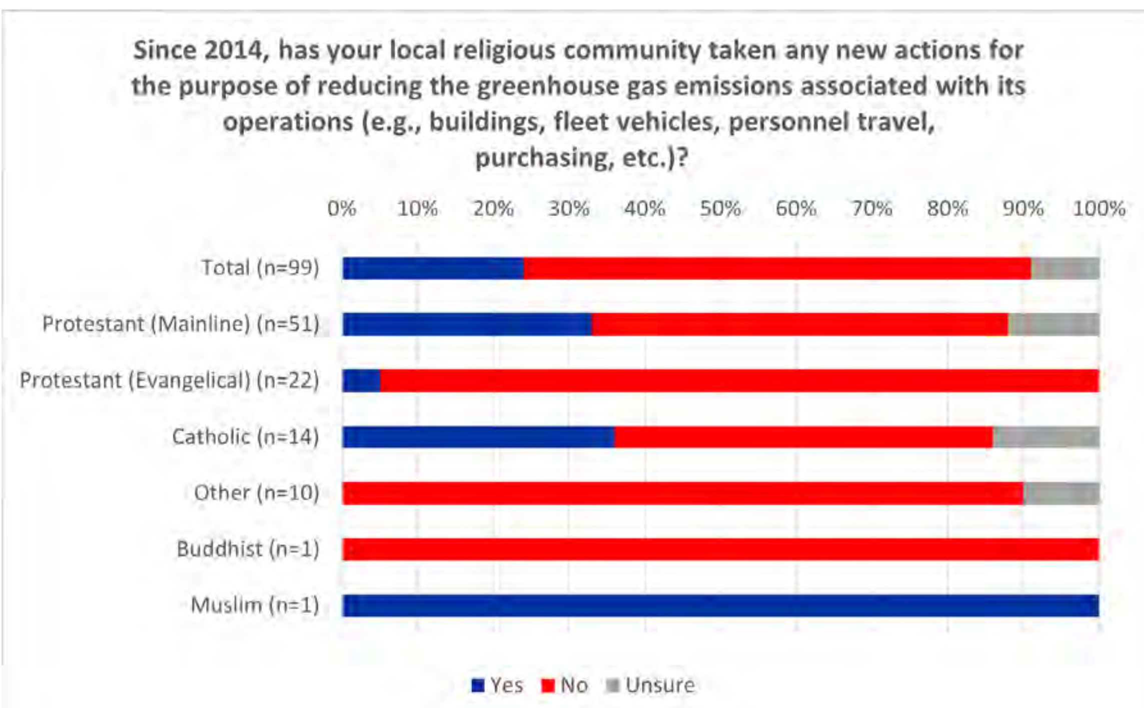


Figure 13.13. Laity, survey 2.

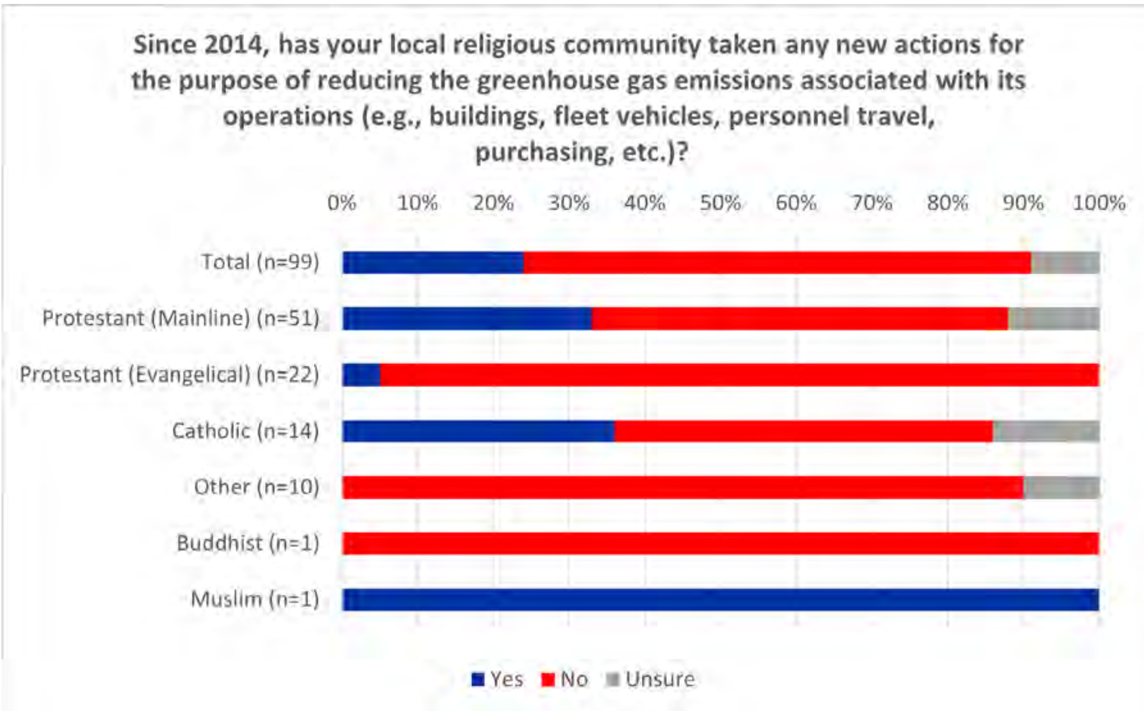


Figure 13.14. Religious leaders, survey 2.

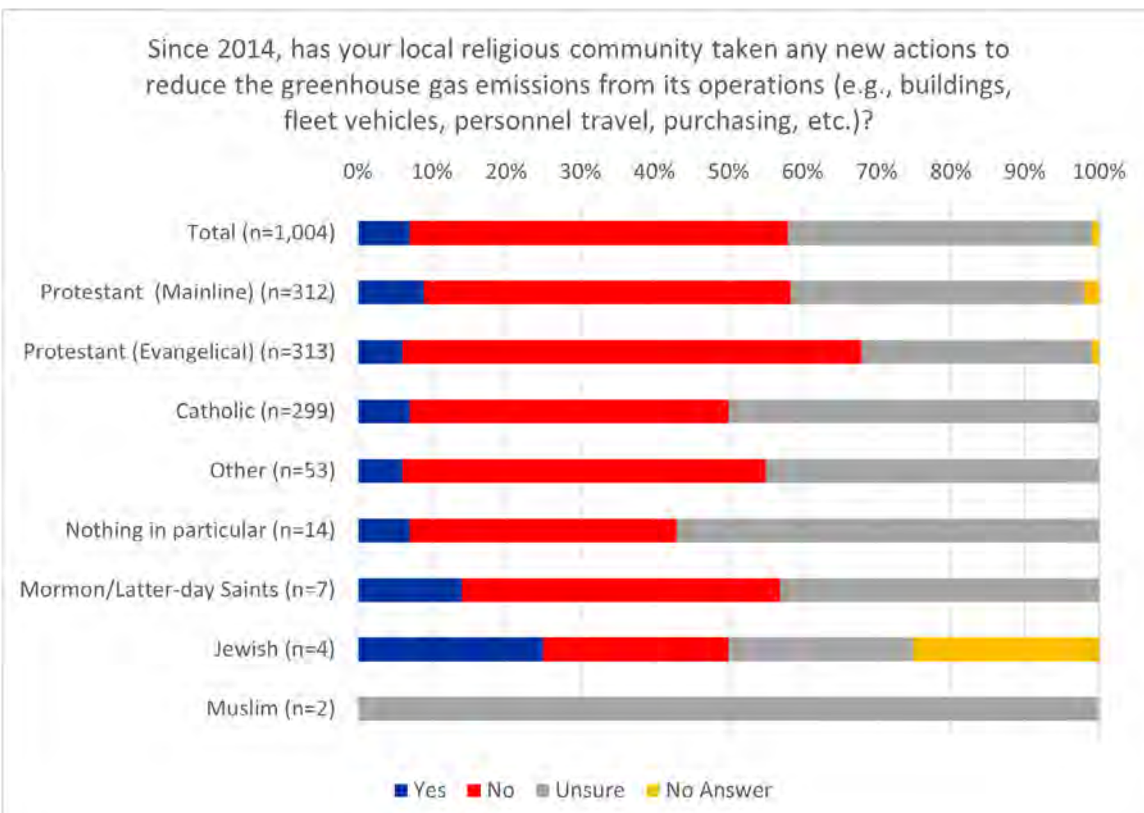


Figure 13.15. Laity, survey 2.

No specific faith tradition held a single perspective on this topic. In most cases, this survey revealed a variety of viewpoints from each faith tradition. Individuals from differing faith backgrounds often expressed similar opinions, citing shared values or barriers to taking action. As a result, the survey findings will be organized based on belief about human-caused climate change rather than religious affiliation.

Religious leaders who do not believe in climate change

As noted, 35% of respondents do not believe in human-caused climate change. Across religious traditions, many of these respondents did not incorporate climate change discussions into religious activities, such as education, prayer, or teaching. Those who reported not including climate change in teaching and education often disagree with published scientific data and cited doubts about the methods or credibility of climate scientists. This sentiment was often paired with the belief that climate change is politically motivated or too controversial for discussion within their religious community. Some respondents felt religious communities should not be engaged in political matters despite many religious leaders' faith-based advocacy for climate policies (Wells, 2023).

Unsurprisingly, some respondents who do not believe in human-caused climate change did not identify climate change as an important issue. Many emphasized that their theology does not align with their perceptions of movements focused on mitigating climate change. Some Christian organizations appeared to prioritize messages of salvation that are disconnected from present ecological concerns or only teach about topics that they believe are explicitly discussed in the Bible.

Others cited the Bible to argue that humans should not focus on addressing climate change because God, not human activity, controls the climate. These rationales contributed to a lack of congregational action, which is also influenced by additional reasons. For example, some respondents viewed climate solutions as impractical, especially in rural communities with limited infrastructure to support options like electric vehicles. Others noted perceived financial barriers to implementing more energy-efficient operations.

Religious leaders who are unsure about climate change

Many respondents who were uncertain about the reality of climate change share sentiments with those who do not believe in anthropogenic climate change. However, some individuals in this group still included climate change in their communal prayers and took steps to lower their carbon footprint.

Leaders who were unsure about human-caused climate change rarely included this topic in their education or teaching. They cited many of the same concerns as those who deny human-caused climate change. A few respondents in this category mentioned that they lacked sufficient information on this topic to adequately include it in their educational offerings.

Some undecided leaders incorporated climate change into their communal prayers due to the increasing visibility of extreme weather in their communities. In addition, one Protestant leader noted that they include this topic in their prayer because the resource they use for liturgical activity addresses climate change.

Individuals in this category cited a lack of resources and interest in the topic as reasons for not taking action to reduce greenhouse gas emissions. Few respondents cited disbelief as a barrier to action. Many noted that they did not have the financial means to switch to energy-efficient solutions. Others expressed skepticism about the significance of their emissions contributions or reductions.

Although this group of leaders did not firmly believe in climate change, many still took steps to reduce their emissions. These individuals often cited personal financial incentives, such as lower utility costs, as motivation. Some also mentioned the influence of their local religious community in motivating changes. One individual noted that they were inspired by the biblical call to care for creation.

Religious leaders who believe in climate change

Of the 51 religious leaders who believe in human-caused climate change, many incorporated discussions about it into religious activities and took steps to mitigate their contributions to global warming. Individuals across various religious traditions commonly cited stewardship as a motivating factor for their actions. One Muslim respondent expressed a sense of responsibility to care for the environment. Protestant respondents similarly expressed a commitment to caring for creation. Some respondents wanted to achieve justice for communities disproportionately affected by climate change.

In contrast to the respondents who do not believe in human-caused climate change, those who believe highlighted climate research as a factor in shaping their perspectives. Additionally, they recognized the impact of extreme weather events and often use communal prayers to cope with grief from these incidents. In some cases, the inclination to include climate change in prayer and education came from higher religious authorities, such as national or regional religious leaders. In many cases, the desire for action arose organically from the congregation.

Many faith communities whose leaders believe in human-caused climate change have made substantial efforts to reduce their emissions. Active members of these communities often played an important role in facilitating climate discussion and promoting action, particularly in communities with fewer resources. Common activities included installing energy-efficient heating and cooling systems or lighting fixtures, recycling and composting, and efforts to reduce consumption or purchase locally sourced supplies.

Despite these isolated activities, no responding community has made a comprehensive operational commitment to a science-based greenhouse gas emission reduction target, such as achieving net zero carbon emissions by 2030. This was particularly noteworthy since, as noted above, many higher religious authorities to whom local leaders report have explicitly called for comprehensive science-based climate action.

While the desire to take climate change action was considerable, these communities still face barriers. Respondents expressed financial restraints in market pricing and internal budgeting, limiting their access to climate solutions. Others felt unsure of where to begin, expressing a need for an educational framework to guide them. Some newer leaders hesitated to discuss climate change with their congregations, recognizing that it can be contentious. Although they believe in climate change, they felt they lacked the platform to discuss it with their local religious communities.

Discussion

Both surveys showed weak religious responses to climate change across Nebraska. These findings are unsurprising for at least two reasons. First, they align with national patterns of religion and climate change. For example, Evangelical Protestants in the U.S. and those who responded to both surveys are less likely to believe in human-caused climate change than Mainline Protestants or Catholics (Pew Research Center, 2022; PRRI Staff, 2023).

Additionally, the silence on climate change among Mainline Protestant leaders is evident nationally and in Nebraska. According to the Pew Research Center (2022), 35% of U.S. Mainline Protestants report not hearing climate change discussions in pastor sermons. In Nebraska, 24% of Mainline Protestant respondents from Survey 1 (religious leaders) indicated that their most senior appointed/ordained local religious community leader never speaks publicly to their congregation about climate change (Figure 13.4). Additionally, 49% of Nebraska Mainline Protestant respondents to Survey 2 reported the same (Figure 13.5).

A similar pattern of silence exists among Catholics. Nationally, 41% of U.S. Catholics report that they do not hear homilies about climate change (Pew Research Center, 2022, p. 60). In Nebraska, 36% of Catholic respondents to Survey 1 (religious leaders) noted that their most senior appointed/ordained local religious community leader never speaks publicly to their congregation about climate change (Figure 13.4). Additionally, 51% of Catholic respondents to Survey 2 (the laity) reported that their most senior appointed/ordained local religious community leader never speaks publicly to their congregation about climate change (Figure 13.5).

Since partisan identity appears to trump religious tradition on climate change for some believers, unlocking the potential of religions in Nebraska to address human-caused climate change will likely require efforts to separate morality from partisanship in climate change discussions. This is echoed by U.S. Catholic bishops in their landmark climate change teaching *Global Climate Change: A Plea for Dialogue, Prudence, and the Common Good* (U.S. Conference of Catholic Bishops, 2001), which states

> **At its core, global climate change is not about economic theory or political platforms, nor about partisan advantage or interest group pressures. It is about the future of God's creation and the one human family. It is about protecting both "the human environment" and the natural environment. It is about our human stewardship of God's creation and our responsibility to those who come after us.**

One potential pathway forward is for religious communities to access federal climate mitigation funding through the 2022 Inflation Reduction Act (IRA). As the International Energy Agency summarizes,

> **The IRA includes a combination of grants, loans, tax provisions, and other incentives to accelerate the deployment of clean energy, clean vehicles, clean buildings, and clean manufacturing. This includes investments in deploying clean energy, expanding the electricity grid, developing domestic clean technology manufacturing, incentivizing uptake of electric vehicles, reducing methane emissions, increasing the efficiency of buildings, improving the climate resilience of communities, and other areas. In total, around 370 billion USD will be disbursed for measures dedicated to improving energy security and accelerating clean energy transitions. (IEA, 2024)**

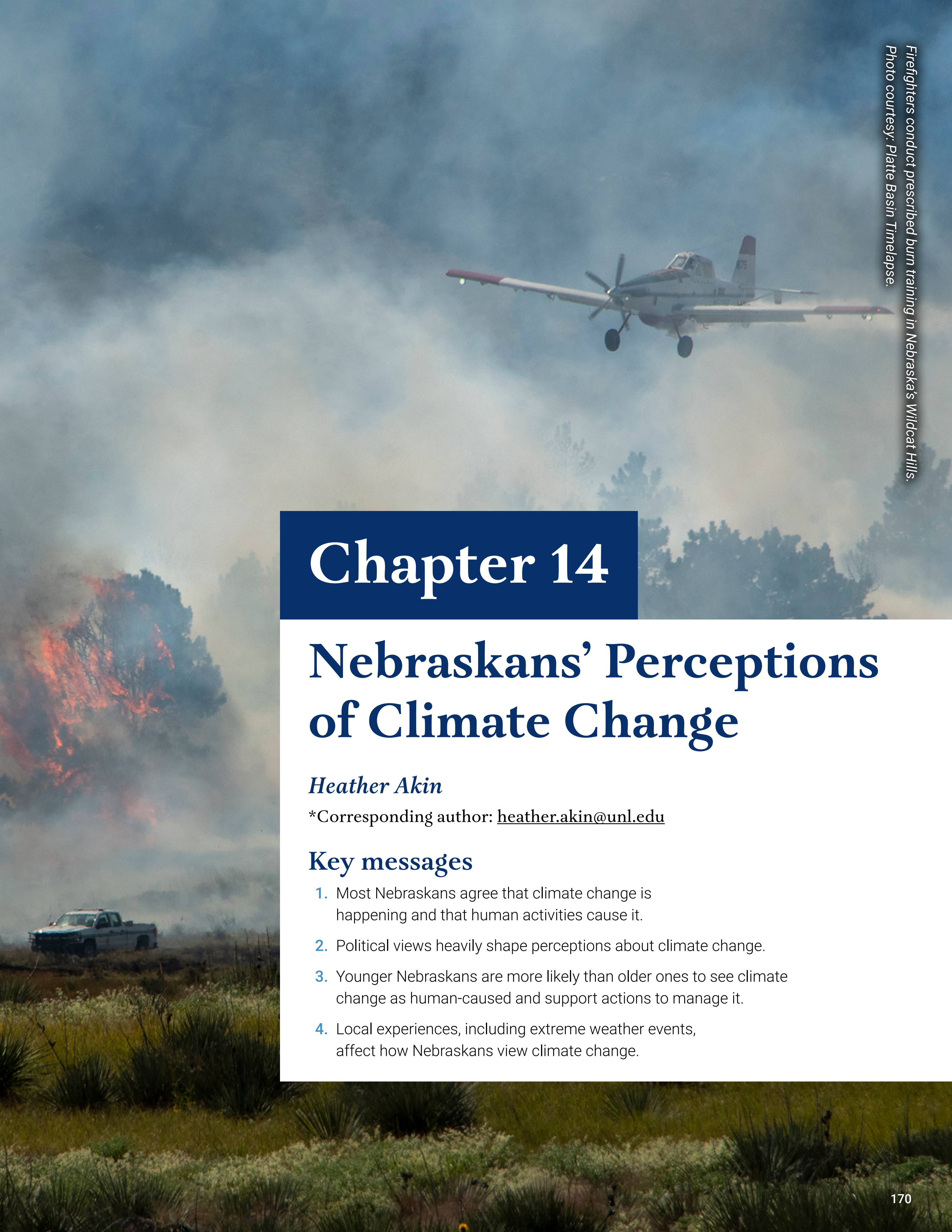
The 2025 One Big Beautiful Bill Act (OBBBA), signed by President Trump, severely restricted and eliminated IRA clean energy funding (H.R.1 - 119th Congress, 2025). Nebraska's congressional delegation unanimously supported the Bill. Before OBBBA, religious communities used the IRA to reduce their greenhouse gas emissions while saving money on energy costs. As noted above, Horizons Community United Methodist Church in Lincoln installed solar panels with a $21,600 IRA federal tax credit and a grant from Nebraska Interfaith Power and Light (Israel, 2024).

Many religious traditions had published resources on accessing IRA funding (Catholic Climate Covenant, 2024; Episcopal Church, 2024; Tavcar, 2023; United Church of Christ, 2022; United Methodist Creation Justice Movement, 2023). The ecumenical Interfaith Power and Light (2024) also published guides to IRA funding, and Nebraska Interfaith Power and Light could assist local religious communities, as it did for Horizons Community United Methodist Church in Lincoln (Israel, 2024).

Although IRA funding is deeply curtailed, ONE RED remains a potential clean energy and efficiency opportunity for state religious communities (NDEE, 2024d). In 2024, the Nebraska Department of Water, Energy, and Environment received a $307 million Climate Pollution Reduction Implementation Grant from the U.S. Environmental Protection Agency Agency"(EPA) to support this initiative. As of August 2025, the grant appeared solvent despite efforts to cancel billions of dollars from other EPA grants (NDEE, 2024d). If it remains, religious communities could apply to two ONE RED programs: the Non-Residential Energy Efficiency Program ($30 million, which funds up to 50% of project costs) and the Non-Residential Solar Program ($28 million, which funds up to 60% of project costs).

However religious communities discern funding climate change mitigation, doing so will likely require a shift toward what the Vatican calls "ecological economics" that incorporate social and environmental costs of action and inaction into financial assessments (Dicastery for Promoting Integral Human Development, 2025). As Pope Benedict XVI (2010) summarizes,

> **It is not hard to see that environmental degradation is often due to the lack of far-sighted official policies or to the pursuit of myopic economic interests, which then, tragically, become a serious threat to creation. To combat this phenomenon, economic activity needs to consider the fact that "every economic decision has a moral consequence" and thus show increased respect for the environment. When making use of natural resources, we should be concerned for their protection and consider the cost entailed—environmentally and socially—as an essential part of the overall expenses incurred.**



Firefighters conduct prescribed burn training in Nebraska's Wildcat Hills.
Photo courtesy: Platte Basin Timelapse.

Chapter 14

Nebraskans' Perceptions of Climate Change

Heather Akin

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Key messages

1. Most Nebraskans agree that climate change is happening and that human activities cause it.
2. Political views heavily shape perceptions about climate change.
3. Younger Nebraskans are more likely than older ones to see climate change as human-caused and support actions to manage it.
4. Local experiences, including extreme weather events, affect how Nebraskans view climate change.

Introduction

Nebraskans are experiencing the effects of climate change, both directly and indirectly, as changing weather patterns, intensifying extreme events, shifting growing seasons, and impacting communities across the state (see Chapters 8, 10, and 11). Views about climate change among Nebraskans and the broader U.S. public are complex. They often reflect an interplay of social, psychological, geographic, and scientific factors that are not simply a matter of accepting or denying the available evidence. Research examining public perceptions of climate change finds that recognizing and acknowledging how and why people form their views—by considering local values and experiences—provides deeper insight into the social dimensions of climate science.

Nebraskan's opinions and attitudes

Surveys indicate that most Nebraskans (67%) believe climate change is occurring, and 52% attribute it to human-caused greenhouse gas emissions (Marlon et al., 2023). These figures are comparable to, but slightly lower than, national averages, where 72% of Americans believe climate change is happening, and 58% link it to human activities (Marlon et al., 2023). Although more than half of Nebraskans express concern, the level of worry and trust in scientific evidence has gradually shifted. Stark differences in views about climate change exist along political lines. A 2019 survey found that 86% of Democrats in Nebraska expressed concern about climate change, compared to 64% of moderates, and 30% of Republicans. While 5% of Democrats reported that they were "not at all concerned," this rose to 43% among Republicans (Bureau of Sociological Research, 2019). These data, and those from other studies, illustrate that individuals' stances about climate change tend to be closely tied to their social identities and community affiliations (Ehret et al., 2018; Hornsey et al., 2016; Kim et al., 2023).

Researchers studying attitudes toward climate change find differences in views, despite the scientific consensus that human activity is causing climate change (Lynas et al., 2021; Myers et al., 2021). These differences reflect factors beyond scientific evidence,

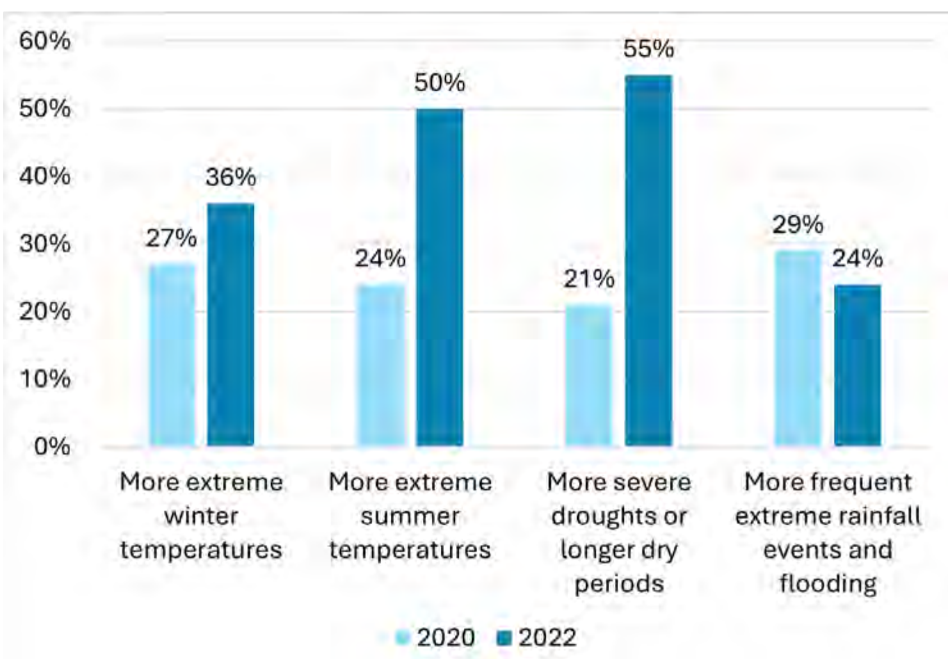

Figure 14.1. Rural Nebraskans' concerns about future extreme weather events, 2022 (N = 1,979) and 2022 (N = 1,105). (Source: Vogt et al., 2022)

such as personal experiences, social values, political affiliations, and collective identities (Kahan et al., 2012; McCright & Dunlap, 2011). Even when individuals are aware of the scientific evidence of climate change, it may not influence beliefs. Instead, beliefs are often tied to community norms and personal experiences. Political polarization, mistrust, and exposure to misinformation can further reinforce these viewpoints (Bugden, 2022; Mashamaite, 2023; Treen et al., 2020).

Generational differences also play a role in shaping climate change perceptions. Younger Nebraskans, including Millennials (born between 1981 and 1996) and Generation Z (born between 1997 and 2012), show higher levels of concern about climate change than older Nebraskans and are more likely to attribute climate change to human causes (Vogt et al., 2015, 2022). Surveys find that younger populations often support policies that address climate change mitigation and adaptation, like expanded use of renewable energy, adoption of new agricultural methods, and other efforts to reduce greenhouse gas emissions (Funk, 2021). In contrast, while older Nebraskans are becoming more knowledgeable about climate change, they may express deeper skepticism that human activities cause climate change and associate less urgency about addressing it. These generational patterns in Nebraska parallel national trends. Younger populations of Americans are expressing stronger feelings about the personal relevance of climate change and concern about the future than older ones (Funk, 2021).

Agriculture is central to Nebraska's economy and cultural identity, which makes local experiences with the changing climate particularly relevant. Extreme weather events—including flooding and drought (see Chapters 2 and 3)—are altering growing seasons and agricultural production methods in ways that will impact many Nebraskans' livelihoods (see Chapter 8) (Zobeidi et al., 2020). While many in agricultural communities are experiencing these changes firsthand, some express uncertainty about the influence of human activities or raise concerns about the effectiveness of climate change policies. They worry that these policies could undermine traditional production practices and local economies (Calloway et al., 2022; Howard et al., 2020; James et al., 2014).

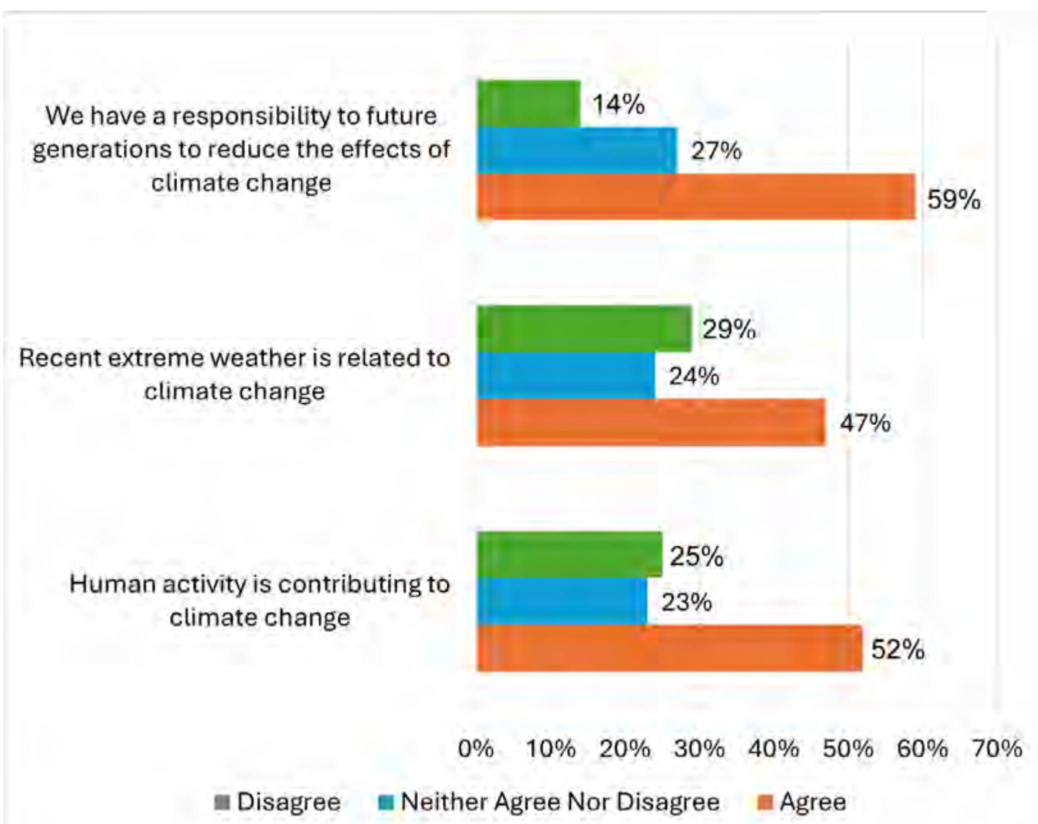

Figure 14.2. Rural Nebraskans' views toward climate change, N = 1,105. (Source: Vogt et al., 2022)

Insights from the Nebraska Rural Poll suggest that rural Nebraskans have noticed changes in the climate in their communities. According to the 2022 Nebraska Rural Poll, many report observing changes in local weather patterns (Figure 14.1) and environmental conditions. Concerns about these effects vary across regions of the state. For instance, 89% of Panhandle residents are concerned about more extreme droughts in the future. However, the extent to which Nebraskans attribute these changes to human activities also differs. Some Nebraskans express skepticism or uncertainty about human influence, while others acknowledge this influence and express deep concern about the impact on future generations (Figure 14.2) (Vogt et al., 2022). In Nebraska's rural communities, the acknowledgment of climate variation often stems from firsthand experience with changing precipitation, temperature fluctuations, or altered growing seasons. While many rural Nebraskans demonstrate social resilience—often embodied in the phrase "Nebraska Strong"—climate change effects are taking a toll on individuals' mental health, particularly those working in agriculture. This is predicted to worsen in the coming years (Howard et al., 2020).

Factors influencing public opinion

Media coverage has influenced perceptions of climate change (Boykoff & Boykoff, 2007; Diehl et al., 2021). Past analyses of U.S. media identified a pattern of "false balance," where coverage treated established science and fringe skepticism as equally credible viewpoints (Adam et al., 2020; Chinn & Pasek, 2020; Dixon et al., 2015). Although many outlets have moved away from this approach, the legacy of these early media portrayals continues to affect public memory. Strategic disinformation campaigns have also undermined public understanding of climate change. Some special interest groups and corporations have invested in efforts to cast doubt on scientific consensus or downplay the seriousness of the issue (Boussalis & Coan, 2016; Brulle et al., 2020; Supran et al., 2023). Such messaging often aligns with existing political divides, reinforcing skepticism and discouraging open dialogue.

Declining trust in scientists, government officials, and other institutions has also influenced how climate information is received (Kennedy & Tyson, 2023; Kulin & Johansson Sevä, 2021). In Nebraska and elsewhere, where scientific information may come from universities, government agencies, and media, diminished trust can hinder the acceptance of new evidence or engagement with proposed strategies. Some members of the public may question institutions' objectivity or suspect that climate policies may not align with local priorities. Recognizing that trust stems from a history of positive and negative interactions between communities and institutions is one explanation of why perspectives can diverge from scientific consensus (Bugden, 2022). Research suggests that recognizing and valuing the perspectives of all Nebraskans, including those who challenge science, can enhance understanding of the social realities shaping climate discourse (Calloway et al., 2022; Miner et al., 2023). Skepticism or denial may stem from legitimate economic worries, cultural identity, or apprehension about external decision-making rather than a mere lack of information (Kahan et al., 2012; Kulin & Johansson Sevä, 2021; Wong-Parodi et al., 2016).

Conclusions

This multidimensional picture of climate change perception is essential for understanding the complex ways people engage with the issue of Nebraska's changing climate. Evidence from surveys, interviews, and observational studies suggests that how people interpret climate data, weigh scientific findings, and consider solutions is incredibly complex. Agricultural adaptations, shifts in energy use, levels of trust, media use, and direct experiences are interrelated with social, cultural, and political contexts. Acknowledging and valuing the full spectrum of perspectives (see Chapters 8 and 10), including those that challenge scientific consensus, offers a more nuanced understanding of why certain views persist (Bremer & Meisch, 2017; Miner et al., 2023). As public responses evolve and communities navigate the changing climate in our state, the paths forward—including approaches to mitigation, adaptation, and resource management—are likely to be guided as much by these social dimensions as by the underlying scientific and environmental realities.

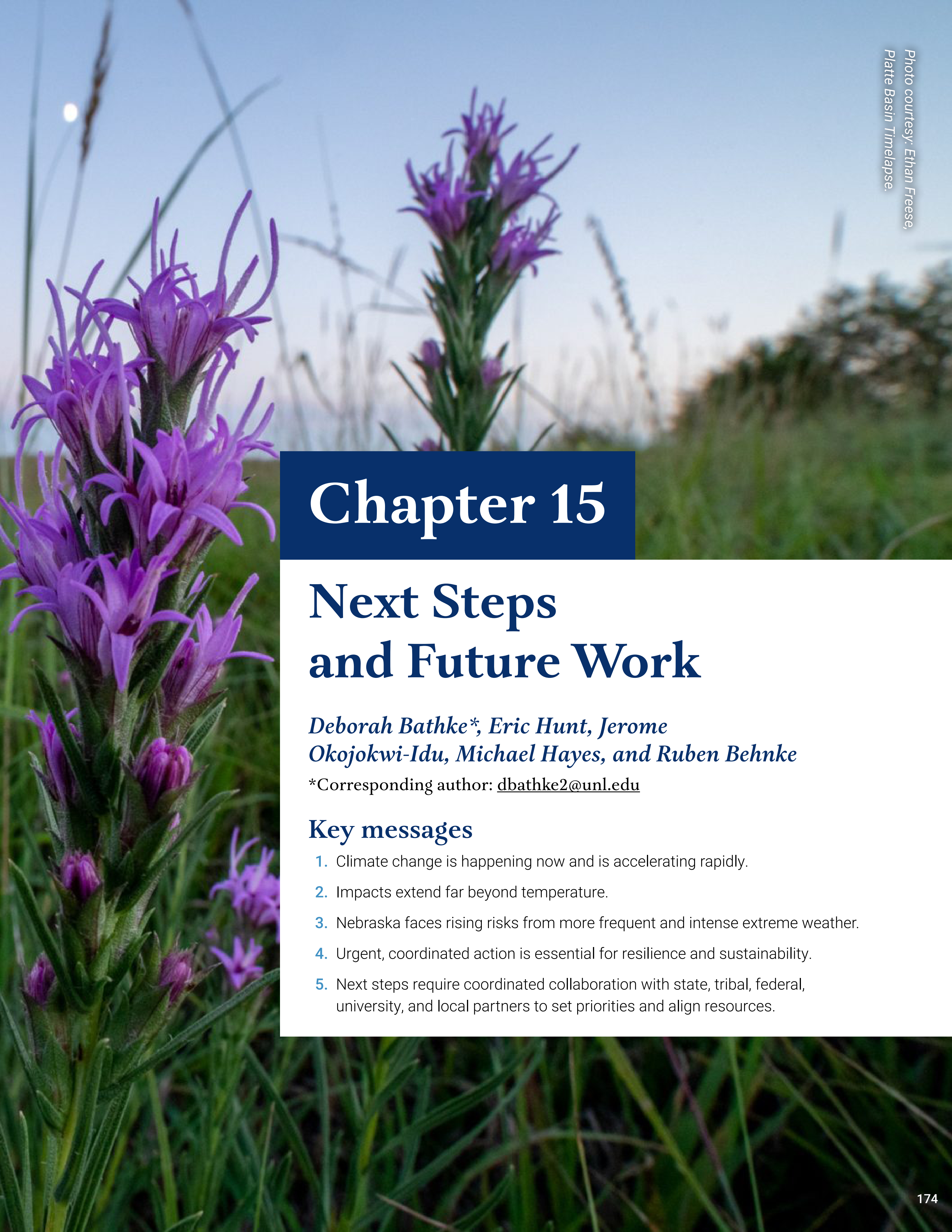

Photo courtesy: Ethan Freese, Platte Basin Timelapse.

Chapter 15

Next Steps and Future Work

Deborah Bathke, Eric Hunt, Jerome Okojokwi-Idu, Michael Hayes, and Ruben Behnke*

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Key messages

1. Climate change is happening now and is accelerating rapidly.
2. Impacts extend far beyond temperature.
3. Nebraska faces rising risks from more frequent and intense extreme weather.
4. Urgent, coordinated action is essential for resilience and sustainability.
5. Next steps require coordinated collaboration with state, tribal, federal, university, and local partners to set priorities and align resources.

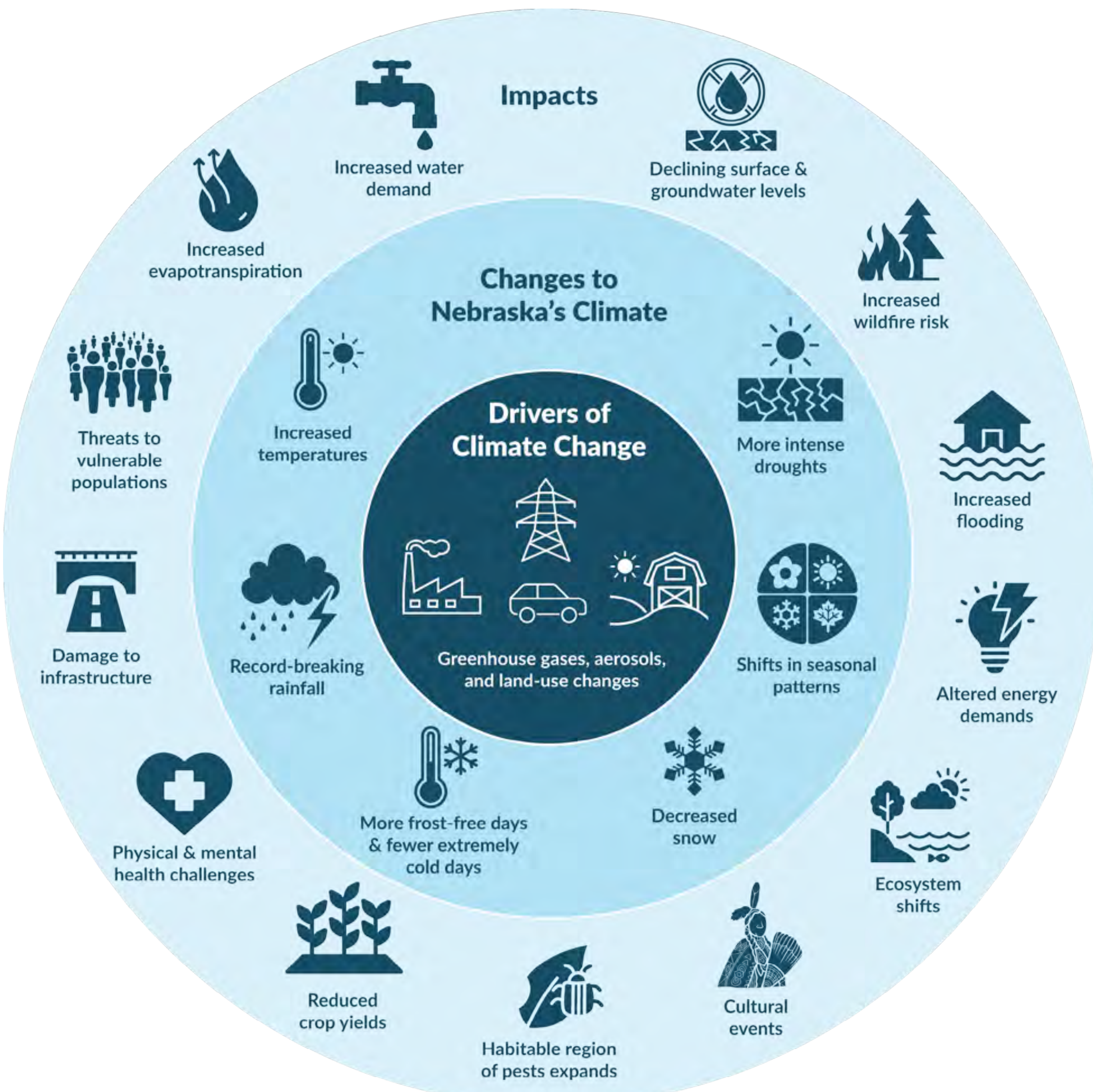
Summary of key findings

Human-caused warming is disrupting natural and human systems worldwide at an unprecedented pace—approximately ten times faster than the warming that followed the last ice age. The past decade (2015–2024) contains the ten warmest years in the 175-year global record, highlighting the accelerating trend.

Rising greenhouse gases, declining snow and ice, sea level rise, shifting precipitation patterns, and more frequent extreme events are among the more than 50 indicators of climate change. Local and regional experiences are shaped by natural variability, geography, land cover, and the vulnerability and adaptive capacity of people and ecosystems.

Nebraska's climate has already become warmer and wetter, with greater variability and distinct seasonal shifts. Communities are experiencing record-breaking heat, more extreme wet and dry conditions, and declining snow cover (Figure 15.1). Without major emissions reductions, these risks will intensify throughout the century.

Figure 15.1. Global warming drivers, changes, and impacts. (After: Future Learn, 2018. Contains public sector information licensed under the Open Government Licence v3.0.)



These shifts present urgent challenges for agriculture, water resources, energy, ecosystems, infrastructure, public health, and vulnerable communities. Reducing these risks, strengthening resilience, and ensuring long-term sustainability requires proactive planning, integration of scientific and Indigenous knowledge, community engagement, and solutions that also consider economic concerns.

Next steps and future work

Building on this report, the next steps require collaboration with state, tribal, federal, university, and local partners to identify needs, set priorities, and align resources to complete the activities below, as determined by the report authors and the advisory board.

1. Support clear and concise communication of scientific findings to help translate the report findings into tangible actions by:
    - Housing this report on the Nebraska State Climate Office website (https://nsco.unl.edu).
    - Rolling out the report to agencies, organizations, and communities via seminars, presentations, and meetings.
    - Developing an online searchable toolkit for the mitigation, adaptation, and resilience options presented in the supplemental report.
    - Creating infographics to simplify and help explain and summarize report findings.
    - Gathering examples of how climate change is already impacting Nebraskans.
    - Providing links to related resources, tools, and planning documents.
    - Engaging communities to address their needs and questions.
2. Partner with state, tribal, federal, university, and other organizations to secure funding to enhance data collection and infrastructure via:
    - Modernizing and expanding data collection via the Nebraska Mesonet (https://nemesonet.unl.edu).
    - Developing a statewide climate data portal to facilitate decision-making and the development of climate-related tools.
3. Promote planning for a climate-resilient Nebraska through:
    - Raising awareness about climate change.
    - Promoting the understanding of the scientific basis for climate change and the urgent need for action.
    - Emphasizing local impacts and the specific challenges faced by communities.
    - Highlighting the opportunities for mitigation, adaptation, and resilience identified in the supplemental report.
    - Sharing success stories of successful climate action initiatives.
4. Support evidence-based policy development and decision-making by:
    - Disseminating research findings via the Nebraska State Climate Office website (https://nsco.unl.edu).
    - Summarizing report findings with statewide and regionally relevant information.
    - Making data more accessible and visible through dashboards, infographics, and other visualizations.
    - Providing necessary resources, including data, tools, and training.

5. Integrate climate education and engagement across subjects, grade levels, and non-traditional settings by:
   - Working with K–12 schools and after-school programs on curriculum and activities.
   - Collaborating with artists and writers to share findings in creative ways.
   - Coordinating with the Osher Lifelong Learning Institute and other senior-focused groups.
   - Partnering and supporting climate-related programming with tribal colleges.
   - Engaging religious institutions and nonprofits to help share the report's findings.
6. Improve future climate change assessments and adaptation efforts by addressing the uncertainties and knowledge gaps identified by the chapter authors. These include:
   - Producing higher-resolution regional climate simulations to enhance Nebraskans' decision-making capabilities related to preparing for and adapting to changes in climate.
   - Researching surface-groundwater interactions, modeling how large-scale climate patterns influence Nebraska's groundwater, and conducting analyses and case studies on how conservation measures impact both groundwater and surface water.
   - Assessing residents' willingness to use clean energy sources, evaluating opinions on decentralizing power sources, expanding studies on energy efficiency and storage technologies, and advancing strategies to lower greenhouse gas emissions from agriculture.
   - Strengthening systems to monitor climate-related health impacts, studying how extreme heat, air pollution, and drought affect physical and mental health, the health effects of events like heat waves, floods, droughts, wildfires, and storms, and assessing the ability of local healthcare systems to respond to climate events and adapt infrastructure accordingly.
   - Promoting the fusion of Indigenous Knowledge with science and advancing Indigenous climate adaptation strategies.
   - Identifying climate risks faced by at-risk communities, measuring climate justice outcomes related to energy infrastructure, and evaluating how climate and environmental justice principles are applied in state policies and programs.
7. Establish a standardized process to ensure regular and consistent updates to future Nebraska climate change assessments. This includes:
   - Designating an agency or working group to oversee and coordinate the update process.
   - Defining a clear reporting cycle (e.g., every 5-6 years or following every national climate assessment).
   - Allocating sufficient funding to support data collection and analysis.

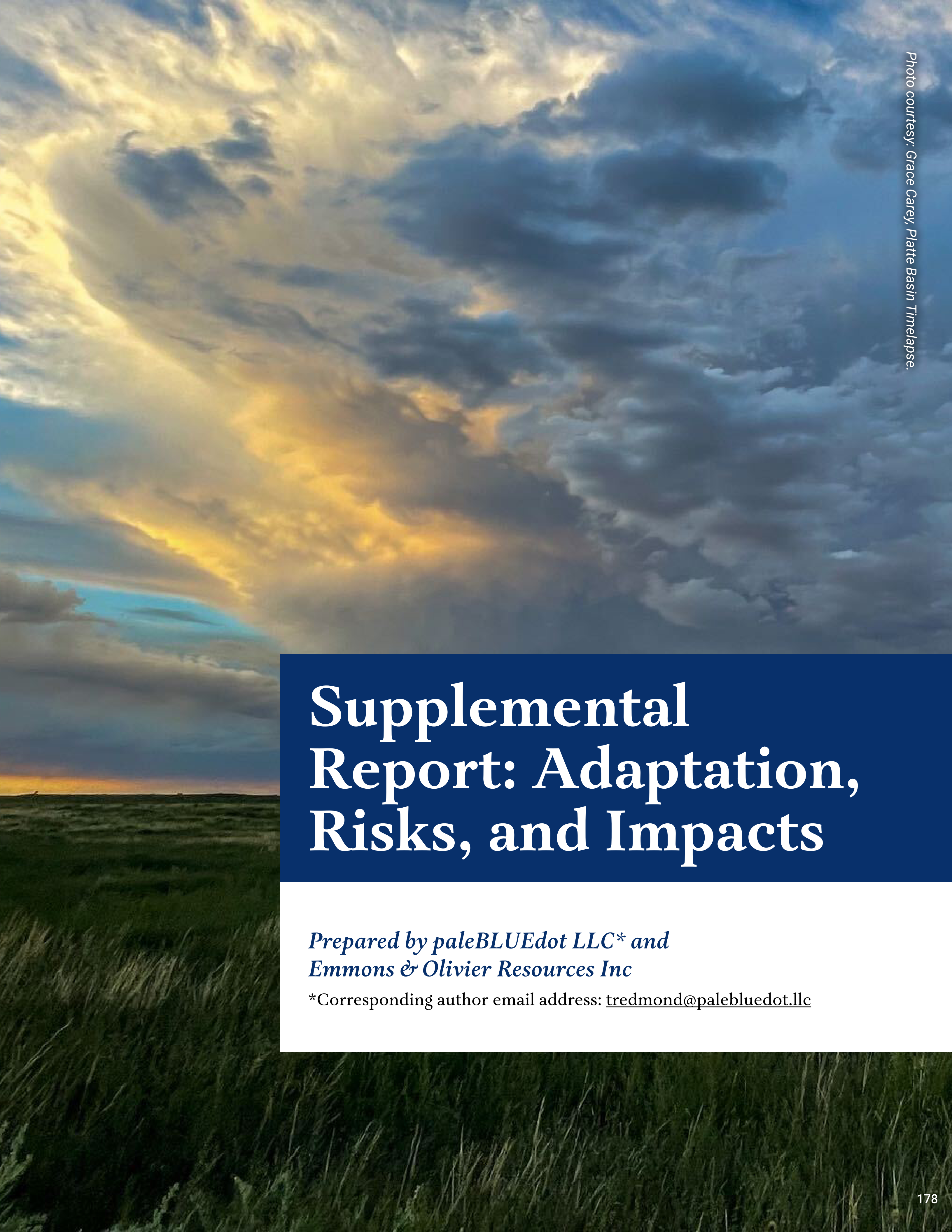


Photo courtesy: Grace Carey, Platte Basin Timelapse.

Supplemental Report: Adaptation, Risks, and Impacts

Prepared by paleBLUEdot LLC and*
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Introduction

By leveraging existing resources and opportunities, Nebraskans can anticipate, plan for, and adapt to a changing climate. Climate impacts will vary across different parts of Nebraska, with local communities having various levels of awareness and understanding of the risks and vulnerabilities they face.

If greenhouse gas emissions keep rising at the current pace, Nebraska's average annual temperature could increase by 5–6°F in the next 25 years (relative to 1950–2014), and by up to 11.5°F by the end of the century (Chapter 4). With this level of warming, temperatures would exceed the hottest annual average temperatures – those of the Dust Bowl era. In Nebraska, warmer temperatures manifest as more frequent and severe heat waves, intense rainfall, and drought—all of which affect communities, ecosystems, and the state's economy.

The choices society makes today will shape Nebraska's climate future. Without meaningful mitigation, extreme weather and its harmful climate impacts will intensify, resulting in greater damage and higher economic costs for the state (USGCRP, 2023).

Recognizing this, the Nebraska Department of Environment and Energy (NDEE) has taken important steps (NDEE, 2024b):

- In 2023, NDEE received a $3 million EPA planning grant to develop Nebraska's first statewide climate action plan. This process involved consultation with stakeholders across the state and resulted in a Priority Climate Action Plan identifying high-impact strategies to reduce emissions through voluntary actions and financial incentives.
- In 2024, NDEE secured a $307 million EPA implementation grant—the largest federal grant in its history—to implement these mitigation actions over the next five years.[1]

This supplemental report builds on those efforts, as well as those undertaken by agencies, organizations, and communities across the state. With limited time (1 year) and resources ($150,000), this supplemental report is designed to support concerned decision-makers and community members across Nebraska as they navigate climate impacts and the risks they are facing. It:

- Provides a menu of recommended strategies and example actions to reduce vulnerabilities and build resilience.
- Aligns with the climate risks identified in the focus topics (Chapters 5–12)
- Draws from paleBLUEdot's extensive analysis of climate resilience actions, trends, and best practices from
- Provides a menu of strategies and example actions are provided to reduce vulnerabilities and build resilience, based on the report's findings, Nebraska's climate risks (Chapters 5–12), and paleBLUEdot's national review of 77 climate vulnerability assessments and adaptation plans (Appendix C).
- Integrates Nebraska-specific guidance documents and research, reviewed by EOR, to ensure recommendations are relevant to local conditions.

Guide to this supplemental report

This supplemental report consists of the following components for each focus topic in chapters 5 through 12.

Part 1: Options and Opportunities

Key messages related to each focus topic are repeated for quick reference.

Adaptation and resilience options and opportunities

This section provides recommendations for strategies

[1] *The current status of this grant can be found at NDEE's ONE RED website: https://dee.nebraska.gov/aid/one-red-opportunity-nebraska-reducing-emissions-decarbonization/one-red-implementation-grant.*

and examples of detailed actions that can be implemented to address the climate vulnerabilities and risks outlined in the Focus Topics (chapters 5–12). These recommendations intend to provide initial guidance to this broad audience of decision-makers seeking ideas on increasing Nebraska's resilience. Ideally, these preliminary recommendations, in conjunction with the findings of scientific assessment, should be used as a foundation for creating state- and community-specific climate action and resilience plans.

Example actions that support each strategy recommendation are based on the findings found in each of the Focus Topics (Chapters 5–12) and through an extensive national audit of climate and resilience actions, trends, and best practices. The audit effort included the following:

» paleBLUEdot staff reviewed all available state climate vulnerability assessments and adaptation plans. The team surveyed all 50 states and the District of Columbia for relevant plans. In total, 77 plans were identified and reviewed for relevant examples of resilience actions across sectors that aligned with the Focus Topics included in Nebraska's 2024 Climate Change Impact Assessment Report.

» EOR staff reviewed a range of climate and climate-related guidance documents developed for communities in Nebraska. These documents included various plans and reports that address how climate change might impact different areas of the state and what actions can be taken to adapt to these changes.

A complete list of the plans and documents reviewed can be found in Appendix C.

Actions are organized by those that could be implemented by state leadership and agencies; those that could be implemented by tribal, local governments, or public power districts; those that the agricultural community could implement; and those that businesses, households, and individuals. Note: not every level of decision-making is available for every focus topic.

A searchable database of these options will be available on the Nebraska State Climate Office website at https://nsco.unl.edu.

Part 2: Risk assessment and impact summaries

Climate hazard risk assessment

These charts highlight the overall comparative risk of each climate hazard by Focus Topic, supporting effective resilience planning and implementation within limited funding and resources constraints. Climate change affects everyone, making it essential to prioritize risks without overlooking any hazard or population, regardless of their vulnerability status. While identifying overall risk levels helps with comparative prioritization, all risks must be evaluated and monitored. Risks classified as low or moderate at the state level may still pose high or very high risks to specific regions or communities within Nebraska.

Climate risks are ranked by confidence (Box 1.3) in future change (Chapter 4) and impact (Chapters 5 - 12). Overall hazard risks are estimated by multiplying confidence in future change by impact level and timeframe using the values described below.

Confidence in future change:
Low = 1; Medium = 2;
Medium-High = 2.5; High = 3; Very High = 4

Impact Level:
Low = 1; Moderate = 2; High = 3

Timeframe:
Long-term = 1; Medium-term = 2;
Short-term = 3; Current = 4

Comparative risk levels are determined based on the total scores as follows: Very Low < 4; Low < 8; Moderate < 17; High < 26; Very High ≥27

Climate impacts summary

These charts summarize the potential impacts identified or anticipated in each Focus Topic's vulnerability assessment chapter (Chapters 5–12). The impacts are organized by the climate hazards most relevant to that Focus Topic and were developed by paleBLUEdot LLC and EOR, in consultation with the report's climatologists and each Focus Topic's chapter author.

Part 1: Options and opportunities

Water

Key messages

1. Changes in precipitation impacting water availability intersect multiple issues, including energy, health, agriculture, and more.
2. Nebraska's residents and agriculture sector rely heavily on the state's groundwater resources for irrigation and drinking water.
3. If appropriately managed, groundwater will continue to be Nebraska's best resource for resiliency against future climate change.
4. Climate change will have complex impacts on Nebraska's water, likely affecting both groundwater and surface water quantity and quality. These impacts will ripple throughout Nebraska's economy, communities, and environment.
5. With climate change, irrigation water demand will likely increase as the growing season becomes longer and the rate of evapotranspiration increases.
6. At the state level, the trends in groundwater-level changes tend to follow the trends in precipitation.
7. Drought impacts on Nebraska's groundwater and surface water may be more severe as the climate warms.

Adaptation and resilience options and opportunities

Strategy W1: Protect and restore water resource ecosystem functions and values.

Protection of existing water resources provides a proactive, cost-effective way to maintain ecosystem functions and values, including groundwater recharge, filtration, and flood storage capacity. In particular, wetlands protection is integral to this process, given the challenges of locating suitable sites for replacement wetlands that replicate their functions and values. Restoration of functions and values of degraded water resources offers the opportunity to restore groundwater recharge, filtration, and flood storage capacity while also realizing co-benefits such as habitat creation.

Example state actions

- W1-1: Review and update Natural Resource District rules to align with best practices for water resource protection from other states.
- W1-2: Ensure no net loss of wetland area.

- W1-3: Increase grant opportunities for climate change adaptation projects and prioritize the funding of projects that incorporate climate change impacts in project design and implementation.
- W1-4: Develop an assistance program to help property owners put lands into conservation easements to retain ecosystem services.
- W1-5: Provide funding and technical assistance for green infrastructure, best management practices, and nature-based adaptation.

Example local government and public power actions

- W1-6: Protect and restore lake, river, stream, and wetland buffers.
- W1-7: Protect and restore deep pools in streams for cool water aquatic life (refugia).
- W1-8: Expand water conservation education and outreach programs and materials to address audience-specific interests related to topics such as water conservation, water quality, and recreation.
- W1-9: Improve water management to sustain aquatic ecosystems.
- W1-10: Fund and enhance stream and lake quantity and quality monitoring.

Example agricultural community actions

- W1-11: Implement sustainable farming practices such as those described in Table SR 8 to improve water quality and preserve water quantity.

Example business, household, and individual actions

- W1-12: Plant native landscape species that require less irrigation (i.e. turf conversion).
- W1-13: Direct downspouts to rain gardens and/or vegetated areas so stormwater runoff is intercepted and allowed to infiltrate into the groundwater system.
- W1-14: Incorporate local knowledge into local conservation and restoration efforts.

Strategy W2: Adaptively manage groundwater

Nebraska relies heavily on its groundwater resources for agricultural irrigation and drinking water. To date, steps, including local regulation and restrictions on high-capacity wells, are helping to slow decreasing groundwater levels. Despite current human intervention to move toward a more sustainable groundwater balance, changes in high and low precipitation years will complicate efforts to reach this balance. Efforts will be required to continue conserving water, especially in dry years, and aid in the recharge of groundwater in wet years.

Example state actions

- » W2-1: Work with water compact members to develop strategic pathways for future water allocations.
- » W2-2: Develop a statewide strategy for groundwater recharge.

Example local government and public power actions

- » W2-3: NRDs adaptively manage water pumping regulations.
- » W2-4: Continue groundwater monitoring.
- » W2-5: Proactively adjust water supply management practices and programs to account for climate change impacts to both water supply availability and source water quality.
- » W2-6: Promote nature-based solutions, such as restoring riparian habitats and wetlands, to enhance groundwater recharge and improve water quality.
- » W2-7: Expand water conservation education and outreach programs and materials to address audience specific interests related to topics such as water conservation, water quality, and recreation.
- » W2-8: Adopt a citywide policy promoting water recycling for non-potable uses.

Example agricultural community actions

- » W2-9: Implement sustainable farming practices such as those described in Chapter 8 Strategy #1 to improve water quality and preserve water quantity.
- » W2-10: Reduce excess nutrients in groundwater.
- » W2-11: Enhance groundwater recharge and storage by storing excess water during wet periods.
- » W2-12: Implement water conservation measures and improve irrigation efficiency in agriculture.

Example business, household, and individual actions

- » W2-13: Conserve potable (drinking) water.
- » W2-14: Consider installing rain barrels and watering gardens with rainwater.

Strategy W3: Prepare for increased occurrences of flood and drought conditions

Major flooding and drought events represent the extreme highs and lows of water that pose threats to property, economic activity, human health and well-being, infrastructure, recreation, and more. As natural processes are exacerbated by climate change, proactive efforts to adapt to these changing processes will be critical to reducing the state's vulnerability and helping to manage resources needed in response to major events.

Example state actions

- » W3-1: Help regions improve preparation for drought.
- » W3-2: Prioritize investment in dam and levee repairs based on their potential hazard.
- » W3-3: Update floodplain mapping to account for projected increases in major flood events.

Example local government and public power actions

- W3-4: Protect and restore water resources with the potential for high functions and values related to flood and drought mitigation.
- W3-5: Promote water storage and management to hold and distribute water following large precipitation events.
- W3-6: Develop hydrologic and hydraulic models for larger communities to conduct flood risk/vulnerability assessments using projected rainfall conditions (i.e., redefine riverine flood hazard zones to match the projected expansion of flooding frequency and extent).
- W3-7: Improve public education about the risks of developing in sensitive areas.
- W3-8: Apply green infrastructure strategies and adopt green and complete street design standards.
- W3-9: Maintain and restore wetlands.
- W3-10: Require new development or redevelopment to capture and infiltrate the first 1 or 1.5 inches of rain.
- W3-11: Restrict development in areas buffering water bodies or wetlands
- W3-12: Acquire properties at risk of flooding, use the land for infiltration, and help the property owners resettle in the community.

Example agricultural community actions

- W3-13: Improve the absorptive capacity of farmland through the encouragement and cost-sharing of agricultural best management practices.

Example business, household, and individual actions

- W3-14: Improve the absorptive capacity of farmland through the encouragement and cost-sharing of agricultural best management practices.
- W3-15: Convert turf to native, drought-tolerant native species.

Energy

Key messages

1. Energy-related emissions (fossil fuel burning for electricity, transportation, heat, steam, and fertilizer production) are Nebraska's leading cause of greenhouse gas emissions.
2. Nebraskans consume energy directly (fuel and energy purchases) and indirectly (in products and services).
3. Reducing emissions can have a positive financial impact (reduced energy and fertilizer costs).
4. Nebraskans will need to consider where the most significant impacts from energy efficiency and fuel switching can be made at all levels. This includes residential (heating and cooling), commercial (heating and cooling), transportation (vehicles), business-level policy, local policy, state-level policy, and national policy.
5. Emissions reduction goals should be compatible with reliability goals.

Adaptation and resilience options and opportunities

Strategy E1: Accelerate decarbonization of Nebraska's energy systems.

Decarbonizing Nebraska's energy systems is crucial for reducing greenhouse gas emissions and mitigating climate change. Nebraska's energy consumption significantly impacts climate change primarily through burning fossil fuels, accounting for 69% of the state's total energy use. These emissions contribute to global warming and climate change. Additionally, burning fossil fuels releases air pollutants, including particulates, volatile organic compounds, and nitrogen oxides, which further degrade environmental quality. Transitioning to cleaner energy sources like wind, solar, and biofuels can lower emissions, improve air quality, and enhance public health. Additionally, decarbonization can lead to economic benefits by adopting more efficient technologies and creating new jobs in the renewable energy sector. Preparing for climate risks and extreme weather events is also essential to ensure the reliability and resilience of Nebraska's energy infrastructure.

Example state actions

- E1-1: Establish a State of Nebraska Electricity Renewable Energy Standard to support and align with existing public utility 100% clean energy goals.
- E1-2: Increase state electricity procurement to 100% renewable by 2040.
- E1-3: Adopt solar-ready and renewable-energy generation building code requirements.
- E1-4: Investigate options for establishing a Renewable Fuels Standard (RFS) for heating fuels.
- E1-5: Study the feasibility of encouraging greater utility-scale renewable energy development by reducing property taxes on new renewable energy in Nebraska.
- E1-6: Include non-energy benefits of low- and zero-emission energy generation in cost assessment requirements of public utility Integrated Resource Planning (IRP) and State of Nebraska capital planning.

- E1-7: Finance programs, incentives, policies, and research for increased capture of the significant opportunity in Nebraska for renewable energy adoption.

Example local government and public power actions

- E1-8: Update zoning codes to identify and address alternative energy systems and their use on private property.
- E1-9: Coordinate and promote separate residential and commercial Solar Group Purchase and Electrification Group Purchase campaigns to reduce the cost of solar PV, solar thermal, and heat pump adoption through volume purchasing power and district-level planning.
- E1-10: Identify and deploy the next generation of electric grid technologies (https://www.energy.gov/sites/default/files/2022-05/Next%20Generation%20Grid%20Technologies%20Report%20051222.pdf).
- E1-11: Include non-energy benefits of low- and zero-emission energy generation in cost assessment of public utility Integrated Resource Planning (IRP).
- E1-12: Explore the creation of green hydrogen or an energy efficiency utility.

Example business, household, and individual actions

- E1-13: Install solar photovoltaic (PV) or solar thermal panels at your home or business and receive a 30% federal tax credit.
- E1-14: If you don't own your home (or if your home is not suitable for solar), support solar development by subscribing to community solar or purchasing renewable energy through your utility.
- E1-15: Replace your business's or home's heating and cooling system and appliances like ranges, water heaters, and clothes dryers with energy-efficient electric options like heat pumps.

Strategy E2: Accelerate energy efficiency improvements to buildings and industrial uses and processes.

Increasing the energy efficiency of Nebraska's energy systems is vital for adapting to climate change. Energy efficiency can improve the resilience of Nebraska's energy systems during climate impacts like heat waves or extreme weather events through reduced energy demand, enhanced reliability, cost savings for reinvestment, and flexibility. Increased energy efficiency also lowers reliance on fossil fuels, reducing greenhouse gas emissions, and improving air quality. Additionally, energy efficiency can lead to cost savings for consumers and businesses, making the energy system more resilient and sustainable. Efficient energy use also supports the integration of renewable energy sources, further reducing environmental impact and enhancing the reliability of the energy infrastructure in the face of extreme weather events and other climate-related challenges.

Example state actions

- E2-1: Adopt and maintain state building codes to within one cycle of current best practices for energy efficiency.
- E2-2: Establish an Energy Efficiency Resource Standard establishing annual energy efficiency savings program goals for utilities.

- E2-3: Support the State of Nebraska agency and publicly funded projects that address deferred maintenance, energy efficiency, and alternative energy with the greatest potential for emissions reductions in the immediate future.
- E2-4: Include non-energy energy efficiency benefits in public utility Integrated Resource Planning (IRP) cost assessment requirements and State of Nebraska capital planning.
- E2-5: Expand energy efficiency programs for residential and commercial buildings.
- E2-6: Explore the development of a Nebraska Energy Saving Mortgage to provide a tiered incentive encouraging the purchase and construction of highly efficient homes. Example, State of Colorado.
- E2-7: Establish State of Nebraska Appliance Standards that set energy efficiency targets for appliances.

Example local government and public power actions

- E2-8: Adopt and maintain building codes to within one cycle of current best practices for energy efficiency.
- E2-9: Require projects receiving city financial incentives or support to be built to meet or exceed an electricity and heating renewable energy standard.
- E2-10: Develop and expand meter-based incentive programs targeted at energy efficiency.
- E2-11: Establish an energy reporting program, or Energy Benchmarking, for homes and commercial buildings, including existing private buildings, existing public buildings, and new construction.
- E2-12: Promote energy conservation and efficiency through outreach, communication, and community and public engagement.
- E2-13: Advance the deployment of energy storage projects. Example, business, household, and individual actions.
- E2-14: Conduct an energy audit on your business or home to identify energy efficiency and cost-saving improvements.
- E2-15: Implement ongoing energy efficiency changes, such as using smart thermostats, adjusting your thermostat temperature to slightly warmer in the summer and cooler in the winter, using ENERGY STAR–certified appliances, and adopting other energy efficiency strategies recommended by your utility.

Strategy E3: Strengthen the energy sector's ability to handle climate-related disruptions, adapt to supply changes, and meet rising energy demand.

Strengthening Nebraska's energy sector to handle climate-related disruptions, adapt to supply changes, and meet rising energy demand will enhance the state's resilience. Preparedness for extreme weather and investing in resilient infrastructure improvements can minimize the impact of events such as heat waves, droughts, and floods. Diversifying energy sources, increasing flexibility in energy generation, and increasing energy storage ensure reliability amid supply changes, such as the retirement of coal and nuclear plants and the rise of natural gas, wind, and solar. Combined with energy efficiency improvements, these efforts can collectively build a robust energy system that can withstand disruptions, adapt to evolving conditions, and meet future needs.

Example state actions

- E3-1: Collaborate with Nebraska Public Utilities to identify, pilot, and implement a variety of energy efficiency, load management, and distribution system operation methods to reduce peak demand.
- E3-2: Collaborate with Nebraska Public Utilities to identify, pilot, and implement a variety of backup power supplies, intelligent controls, smart analytics, microgrids, and distributed generation to better respond to disruptions.
- E3-3: Create an Energy Storage Standard establishing energy storage capacity deployment or procurement goals for utilities.
- E3-4: Include benefits of energy storage such as peak demand reduction, frequency regulation, energy arbitrage, increased resilience, reduced land use, and jobs creation in cost assessment requirements of public utility Integrated Resource Planning (IRP) and State of Nebraska capital planning.
- E3-5: Support a wide variety of energy storage ownership, application, and business models through incentives and programs.

Example local government and public power actions

- E3-6: Ensure that new or substantially modified jurisdictional electric transmission facilities are designed, built, and operated for resiliency regarding heavy precipitation and flooding, extreme temperature events, severe weather events, wildfires, and physical/cyber security threats.
- E3-7: Develop energy storage programs for all customer types to reduce peak demand, support electric grid reliability, and improve the effectiveness of solar and other renewable energy options.
- E3-8: Ensure equitable implementation of grid resilience actions by partnering with high-risk neighborhoods and non-governmental organizations to develop resilience hubs—community facilities that offer power and other services during times of need.
- E3-9: Expand district heating, cooling, and microgrids through district-level planning and a potential requirement for new large buildings to study the costs and benefits of connection.
- E3-10: Conducted a community-wide grid capacity, resilience, and conditions assessment, including recommendations identifying renewable energy capacities and potentials, including renewable energy backup.
- E3-11: Identify and prioritize solar, energy storage, and microgrid backup power projects at mission-critical community facilities.

Ecosystems

Key messages:

1. Change is driving rapid ecosystem transformations.
2. Species changes and biodiversity loss are accelerating.
3. Impacts on ecosystem services create risks and opportunities.

Adaptation and resilience options and opportunities

Strategy ES1: Enhance the resilience and adaptive capacity of ecosystems.

Ecosystem transformation refers to significant and lasting changes in an ecosystem's structure, function, and composition. Historically, this transformation has been driven by human alteration to the landscape (i.e., urbanization, industrialization, agricultural expansion), but more recently, it has been driven by climate change. Nebraska's ecosystems are experiencing and are expected to undergo significant transformations due to climate change. These changes affect the state's prairies, agricultural landscapes, wetlands, and riparian systems. This affects the state's wildlife and the migratory species that access Nebraska's landscapes on their way to critical habitats used for reproduction and overwintering. As the Nebraska Natural Legacy Project reports, much of the state's existing natural habitat and the biological diversity it supports reside on lands under private ownership.

Example state actions

- ES1-1: Increase collaboration and communication.
- ES1-2: Improve conservation programs and incentives.
- ES1-3: Focus conservation on the best opportunities (i.e., restore and conserve natural ecosystems with an emphasis on native prairies and wetlands).
- ES1-4: Promote management that is more compatible with conserving biological diversity (i.e., utilize the Resist-Accept-Direct (RAD) framework to guide adaptive ecosystem management).
- ES1-5: Maintain and expand the network of public and private conservation lands.
- ES1-6: In collaboration with the Nebraska Department of Education, seek to address important issues related to biological diversity in state education content standards—specifically, but not limited to, state science standards. Additionally, work with the Nebraska Department of Education to adopt and incorporate the Nebraska Environmental Literacy Plan. This plan seeks to develop environmentally literate students and ensure that all students, by the time they graduate high school, are knowledgeable about Nebraska's natural resources and environmental issues and are willing to act on this knowledge to help conserve our natural legacy and solve our environmental problems.
- ES1-7: Demonstrate success by establishing and promoting Natural Legacy Demonstration Sites across Nebraska.

- ES1-8: Restore grassland systems with an emphasis on controlling woody plant encroachment, particularly eastern red cedar.
- ES1-9: Support existing cooperatives, such as the Nebraska Invasive Species Project, with the intent to organize a diverse network of agencies and organizations to gather and share information about invasive species, new control measures, control efforts that are underway, distribution of invasive species, and funding issues. Collaboratively develop and widely distribute a list of all known invasive species that threaten the state's biological diversity and develop best management practices that can be used to control or reduce the spread of those species.
- ES1-10: Seek to remove or create bypass structures around dams and other impediments that restrict the natural movement of aquatic species.

Example local government and public power actions

- ES1-11: Support progress toward sustainable development.
- ES1-12: Collaborate with planning commissions, county commissions, and building associations to site new development to reduce fragmentation of existing natural communities.
- ES1-13: Identify sites conducive to greenway development and provide resources and support to help communities engage in collaborative planning to develop long-term strategies that meet conservation, economic, and recreational goals (i.e. create a GIS layer that identifies priority areas that local units of government or NGOs can use to prioritize activities such as greenway development).
- ES1-14: Support existing programs that promote the development of natural communities (e.g., prairies, wetlands, native woodlands) at schools, parks, government offices, housing developments, businesses, etc., that the public can use to learn about biological diversity.
- ES1-15: Sponsor wildlife-related events (e.g., eagle viewing days, crane celebrations, hunter breakfasts, fishing tournaments) that have recreational, educational, and entertainment value and provide community economic benefits.
- ES1-16: Work with partners, such as Cooperative Extension, to develop and conduct workshops for landowners, producers, community leaders, conservation practitioners, educators, and others on topics such as prairie conservation, at-risk species management, invasive control, forest management, aquatic resources, available cost-share programs for projects, and so on.
- ES1-17: Use multiple media outlets (e.g., television/radio, print advertisements, internet, billboards, public displays) to increase awareness and support for Nebraska's biological diversity and inform the public of progress made to conserve species and habitats.
- ES1-18: Control invasive species in natural ecosystems.

Example agricultural community actions

- ES1-19: Raise awareness about the role of farming and ranching in biological diversity conservation. Develop mentoring programs for landowners regarding ecologically sound farming and ranching practices. Create farmer-to-farmer networks where landowners can share information and help each other with projects.
- ES1-20: Develop and implement early detection and rapid response programs for invasive species, pests, and pathogens.
- ES1-21: Use and promote restoration and management techniques that utilize native, locally adapted species whenever possible. Discourage the use of nonnative species in restoration/ management projects.
- ES1-22: Discourage the placement of woody plantings and food plots within natural grassland communities, especially when it will result in increased fragmentation.

Example business, household, and individual actions

- ES1-23: Increase participation in nature-based recreation.
- ES1-24: Raise awareness about the role of urban/suburban backyards in biological diversity conservation. Develop mentoring programs for landowners regarding ecologically sound landscaping and gardening practices. Create neighbor networks where landowners can share information and help each other with projects.
- ES1-25: Use and promote restoration and management techniques that utilize native, locally adapted species whenever possible. Discourage the use of nonnative species in restoration/ management projects.

Strategy ES2: Species changes and biodiversity loss are accelerating. Facilitate species and ecosystem adaptation to climate change.

Climate change is influencing species and ecosystems by altering fundamental interactions with other species and the physical environment, leading to a cascade of impacts throughout ecosystems. Climate change is already having a significant impact on species including shifts in species distributions (i.e., shifting their distribution to higher/cooler elevations or latitudes), changes in phenology or timing of annual life-cycle events of species (i.e., shifts to breeding, hibernation, migration, or pollination), and decoupling of coevolved interactions (i.e., emergence of an insect may become out of sync with the flowering time of its host plant). In addition, climate change is expected to alter ecological processes such as fire patterns and hydrology and exacerbate a number of non-climate stressors such as habitat loss and fragmentation, pollution, and the spread of invasive species, pests, and pathogens.

Example state actions

- ES2-1: Protect and maintain a network of conservation areas thereby promoting biodiversity corridors to support species migration and adaptation. Focus on areas that offer the best opportunities to conserve the full array of biological diversity and the best chances for success as identified in the Nebraska Natural Legacy Project.
- ES2-2: Improve the quality of public lands critical to conserving biological diversity by using management approaches such as prescribed burns and grazing appropriate to local plant communities.

- ES2-3: Address major knowledge gaps regarding how fish and wildlife populations will persist in changing environments.
- ES2-4: Develop and distribute a "best management practices guide" on prescribed burning that can be used to improve the management of grasslands, woodlands, and riparian areas for biological diversity. Include information on sources of technical information, funding programs, equipment needed, and so on.
- ES2-5: Utilize an adaptive management approach in implementing adaptation strategies.
- ES2-6: Develop and distribute a "best management practices" guide on grazing that can be used to improve the management of grasslands and riparian areas for biological diversity. Include information on sources of technical information, funding programs, wildlife-friendly fencing specifications, and so on.
- ES2-7: Promote and support the development of locally based grazing cooperatives and incentive programs that can facilitate grazing of playa wetlands, small disjunct prairie sites, woodlands, and other sites with low grazing income potential.
- ES2-8: Develop an integrated water management plan for all water uses throughout the state.
- ES2-9: Strengthen existing or establish new statewide partnerships for promoting wetland, river, and stream conservation.
- ES2-10: Evaluate the impacts of new dams, additional groundwater and surface water withdrawals, channelization, and levy/dike construction on biological diversity.
- ES2-11: Collaborate with natural resource organizations and others to develop a list of preferred plant materials (e.g., trees, shrubs, grasses, forbs) that can be used in urban and rural settings with little threat to biological diversity. Develop guidelines that will help ensure that potentially invasive species do not spread to natural communities.
- ES2-12: Develop guidelines for applying herbicides and using biocontrols targeted at invasive species so impacts on biological diversity are minimized.
- ES2-13: Initiate a public outreach campaign on the impacts of invasive species on biological diversity.
- ES2-14: Incentivizes private landowners to maintain natural habitats and cooperatively manage large blocks of habitat as complexes that conserve biological diversity.
- ES2-15: Work with agricultural and conservation partners to prioritize the installation of conservation buffers, conservation tillage practices, and so on, within watersheds where the benefits to biological diversity would be highest.
- ES2-16: Conduct inventories to identify additional Biologically Unique Landscapes that contain high-quality examples of ecological communities and populations of at-risk species.
- ES2-17: Continue inventory of the currently described Biologically Unique Landscapes to better identify areas within them where multiple conservation objectives can be met.
- ES2-18: Provide information to conservation planners and practitioners to help focus conservation actions. Decision-support tools (e.g., GIS data, models) may be used to evaluate options.
- ES2-19: Work to ensure that high-quality occurrences of all terrestrial and aquatic community types in Nebraska are protected and managed for the long term.
- ES2-20: Work to ensure that occurrences of viable populations of at-risk species are under long-term protection and management.
- ES2-21: Monitor changing conditions and population fluctuations to adapt management efforts better as needed.
- ES2-22: Start a natural areas program (modeled after successful programs in other states) that identifies and protects biologically unique sites that are managed to perpetuate Nebraska's biological diversity.
- ES2-23: Through conservation easements, facilitate the long-term protection of biologically important lands enrolled in short-term conservation programs (e.g., the Conservation Reserve Program, and private lands programs).

- ES2-24: Seek opportunities to improve management on publicly owned lands not part of the conservation network (e.g., Bureau of Education Land Fund holdings) to increase benefits to biological diversity.

Example local government and public power actions

- ES2-25: Consider the impacts of land-use change on habitat loss and fragmentation.
- ES2-26: Identify and seek to overcome barriers that limit the ability of managers and private individuals to conduct prescribed burning on private and public lands.
- ES2-27: Seek to maintain or restore the natural hydrology of rivers, streams, and wetlands to sustain biological diversity and ecosystem function. Accomplish this through the use of voluntary incentives, sound bioengineering solutions, and through collaborative decision-making.
- ES2-28: Promote land acquisition policies founded on willing seller/willing buyer principles, maintain the local tax base, and provide equitable compensation to landowners.

Example agricultural community actions

- ES2-29: Promote management that is more compatible with conserving biological diversity. Collaborate with farmers, ranchers, and conservation organizations to identify opportunities and share responsibility for conserving biological diversity.
- ES2-30: For select grasslands, evaluate the use of patch-burn grazing and other grazing systems that combine the interaction of fire and grazing to mimic presettlement disturbances. The timing, intensity, and duration of any fire-grazing system needs to be carefully planned and implemented. Biologists and ranchers should carefully coordinate management strategies.
- ES2-31: For woodland and forest systems, particularly in western Nebraska, use mechanical tree thinning and prescribed fire to increase the system's resiliency to wildfires.
- ES2-32: Use locally adapted native seed sources for pasture and rangeland seedings.
- ES2-33: Utilize livestock grazing/haying systems with built-in drought management contingencies (e.g., grass banking).
- ES2-34: Implement diverse haying strategies (e.g., on wet meadows) that stagger timing and height of cutting, promote increased plant and animal diversity, and avoid peak nesting periods for grassland birds.
- ES2-35: Implement wildlife-friendly conservation buffers, grassed waterways, sediment traps on lands adjacent to wetlands, rivers, streams, reservoirs, and lakes to prevent siltation and protect water quality.
- ES2-36: Implement water conservation measures such as more water-efficient irrigation systems, xeriscape landscaping, and water-conserving appliances.
- ES2-37: Utilize integrated pest management (e.g., non-chemical controls such as biocontrol, tillage, and spot spraying) to minimize impacts on biological diversity.
- ES2-38: Implement conservation practices such as filter strips, grassed waterways, sediment control basins, and grassed buffers to minimize the effects of fertilizers and pesticides on wetlands, streams, rivers, and reservoirs.

- ES2-39: Implement management practices that limit the impacts of nutrients, sedimentation, bacteria, and pesticides to help protect water quality. Examples include, among others, nutrient application on cropland, sediment control on construction sites, incentives for organic and low-chemical farming.

Example business, household, and individual actions

- ES2-40: Protect additional (private) lands through acquisition and conservation easements and by implementing voluntary and incentive-based conservation actions on private lands.
- ES2-41: Learn more about using fire to control woody plant invasion or revitalize grasslands by participating in a workshop hosted by the Prescribed Burn Task Force and Great Plains Fire Learning Network.
- ES2-42: Consult with species experts and perform pre-burn evaluations to minimize impacts on species that may lack the ability to recolonize a site following burning.
- ES2-43: Assess possible risks of invasive species spread from commercialized wildlife operations and take appropriate preventative measures.
- ES2-44: Use restoration and management techniques that utilize native, locally adapted species whenever possible.

Strategy ES3: Recognize the value of ecosystem services in promoting climate adaptation.

Ecosystem-based adaptation is a strategy for adapting to climate change that harnesses existing nature-based solutions and ecosystem services such as providing clean water, local air and climate regulation, and risk and disease protection. By addressing increasing pressures on ecosystems, the State of Nebraska will increase its resilience to climate change, benefiting economic development, urban and rural communities, and fish and wildlife populations.

Example state actions

- ES3-1: Promote the value of naturally meandering rivers and streams, the role of floodplains as habitat, and the need to maintain or closely simulate the natural hydrograph of rivers and streams to benefit biological diversity.
- ES3-2: Seek to maintain or restore the natural hydrology of rivers, streams, and wetlands to sustain biological diversity and ecosystem function. Accomplish this using voluntary incentives, sound bioengineering solutions, and collaborative decision-making.
- ES3-3: Facilitate cross-sectoral collaboration and develop integrated policies and frameworks.

Example local government and public power actions

- » ES3-4: Increase awareness and understanding of the benefits of nature-based solutions.
- » ES3-5: Advocate for increased adaptation funding and promote innovative financing mechanisms.
- » ES3-6: Prioritize capital improvement projects that provide stacked benefits/ecosystem services to the community.
- » ES3-7: Plant native vegetation within the road right-of-way to provide stormwater management and pollinator habitat.
- » ES3-8: Increase tree canopy in the urban landscape.
- » ES3-9: Promote ecotourism/recreational opportunities.

Example agricultural community actions

- » ES3-10: Improve soil health to address water and nutrient cycling, reduce potential climate impacts, and confer broader ecosystem services.
- » ES3-11: Install prairie strips—strategically placed native prairie plantings in crop fields—to improve soil health and water quality and provide critical habitat for wildlife and pollinators.

Example business, household, and individual actions

- » ES3-12: Convert turf/lawns to native vegetation to provide stormwater management and pollinator habitat.

Agriculture

Key messages

1. Observed and projected changes to temperature and precipitation trends have the potential to significantly impact crop and rangeland productivity, necessitating adaptation efforts.
2. The most important potential impacts on agriculture in Nebraska include increasing rainfall variability, shifts to rainfall seasonality, increases in drought intensity, increased temperatures, decreased days with very cold temperatures, increased wildfires, and increased hail frequency and intensity. Such impacts have the potential to significantly reduce field crops and rangeland productivity.
3. Field crop adaptation options include improvements to plant genetics, management shifts to crops grown and/or cropping systems, and soil and water management shifts.
4. Rangeland adaptation options include heterogeneity-based rangeland management (e.g., pyric herbivory) and shifts to the kind (e.g., species) and class of animal to better adapt to expected challenges.

Adaptation and resilience options and opportunities

Strategy A1: Promote sustainable farming practices, such as soil conservation, water management, and integrated pest management, to ensure long-term resilience in Nebraska's agricultural systems.

Example state actions

- A1-1: Support the implementation of agricultural best management practices (BMPs) through grants and cost-sharing opportunities.

Example local government and public power actions

- A1-2: Support the implementation of agricultural BMPs through regulatory and permitting alignment and cost-sharing opportunities.

Example agricultural community actions

- A1-3: Increase implementation of soil management practices associated with improving soil health. Practices such as conservation tillage, cover crops, perennial crops, and crop rotation are known to improve water retention, reduce runoff, and potentially decrease the need for fertilizer inputs and herbicide use. Soil health practices can potentially buffer negative climate impacts in both flooding and drought conditions.
- A1-4: Prioritize residue management practices that armor soil throughout the year for erosion prevention.
- A1-5: Shift to perennial crops that provide soil protection year-round.
- A1-6: Implement conservation irrigation efforts, including shifts to irrigation technologies such as methods of application and scheduling of application, shifts to crops grown, and improved crop genetics for water use.
- A1-7: Optimize irrigation resources.
- A1-8: Install on-farm drainage systems, such as retention ponds or drainage ditches that can help manage excess water and prevent flooding.
- A1-9: Use cattle exclusions (i.e., fencing) and develop alternative water supply systems such as off-takes from natural systems into watering areas.
- A1-10: Efficient irrigation techniques, such as drip irrigation and soil moisture sensors, can help farmers manage water use more effectively, reducing the impact of higher water demands.
- A1-11: The risk of increased pests necessitates best management practices such as scouting and timely pest management, which could interfere with the vernalization requirements of cool-season crops.

Strategy A2: Maintain field crop productivity into the future by implementing crop diversification practices and transitioning to climate-resilient crop systems and agricultural practices.

Variability in precipitation patterns and annual and seasonal shifts in temperature are causing heat and water stress, which will impact future corn and soybean yields. Estimates of crop productivity in the future project yield decline, with some research projecting less biophysically suitable conditions for corn and soybean by the end of the 21st century without further adaptation efforts (Burchfield, 2022). Impacts on wheat yields are mixed. Estimates of crop productivity project yield declines, while others suggest that wheat production could shift toward cooler conditions, leading to the potential for an increase in wheat acreage in Nebraska.

Example state actions

- A2-1: Support research, extension services, and policies to facilitate the development and adoption of climate-resilient crop genetics, including varieties that are heat-tolerant; resistant to drought; less vulnerable to wind and hail damage, pests and diseases, and waterlogging; have shorter growing cycles; and use nitrogen and phosphorus more efficiently.
- A2-2: Provide reliable support via infrastructure, markets, knowledge, equipment, and more. Such needs present significant challenges for producers and potential new business opportunities. Producers in the region note current time and resource limitations as barriers to shifting which crops are grown (Kasu et al., 2019).

Example agricultural community actions

- A2-3: Conduct participatory breeding programs where farmers collaborate in testing and selecting the most resilient varieties for their areas.
- A2-4: Incorporate genes from wild relatives of corn and soybeans to introduce natural resilience to a broader range of climate stresses.
- A2-5: Identify crops that may be more biophysically adapted to be incorporated into future cropping systems (i.e., a recent report projecting the potential for crops grown in Kansas by 2050 found opportunities associated with a shift from crops with lower water demand, such as planting sorghum instead of corn, millet instead of soybean, and rye or oats instead of wheat [Suttles et al., 2024]).
- A2-6: Shifting planting timing and/or planting shorter or longer season varieties to accommodate for shifts in rain (UNL, n.d.).
- A2-7: Diversifying crops could avoid summer water-related stress and damage.
- A2-8: Diversify crops and minimize summer annual crops; use more drought- and heat-tolerant varieties of corn, soy, and wheat.
- A2-9: Including more winter annual or cool-season crops in rotation optimizes rainfall utilization: the main crop is harvested before summer drought, and increased use of different types of crops diversifies the risk of rainfall variability.
- A2-10: Growing a variety of crops, especially those tolerant to waterlogged conditions, can help farmers spread risk and reduce the overall impact of extreme rainfall on their operations.
- A2-11: A longer growing season presents expanded opportunities for cover cropping, relay cropping, and perennial grain or forage crops, as well as the potential for increased livestock integration on cropland. Utilize tools such as advances in plant breeding and crop and climate models to support optimizing such cropping systems.
- A2-12: Shift planting timing by planting shorter season crops or alternative crops could avoid crop water stress with more variable rainfall.
- A2-13: Reduce seeding rates (UNL, n.d.).
- A2-14: More frequent applications of inputs to reduce losses (i.e., split application of nitrogen) (UNL, n.d.).

Strategy A3: Maintain rangeland productivity into the future by implementing heterogeneity-based rangeland management (HRM), which is a conservation and land management approach that emphasizes maintaining and promoting variability in vegetation structure, composition, and function across rangelands.

Example state actions

- A3-1: Lower stocking rates to accommodate fluctuations in streamflow and water availability.
- A3-2: Consider lowering stocking rates to accommodate increasing aridity and subsequent declines in forage production across the state.
- A3-3: Woody plant encroachment into grasslands significantly threatens rangeland livestock production, specifically in highly productive grassland ecosystems like the tallgrass prairie (Engle et al., 2008).
- A3-4: Develop and distribute a "best management practices" guide on grazing that can be used to improve the management of grasslands and riparian areas for biological diversity. Include information on sources of technical information, funding programs, and wildlife-friendly fencing specifications (Schneider et al., 2011).

Example local government and public power actions

- A3-5: Increase the use and frequency of prescribed fire to improve forage conditions and utilize grazing management practices that capitalize on vegetation recovery (and high forage quality) immediately following a fire.

Example agricultural community actions

- A3-6: Shifts to the kind (i.e., species) and class of animal to better adapt to expected challenges (i.e., consider the adoption of bison as a potential alternative to traditional livestock to cope with the effects of climate change).
- A3-7: Altering the class of animal (e.g., moving from cow-calf to stocker steers) or increasing the diversity of animal kinds and classes in a livestock operation to better balance the risk and uncertainty of future climate change effects.
- A3-8: Change the kind and class of livestock to capitalize on changes to the forage base.
- A3-9: Consider changing the kind and class of animal to those better suited to changing aridity and humidity.
- A3-10: Utilize grazing systems that capitalize on increased forage quality following fire (pyric herbivory) but at moderate (i.e., 20–25% harvest use efficiency) stocking rates to avoid steep declines in range condition and heterogeneity.
- A3-11: Reduce restrictions to animal movement and increase the total available area to overcome increased spatial variability in water resources over time.
- A3-12: Change animal grazing timing, kin and class of animal, or multispecies grazing to capitalize on changing forage quality in time.
- A3-13: Promote landscape heterogeneity through managed disturbances.

- A3-14: Improved ventilation and cooling systems, such as fans, sprinklers, and shade structures, can help livestock cope with higher nighttime temperatures and reduce heat stress.
- A3-15: Develop and maintain permanent or semi-permanent water facilities (e.g., water tanks) to meet their livestock's basic physiological requirements during drought.
- A3-16: Promote and support diverse grazing/haying systems on private and public lands that enhance biological diversity and sustain natural communities. Initiate research that evaluates the effectiveness and profitability of biological diversity-friendly grazing/haying systems (e.g., reduced stocking rates, rotational systems) (NE Natural Legacy Project, 2011).
- A3-17: Promote and support the development of locally based grazing cooperatives and incentive programs that can facilitate grazing of playa wetlands, small disjunct prairie sites, woodlands, and other sites with low grazing income potential (Schneider et al., 2011).
- A3-18: Support diverse haying strategies (e.g., on wet meadows) that stagger timing and height of cutting, promote increased plant and animal diversity, and avoid peak nesting periods for grassland birds (Schneider et al., 2011).
- A3-19: Promote the use and availability of locally adapted native seed sources for pasture and rangeland seedings (Schneider et al., 2011).
- A3-20: Promote livestock grazing/haying systems with built-in drought management contingencies (e.g., grass banking).

Strategy A4: Enhance the agricultural community's resilience to climate change by increasing access to financial resources, technical support, and innovative solutions.

Example state actions

- A4-1: Seek and promote economic alternatives that help reduce further conversion of important rangelands and pastures to cropland (Schneider et al., 2011).
- A4-2: Seek and promote economic alternatives that help reduce further conversion of important rangelands and pastures to cropland.
- A4-3: Establish and expand funding programs (e.g., grants, low-interest loans, and subsidies) to help farmers adopt climate-smart practices and technologies.
- A4-4: Develop crop insurance programs tailored to address risks associated with climate variability (e.g., drought, floods, and temperature extremes).
- A4-5: Facilitate access to carbon markets and incentive programs for practices that sequester carbon and reduce greenhouse gas emissions.
- A4-6: Expand agricultural extension services with expertise in climate adaptation, including tailored solutions for local conditions.
- A4-7: Focus on equitable access to financial and technical resources, especially for marginalized communities within the agricultural sector.

Example local government and public power actions

- A4-8: Advocate for policies prioritizing climate adaptation funding for smallholder and underserved farmers.

Example agricultural community actions

- A4-9: Ensure the supply of cover crop seed meets the increasing demand under future climate conditions.
- A4-10: Support research and demonstration projects to showcase best practices and emerging technologies.
- A4-11: Develop and promote tools like decision-support software, weather prediction apps, and precision agriculture technologies to guide climate-adaptive farming.
- A4-12: Offer training on using data-driven technologies to optimize yields while conserving resources.
- A4-13: Participate in peer-learning opportunities and farmer-led innovation networks to foster knowledge-sharing and collaboration.

Human Health

Key messages

1. Climate change is associated with adverse health outcomes in Nebraska, including heat-related morbidity and mortality during heat waves, physical and mental health impacts during drought and flood events, and increased risk of certain infectious diseases like West Nile virus due to changing temperature and precipitation patterns.
2. Some Nebraskans are more impacted by the health impacts associated with climate change than others.
3. Adaptation and mitigation efforts addressing the health impacts of climate change can protect Nebraskans.

Adaptation and resilience options and opportunities

Strategy H1: Mitigate the impacts of climate change on public health.

Implementing measures to adapt to and mitigate the health impacts of climate change can protect Nebraskans. This includes developing climate action and resilience plans that enhance emergency preparedness, improve air quality, set emission reduction targets, and enhance public health initiatives.

Example state actions

- H1-1: Identify, prioritize, and incorporate climate change mitigation and adaptation strategies into health planning and regulations. Include actions that promote healthy living and reduce greenhouse gas emissions and toxic pollutants.
- H1-2: Consider climate resilience, health benefits, future climate, and cumulative impacts, including historical burdens, in cost assessment requirements for the State of Nebraska planning and investment decisions.
- H1-3: Incorporate current information about climate change projections and impacts into state and local emergency planning efforts and emphasize climate-related disaster preparedness in emergency response plans, including the Emergency Operations Plan, Behavioral Health All-Hazards Disaster Response and Recovery Plan, and Department of Health and Human Services Disaster Plan.
- H1-4: Collaborate with local governments to help incorporate healthy living strategies into land-use planning and regulations. These include development that concentrates growth in compact, walkable urban centers to avoid sprawl.
- H1-5: Increase public health capacity, funding, collaboration, and adaptation resources for local public health departments, local governments, and agencies supporting Nebraska's vulnerable populations.
- H1-6: Work with partner agencies on policies to improve and protect air quality and water security based on health and environmental data, implement health-based standards, and remain proactive in identifying emerging contaminants, vectors, and diseases of concern related to climate change.

- H1-7: Implement enhanced surveillance of vectors and related diseases.
- H1-8: Implement better surveillance for injury and other flood-related health outcomes, including increased syndromic surveillance for flood events.
- H1-9: Improve our understanding of human health impacts of climate change and extreme weather through continued interdisciplinary studies at the University of Nebraska and with agency scientists. Further work needs to focus on better understanding the risks, identifying the areas and populations at greatest risk, and exploring new methods to address the identified risks.

Example local government and public power actions

- H1-10: Partner with area agencies to develop a Natural Disaster Response, Relief, and Recovery Plan. Focus on communications, property adaptation and resiliency, housing needs, risk assessment, land acquisition, and critical infrastructure resilience. Identify the location of critical facilities, including hospitals, medical service providers, senior homes, childcare facilities, shelters, major and alternate transportation routes, public transit facilities, and locations where hazardous chemicals are used or stored.
- H1-11: Improve health and transportation system resilience to floods using updated NOAA Atlas 14 precipitation projections.
- H1-12: Conduct a needs assessment of accessible community centers for extreme weather or other emergencies. Create a development improvement plan, if needed.
- H1-13: Develop post-flood vector control plans.

Example business, household, and individual actions

- H1-14: Put together an emergency preparedness kit for your household or business.
- H1-15: Prepare your home for the extremes. Understand the risk of extreme weather, extreme temperatures, flooding, or wildfire, and take action to safeguard your home or business.

Strategy H2: Build resilience in climate-vulnerable communities.

Climate change disproportionately impacts vulnerable communities, including people of color, Indigenous populations, low-income groups, and those with chronic health conditions. Addressing their specific needs reduces health disparities, promotes equity, and improves outcomes by mitigating climate-related health issues like heat illnesses, respiratory conditions, and mental health challenges. Strengthening infrastructure and emergency response systems in these communities enhances preparedness for extreme weather, reducing injury, illness, and death risks.

Example state actions

- H2-1: Collaborate with local health departments and communities facing climate and health inequities to develop a shared vision and action plan for protecting health equity and well-being in a changing climate.
- H2-2: Actively engage with priority communities in a coordinated and well-resourced way so underrepresented voices are centered in the development of climate policies, programs, and public investments
- H2-3: Improve wildfire smoke guidance for schools, children, and other vulnerable populations, including low-income populations, communities of color, and tribal communities.

- H2-4: Encourage the development of climate vulnerability assessment and action plans in communities and cities across the state
- H2-5: Enhance the ability of local organizations to understand climate risks and reach vulnerable populations.
- H2-6: Increase air quality monitoring, particularly in rural communities.
- H2-7: Set up temporary respiratory health clinics or expand telehealth services in areas affected by wildfires.
- H2-8: Develop community mental health programs and peer support networks in agricultural communities.

Example local government and public power actions

- H2-9: Improve weatherization and energy efficiency in under-resourced and vulnerable communities.
- H2-10: Establish heating and cooling centers in under-resourced and vulnerable communities, supported by renewable energy generation and battery backups.
- H2-11: Install and maintain additional shade structures, tree canopy, water features, and drinking water stations in public spaces. Target early adoption for areas identified as having high potential for urban heat island impacts, particularly within under-resourced and vulnerable residential neighborhoods.

Strategy H3: Implement public health initiatives that educate Nebraskans on the impacts of climate change and the health benefits of adaptation and mitigation efforts.

Educating the public raises awareness about the specific health risks associated with climate change, such as heat-related illnesses, respiratory conditions, and vector-borne diseases, enabling individuals to take proactive measures to protect themselves. Meanwhile, understanding the health benefits of adaptation and mitigation efforts, such as improved air quality, reduced heat exposure, and enhanced mental health, motivates individuals and communities to participate in and support these efforts.

Example state actions

- H3-1: Improve education and messaging regarding Nebraska's priority climate impact risks and actions to protect health, especially for populations with greater vulnerability and risk.
- H3-2: Convene an expert workgroup to assess the state's existing climate, health education, and communication capacity. Then, establish a communication protocol that includes best practices for communicating climate and health risks, vulnerabilities, and adaptation opportunities, with attention paid to impacts on underserved or overburdened communities.
- H3-3: Expand training and education of health and social services providers, including mental health agencies, to build capacity to respond appropriately to human health risks of climate change.
- H3-4: Educate other sectors of state government about public health climate change impacts and adaptation.

Example local government and public power actions

- H3-5: Provide vulnerable populations with information on what they need to know and how to prepare for and address the risks of climate change.
- H3-6: Promote indoor air quality improvements, including use of air purifiers and proper ventilation.
- H3-7: Engage and motivate citizens and organizations to take action to build resilient communities.
- H3-8: Establish an Adopt-a-Neighbor campaign, or "neighborhood resilience watch," to create neighborhood-level support for vulnerable individuals during extreme weather events and emergencies.

Communities and the Built Environment

Key messages

1. Nebraska communities have faced an increased likelihood of extreme weather and climate events, leading to longer durations, broader geographic impacts, higher costs, and deeper social consequences.
2. Nebraska's urban and rural areas are at heightened risk of extreme future weather and climate events and increased physical and social vulnerabilities.
3. To address these challenges, key strategies for reducing the potential risks of climate change include effective land-use planning, sound natural system preservation, essential infrastructure improvements, ongoing public engagement, and regional cooperation.

Adaptation and resilience options and opportunities

Strategy C1: Enhance Nebraska's infrastructure resilience.

Strengthening roads, bridges, and rail systems can ensure reliable access to emergency services and supply chains during floods or severe storms while modernizing water systems can safeguard water quality and availability in the event of droughts or infrastructure damage. Similarly, upgrading energy grids to withstand extreme heat, ice storms, and high winds can prevent widespread power outages, critical for maintaining public safety, healthcare, and economic stability. By proactively investing in resilient infrastructure, Nebraska communities can reduce recovery costs, protect vital resources, and build a foundation for sustainable growth in an era of climate uncertainty.

Example state actions

- C1-1: Develop a Climate Mitigation and Resilience Plan for the State of Nebraska.
- C1-2: Require consideration of climate risks, response strategies, and adaptation standards in capital planning, including the site selection, design, and construction of state-funded infrastructure projects.
- C1-3: Require incorporation of climate impacts and response strategies in the state's long-range transportation plans; mode-specific plans for highways, rail, aviation, and ferries; and regional transportation plans.
- C1-4: Develop transportation design and engineering guidance to minimize climate change risks.
- C1-5: Advance the adoption and enforcement of progressive building codes and design standards to reduce the vulnerability of structures to climate-related hazards.
- C1-6: Adopt regulatory and incentive programs to encourage state, tribal, and local transit organizations, public works departments, utilities, and other partners to demonstrate awareness of infrastructure and system climate risk vulnerabilities and implement resilience measures.

- C1-7: Identify existing or establish new Nebraska-specific tools to share with local governments, state and tribal agencies, and local communities to help them understand key vulnerabilities to climate impacts and what actions can be taken.

Example local government and public power actions

- C1-8: Integrate climate change into county, municipal, and public power district planning documents and initiatives to help guide local actions.
- C1-9: Evaluate the vulnerability of critical energy and communication infrastructure to the impacts of climate change, including risks of damage and the potential for disruptions and outages from flooding, extreme heat, wildfires, erosion, and extreme weather events.
- C1-10: Evaluate the vulnerability of critical transportation infrastructure and integrate climate adaptation and resilience principles into design, construction, and operation.
- C1-11: Improve or enhance the permitting of infrastructure projects with established climate resilience and mitigation guidance and standards.
- C1-12: Update stormwater design standards to address expected changes in precipitation, focus on low-impact development techniques, address flash flooding, and preserve natural streams and wetlands to reduce flood risks and improve storage during extreme weather events.
- C1-13: Create and implement a plan to conserve and protect floodplains, reducing development impact. Focus on preserving floodplains and restoring native habitats.
- C1-14: Establish a program for acquiring residential properties and local businesses that repeatedly suffer flood damage.

Strategy C2: Promote climate-informed land-use planning.

Integrating climate projections into land-use planning is essential for strengthening community resilience across Nebraska. Communities can develop effective mitigation strategies by assessing localized climate impacts and identifying vulnerable areas—such as floodplains, drought-prone regions, and zones at risk of extreme weather. These include updating zoning regulations to limit development in high-risk areas, implementing green infrastructure to manage stormwater, and revising building codes to ensure structures withstand extreme conditions. Using climate data in planning helps protect residents, safeguard infrastructure, reduce economic losses, and promote sustainable development, ensuring Nebraska is better prepared for future challenges.

Example state actions

- C2-1: Develop specific and actionable guidelines and technical assistance to local communities on sustainable, resilient, and equitable land-use and community development planning that explicitly considers climate change impacts and resilience.
- C2-2: Evaluate and propose revisions of laws and rules that govern land use and other programs to effectively address resilience to climate change impacts.
- C2-3: Review, revise, and enhance building and site design standards in flood and wildfire hazard zones to improve resilience.
- C2-4: Provide outreach and education to local governments on opportunities to reduce risks from climate change in their communities via updates and changes to local land-use ordinances.

Example local government and public power actions

- » C2-5: Identify and address land use and infrastructure creating disproportionate risks for minority and low-income communities.
- » C2-6: Incorporate climate risk reduction strategies into the community's comprehensive plan, watershed plan, hazard mitigation plan, emergency management plan, or program operational guidance materials.
- » C2-7: Avoid development in highly vulnerable areas and promote sustainable development in appropriate, less vulnerable areas. Adopt zoning changes or special overlay districts to designate high-risk areas of flooding or wildfires.
- » C2-8: Implement the transfer of development rights or other incentives to enable developers to increase densities on low flood-risk parcels while keeping flood-prone areas undeveloped.
- » C2-9: Facilitate informational events and resources to educate residents and businesses on topics related to sustainability and resilience.
- » C2-10: Implement urban tree canopy and forest management plans and practices to retain biodiversity, resilience, and ecosystem function and services.
- » C2-11: Ensure that facilities that serve vulnerable populations are resilient to climate hazards and have established best practices for responding to emergencies such as flooding, power outages, and extreme heat.
- » C2-12: Connect with existing community groups and facilitate the creation of new ones to focus on resiliency regarding extreme weather events, safety in outdoor recreation, and environmentally themed community involvement activities.

Strategy C3: Increase the resilience of Nebraska communities by fostering greater self-reliance.

Implementing initiatives that promote sustainable food systems, regenerative agriculture, green industries, and local economic development can significantly enhance the resilience of Nebraska communities. Supporting local food production, renewable energy projects, and environmentally responsible businesses reduces dependence on external resources, improves food security, and strengthens self-reliance. These efforts also benefit public health by reducing pollution, increasing access to nutritious food, and promoting cleaner, more efficient systems. By creating jobs and stimulating local economies, such initiatives build stronger, healthier, and more adaptable communities while fostering long-term environmental and economic sustainability.

Example state actions

- » C3-1: Develop a Nebraska Green Job Youth Corps program that prioritizes workforce development and economic diversification while providing temporary work and training opportunities for young adults in natural resource management, resilient agricultural development, conservation, renewable energy, or other sustainability professions.
- » C3-2: Conduct a resilient-economy development assessment. Identify the economic potential and entrepreneurial and job development opportunities derived from adaptation, mitigation, and resilience actions in the Nebraska economy. Specifically, scenarios for potential impacts on low/moderate income and other vulnerable populations should be evaluated.

- C3-3: Working with the University of Nebraska system, identify key opportunities for green-technology-led economic development, prioritize areas that assist with climate change transitions and mitigation, and institute seed-granting opportunities and research capacity-building efforts to grow the state's university expertise and competitiveness.
- C3-4: Establish a Nebraska Green Tech and Business Incubator to support the establishment of innovative energy and sustainability-driven businesses within Nebraska.
- C3-5: Establish a Nebraska Green Bank to support resilient economic development. See Inflation Reduction Act funding and Federal Green Bank for resources.
- C3-6: Promote local and community-based agriculture throughout Nebraska to reduce transportation needs and increase food access, especially in underserved communities.
- C3-7: Establish or expand an Emerging Farmer Program and similar programs to support farmers and agricultural/food entrepreneurs, with particular attention to regenerative practices and advancing inclusion and equity.
- C3-8: Establish consortiums to hold round-table discussions with large employers and industries key to the Nebraska economy, as well as important emerging sectors, to understand potential short-, near-, and long-term impacts to employment sector resilience and coordinate in identifying resilience actions.

Example local government and public power actions

- C3-9: Ensure key business infrastructure is recognized in the community's general hazard mitigation and emergency response plans.
- C3-10: Focus community business development efforts on businesses with lower impacts on natural resources and promote green job creation.
- C3-11: Consider climate change–related risks to local supply chains in implementing the community's economic development strategy.
- C3-12: Collaborate with partners to hold round-table discussions with large employers and industries key to the community's economy and resident employment to understand potential short-, near-, and long-term impacts to employment sector resilience and coordinate in identifying resilience actions.
- C3-13: Revise zoning ordinances to remove barriers to urban agriculture: yard and rooftop food production, beekeeping, front-yard gardens, edible landscaping, and foraging. Examine and pursue other policy levers to increase food production within the community. Utilize available and appropriate parks and recreation lands for urban farming and food production.
- C3-14: Review/update code to provide incentives for multi-unit buildings and developments/subdivisions and commercial developers to preserve topsoil, use finished compost for soil amendment, and provide space for backyard or community gardens.
- C3-15: Plant fruit and nut trees in appropriate city-owned properties and rights-of-way throughout the city. Explore partnerships with local organizations to collect and distribute fruit and nuts from planted trees.

Example business, household, and individual actions

- C3-16: Access information on sustainable business practices through resources like **MIT**, **the University of New Hampshire**, or the **Green Business Benchmark**.
- C3-17: Create a **Disaster Preparedness Plan** or **Preparedness Toolkit** for your business.
- C3-18: Start a vegetable garden in your yard.
- C3-19: See if there is a **community garden** near you, or work with others to start a community garden so you can grow your own food.
- C3-20: Plant fruit or nut trees or shrubs on your property that are well suited for **the hardiness zone**.

Web resources

- https://mitsloan.mit.edu/sites/default/files/2022-06/MITSloan-SustainabilityArticlePublication-F.pdf
- https://open.umn.edu/opentextbooks/textbooks/142
- https://www.greenbusinessbenchmark.com/
- https://www.lisc.org/our-resources/resource/climate-change-preparedness-toolkit-business-development-organizations/
- https://www.lisc.org/our-resources/resource/climate-change-preparedness-toolkit-business-development-organizations/https://www.communitygarden.org/garden
- https://www.arborday.org/shopping/trees/treewizard/getzip.cfm

Indigenous Peoples

Key messages

1. Weather and climate impacts are disproportionately strong in Indigenous communities.
2. Adaptation work is taking place locally with Tribal-led efforts.
3. Self-determination, recognition of rights and sovereignty, and the ability to reclaim and/or reimagine culture are keys to success.

Adaptation and resilience options and opportunities

Strategy I1: Promote self-determination and sovereignty.

Promoting Native American community self-determination and sovereignty strengthens both Tribal and state resilience by fostering sustainable land stewardship and cultural preservation. Supporting Indigenous communities in reclaiming and managing their lands, recognizing their rights, and enabling self-governance empowers Tribes to implement traditional ecological knowledge and practices that enhance environmental resilience. These efforts improve the state's ability to address climate challenges while preserving biodiversity and cultural heritage. Collaborative partnerships with Tribal nations also build mutual trust and shared capacity, creating a more unified and adaptive approach to resilience that benefits the entire state

Example state actions

- I1-1: Establish mechanisms to empower Indigenous communities and organizations to participate in appropriate state agency processes.
- I1-2: Support Indigenous communities in developing their climate adaptation plans, tailored to their specific needs and priorities, based on their traditional knowledge and cultural practices.
- I1-3: Advocate for and support secure land tenure for Indigenous communities, recognizing their role as stewards of critical ecosystems and ensuring their ability to manage land sustainably in the face of climate change.
- I1-4: Provide technical assistance, funding, and training opportunities to Indigenous communities to build capacity for climate adaptation planning and implementation.
- I1-5: Collaborate with Indigenous communities to identify and support strategies to protect and maintain cultural heritage sites, practices, and traditional food sources threatened by climate change across Nebraska.

Example tribal government actions

- I1-6: Develop a community climate adaptation and mitigation plan. Include a focus on energy and food sovereignty.
- I1-7: Invest in training and education for Tribal members, including youth, to build capacity in areas like climate science, environmental management, and policy advocacy.

- I1-8: Actively participate in state and federal decision-making processes related to climate change, ensuring Tribal interests are represented and respected.
- I1-9: Advocate for policies that protect Tribal lands and ensure access to necessary resources for adaptation efforts, such as water rights and funding for climate resilience projects.
- I1-10: Share knowledge and best practices with other Tribes facing similar climate challenges, creating a network of support and collaboration.

Strategy I2: Integrate Indigenous knowledge systems in planning.

Integrating Indigenous knowledge systems into climate resilience planning enhances a state's ability to adapt to and mitigate climate impacts. Developed over generations, Indigenous knowledge offers sustainable resource management practices, improved risk assessment, and locally relevant adaptation strategies. Incorporating these insights supports environmental sustainability, preserves cultural heritage, and fosters equitable policies that respect Indigenous rights and priorities. Engaging Indigenous communities in planning ensures inclusive and ethical decision-making, creating climate strategies that benefit both the environment and the diverse communities it sustains.

Example state actions

- I2-1: Establish formal consultation processes with Indigenous communities to gather knowledge about local ecosystems, climate patterns, and adaptation strategies for inclusion in state planning and programs.
- I2-2: Facilitate workshops and dialogues to share scientific knowledge with Indigenous communities and vice versa.
- I2-3: Empower and support Indigenous communities to lead research projects focused on their traditional knowledge and provide a venue for sharing the research findings with other communities throughout Nebraska.

Example tribal government actions

- I2-4: Regularly consult with elders and traditional knowledge holders to gather insights on past climate patterns, resilience, and adaptation strategies. Integrate knowledge in community plans, communications, and programs.
- I2-5: Empower young people to learn and actively participate in integrating Indigenous knowledge into community plans.
- I2-6: Partner with scientists to design research questions incorporating Indigenous knowledge and perspectives.

Strategy I3: Strengthen food sovereignty and traditional knowledge and practices.

Supporting tribal food sovereignty strengthens statewide climate resilience by promoting sustainable and self-reliant agricultural systems. Tribal communities use diverse farming methods adapted to local ecosystems, enhancing soil health and reducing risks from climate-related crop failures. Local food systems decrease dependence on vulnerable supply chains, ensuring food stability during disruptions. Indigenous ecological knowledge provides valuable strategies for resilient farming and land management. These practices also boost ecosystem services like water filtration, carbon storage, and biodiversity while empowering communities to address climate challenges collectively. Investing in tribal food sovereignty builds stronger, more resilient agriculture and communities statewide.

Example state actions

- » I3-1: Work with Indigenous communities to identify and protect critical habitats for culturally important plants and animals, including wildlife management and plans that consider Indigenous needs.
- » I3-2: Facilitate market access for Indigenous food producers by connecting them with consumers and supporting the development of local food systems.
- » I3-3: Foster partnerships between state agencies, federal agencies, Tribal governments, and nonprofit organizations to effectively address climate change impacts on tribal food systems.

Example tribal government actions

- » I3-4: Explore the development of a community-wide community-supported agriculture (CSA) program focused on increasing affordable access to fresh fruits and vegetables for food-insecure and low-income community members. Offer a tiered system within the CSA program to prioritize and incentivize local farmers using or transitioning to regenerative agriculture practices.
- » I3-5: Establishing a seed-keeping bank to support local growers and traditional values.
- » I3-6: Develop and implement youth and adult curriculum around local food, climate change, and food security through Indigenous and traditional practices.
- » I3-7: Create an Agriculture Resource Management Plan and consider climate change in production and foraging goals and objectives.

Climate Justice and Equity

Key messages

1. Social systems are changing the climate with inequalities in harms and benefits to different social groups.
2. Low-income people of all racial groups and communities of color in Nebraska are likely to face greater exposure to increasing risks from climate change and be more vulnerable to negative climate-related impacts.
3. Climate change–related impacts are likely to reproduce or expand social inequalities in Nebraska without new policy interventions related to housing, workplace protections, and energy.
4. Climate justice requires that all communities be meaningfully and equitably involved in planning for the transitions necessary to adapt to unstoppable climate changes underway and reduce emissions to prevent more extreme future changes.

Adaptation and resilience options and opportunities

Strategy CJ1: Increase community involvement and empowerment.

Climate resilience within Nebraska can be improved through actively involving and empowering vulnerable and marginalized communities in adaptation planning and decision-making. Developing policies that ensure these communities have a platform to voice their concerns and priorities fosters inclusive solutions that reflect diverse needs. Incorporating local knowledge and perspectives into policy development strengthens the relevance and effectiveness of strategies and builds trust and collaboration. Empowering communities in this way enhances their capacity to adapt to climate challenges while ensuring equitable and sustainable outcomes for all.

Example state actions

- CJ1-1: Identify and prioritize communities disproportionately affected by climate change and historically underserved in resource allocation. Use mapping tools and data to develop equitable criteria for recognizing these communities and creating opportunities for their inclusion in state planning and program development.
- CJ1-2: Develop a public engagement plan to capture and prioritize experiences, perspectives, ideas, and strategies most important to community members disproportionately affected by environmental and climate change impacts.
- CJ1-3: Establish mechanisms to empower community members and organizations to participate in appropriate state agency processes.

Example local government and public power actions

- CJ1-4: Establish sustained outreach and engagement efforts that seek to build and maintain direct relationships with under-resourced, traditionally marginalized, and climate-vulnerable populations within the community. Organize regular community meetings focusing on different demographics and locations to address climate action concerns and build awareness of opportunities for the community.
- CJ1-5: Provide education and resources about climate risks to the public, especially those most vulnerable to the potential impacts of high heat and extreme weather.
- CJ1-6: Support the capacity of neighborhood and community groups to implement climate mitigation and adaptation initiatives.

Strategy CJ2: Prioritize targeted investment in vulnerable communities.

Prioritizing investments in infrastructure, housing, and energy efficiency improvements in vulnerable, low-income, and minority communities can strengthen Nebraska's climate resilience. Expanding programs like the Weatherization Assistance Program (WAP) reduces energy burdens, improves living conditions, and promotes affordability. Additionally, creating green spaces and implementing climate-resilient infrastructure in these areas can enhance environmental and social benefits while mitigating climate impacts. To ensure equity, policies should prevent displacement, allowing communities to directly benefit from these improvements. By addressing systemic inequalities, such targeted investments build stronger, more resilient communities while advancing environmental justice.

Example state actions

- CJ2-1: Prioritize state investment and support local government investment in projects and programs that explicitly address climate change impacts and support new or ongoing access to health, safety, job opportunities, natural and cultural resources, and a better quality of life in underserved and overburdened communities.
- CJ2-2: Expand and accelerate weatherization and efficiency improvements for vulnerable communities. Explore revisions to funding and prioritization formulas for the Weatherization Assistance Program (WAP) to ensure distribution equitably addresses impacts, resilience, mitigation opportunity, and support of vulnerable communities where funding is most needed and can have the greatest impact.
- CJ2-3: Commit resources to develop working relationships, information exchange, and trust between agencies and underserved and overburdened communities affected by climate adaptation planning and implementation processes.
- CJ2-4: Examine the socioeconomic impacts of climate change on local communities and identify opportunities to provide climate change adaptation assistance.

Example local government and public power actions

- CJ2-5: Explore the development of one or more Green Zones, a place-based policy initiative aimed at improving health and supporting economic development using environmentally conscious efforts in communities that face the cumulative effects of environmental pollution, as well as social, political, and economic vulnerability.
- CJ2-6: Explore opportunities to broaden the community's economic base with diversification initiatives, such as targeting the development of emerging clusters or industries that build on the region's unique assets and competitive strengths and provide stability during downturns that disproportionately impact any single cluster or industry.
- CJ2-7: Develop a transparent and inclusive decision-making framework designed to achieve climate, equity, safety, health, and prosperity goals.

Strategy CJ3: Increase equitable access to resilience, clean energy, and jobs.

Climate resilience within Nebraska can be enhanced by increasing equitable access to clean energy, resilience resources, and economic opportunities. Promoting the clean energy transition ensures benefits such as job creation, reduced pollution, and lower energy costs are shared equitably. This includes investing in training and employment opportunities for workers from disadvantaged communities in the clean energy sector and ensuring public utilities and renewable energy projects prioritize fair labor practices and community benefits. Additionally, addressing the rising costs of insurance—exacerbated by climate impacts—through subsidies, expanded coverage options, or risk reduction strategies can protect vulnerable populations from financial strain. Together, these efforts create a more inclusive and resilient economy while fostering environmental and social equity.

Example state actions

- CJ3-1: Improve enforcement of worker-related environmental protections and create protections for state employees where absent.
- CJ3-2: Establish a consortium of experts, including groups such as the Western Governors Association, to evaluate options for addressing the rapidly rising insurance cost for businesses, homeowners, and individuals driven by national and regional climate change impacts. Explore options for insurance regulation, incentives, or programs to reduce costs and increase competition.
- CJ3-3: Collaborate with local community leaders, design professionals, developers, and contractors to identify synergistic sustainability, resilience, and mitigation strategies that meet larger climate goals while supporting housing availability, affordability, and workforce development.
- CJ3-4: Promote and support affordable housing in safe areas across the state (e.g., by providing incentives and removing obstacles to building affordable housing in lower-risk areas).
- CH3-5: Establish incentives to support clean energy installations serving under-served and vulnerable communities.

Example local government and public power actions

- CJ3-6: Explore establishing an incentive or cost-sharing program to reduce the costs of solar PV for income-qualified homeowners.
- CJ3-7: Coordinate with partners, including local unions, to develop and promote job training programs to equip individuals with valuable, future-oriented skills that contribute to climate resilience while also providing pathways to employment, particularly for those in disadvantaged communities.
- CJ3-8: Conduct a study to Identify economic opportunities possible through climate resilience and mitigation actions, especially those that can provide opportunities for the community's vulnerable populations and advancement of entrepreneurship.
- CJ3-9: Create an Affordable Housing Plan to identify current and future needs for affordable housing, including scenarios anticipating climate immigration and migration potentials.

Part 2: Risk assessment and impact summaries

Water

Climate hazard risk assessments

Table SR 1. Summary of the water and climate hazard risk assessment

HAZARD	CONFIDENCE IN FUTURE CHANGE (Trends + Projections)	IMPACT LEVEL (Sensitivity Summary)	TIMEFRAME	RISK (Confidence x Impact x Timeframe)
Annual Temperatures (Warmer)	Very High	High	Short-term	Very High
Winter Temperatures (Warmer)	Very High	Moderate	Short-term	High
Spring Temperatures (Warmer)	Very High	Moderate	Short-term	High
Summer Temperatures (Warmer)	High	High	Short-term	Very High
Fall Temperatures (Warmer)	Very High	Moderate	Short-term	High
Heat Waves (More intense)	High	High	Medium-term	High
Cold Waves (Fewer)	High	Moderate	Short-term	High
Nighttime Temperature (Warmer)	Very High	Moderate	Short-term	High

HAZARD	CONFIDENCE IN FUTURE CHANGE (Trends + Projections)	IMPACT LEVEL (Sensitivity Summary)	TIMEFRAME	RISK (Confidence x Impact x Timeframe)
Annual Precipitation Changes	Low	High	Not known	Not known
Winter Precipitation (Increased)	High	Moderate	Short-term	High
Spring Precipitation (Increased)	Medium	Moderate	Long-term	Very Low
Summer Precipitation (Decreased)	Medium	High	Long-term	Low
Fall Precipitation Changes	Low	Moderate	Not known	Not known
Extreme Precipitation (Increased)	High	High	Medium-term	High
Drought (Increased)	Medium-High	High	Long-term	Low
Wildfires (Increased)	Medium-High	Low	Long-term	Very Low
Severe Thunderstorms (Increased)	Medium	Low	Long-term	Very Low
Hailstorms (Increased)	High	Low	Long-term	Very Low
Tornado Impacts	Low	Not Known	Not known	Not known
Snow Cover (Decreased)	High	Moderate	Short-term	High

Climate impacts summary

Table SR 2. Summary of the potential climate impacts and adaptation considerations

HAZARD	POTENTIAL IMPACT—SURFACE WATERS	POTENTIAL IMPACT—GROUNDWATER	ADAPTATION CONSIDERATIONS
Annual Temperatures (Warmer)	Warm water temperatures foster the growth of harmful algae blooms (HABs), which can release toxins harmful to aquatic life, livestock, and human health. Algal blooms also reduce oxygen levels in the water, leading to fish kills. Economic impacts may occur in the recreational sector. Longer growing seasons increase demand for irrigation water and impact water quality. Warmer temperatures would contribute to the growth of harmful organisms. Reduced dissolved oxygen levels would harm aquatic life. Smaller volumes of water would lead to higher concentrations of pollutants. Declining water levels due to increased evaporation can reduce the amount of water available for drinking, irrigation, hydropower, and other uses. Evaporation can destroy wetland habitats, leading to the loss of critical ecosystems that provide water filtration, flood control, and habitat for wildlife.	This increases water demand across sectors from agricultural irrigation to urban water use, increasing groundwater demand. More evapotranspiration (ET) will require more supplemental irrigation to produce the same yield and reduced aquifer recharge.	Implement soil cover to reduce temperature and evaporation. Nebraska Natural Resource District (NRD) regulations limit the amount of water pumped from aquifers, limiting the impact on groundwater levels. Create deep pools in streams for cool-water aquatic life.

HAZARD	POTENTIAL IMPACT—SURFACE WATERS	POTENTIAL IMPACT—GROUNDWATER	ADAPTATION CONSIDERATIONS
Heat Waves/Extremely Hot Temperatures (More intense)	Declining water levels due to increased evaporation can reduce the amount of water available for drinking, irrigation, hydropower, and other uses. Warm water temperatures foster the growth of HABs, which can release toxins harmful to aquatic life, livestock, and human health. Algal blooms also reduce oxygen levels in the water, leading to fish kills. As water levels decline, pollutants such as agricultural runoff, industrial waste, and wastewater become more concentrated, further degrading water quality and making it more expensive to treat for safe use. Higher water temperatures reduce the amount of dissolved oxygen in the water, which can stress or kill fish, amphibians, and other aquatic species. Wetlands, which rely on stable water levels, are particularly vulnerable to evaporation. This can lead to the loss of critical ecosystems that provide water filtration, flood control, and habitat for wildlife. Low stream flows can disrupt the habitats of fish and other aquatic species that rely on consistent water levels for breeding, feeding, and migration.	More ET, requiring more supplemental irrigation to produce the same yield, and reduced aquifer recharge. Extreme heat increases water demand across sectors, from agricultural irrigation to urban water use, placing additional stress on already limited water supplies.	Implement soil cover to reduce temperature and evaporation. Nebraska NRD regulations limit the amount of water pumped from aquifers and limit the impact on groundwater levels. Create deep pools in streams for cool-water aquatic life.
Cold Waves/Extremely Cold Temperatures (Fewer)	This creates more favorable conditions for invasive species. This will impact lake-mixing regimes and accelerate lake evaporation.	Less snow and more rain will result in lower groundwater recharge rates.	Not identified

HAZARD	POTENTIAL IMPACT—SURFACE WATERS	POTENTIAL IMPACT—GROUNDWATER	ADAPTATION CONSIDERATIONS
Nighttime Temperatures (Warmer)	Warm water temperatures foster the growth of HABs, which can release toxins harmful to aquatic life, livestock, and human health. Economic impacts to the recreational sector. Growth of harmful organisms. Reduce dissolved oxygen levels and harm aquatic life. Concentrate pollutants in smaller volumes of water. Declining water levels due to increased evaporation can reduce the amount of water available for drinking, irrigation, hydropower, and other uses. Loss of wetland habitats from evaporation can lead to the loss of critical ecosystems that provide water filtration, flood control, and habitat for wildlife. Warmer nights can alter the temperature and flow of rivers and streams (fish stress and mortality, altered species distribution, decreased biodiversity).	More ET, requiring more supplemental irrigation to produce the same yield and reducing aquifer recharge.	Creating deep pools in streams for cool-water aquatic life.

HAZARD	POTENTIAL IMPACT—SURFACE WATERS	POTENTIAL IMPACT—GROUNDWATER	ADAPTATION CONSIDERATIONS
Winter Temperatures (Warmer)	Warmer winter and changes in precipitation (reduced snowpack, more precipitation as rain) result in less recharge and more flooding. Later ice-in and earlier ice-out dates have impacts on aquatic ecosystems. With more rainfall and earlier snowmelt, nutrient-rich runoff from agricultural and urban areas can enter rivers and lakes more quickly, leading to eutrophication and HABs. Rapid runoff can carry more sediment, pollutants, and contaminants into water bodies, degrading water quality and increasing the cost of water treatment for drinking supplies. As winter temperatures rise, water bodies may warm earlier in the year, reducing dissolved oxygen levels and affecting aquatic ecosystems. Warmer water can also promote the growth of pathogens and algae, further affecting water quality. A potential benefit may be less salt application on roads. Many aquatic species, such as fish, rely on specific seasonal flow patterns for spawning and habitat. Altered streamflow can disrupt these patterns, harming ecosystems that depend on predictable water availability.	Warming winters disrupt the natural recharge of groundwater, which relies on slow snowmelt and infiltration into soils.	Use soil health best practices to reduce field runoff of nutrients and chemicals, thereby improving soil water-holding capacity and infiltration. Maintain and expand wetland acres for water quality and flood protection. Manage excess flows through diverting or pumping into off-channel wetlands or lakes for groundwater recharge. Maintain and improve levees and other flood protection. Implement riparian buffers to reduce erosion and filter contaminants.

HAZARD	POTENTIAL IMPACT—SURFACE WATERS	POTENTIAL IMPACT—GROUNDWATER	ADAPTATION CONSIDERATIONS
Winter Temperatures (Warmer)	Many reservoirs are designed to capture snowmelt over a period of time, but warmer winters can lead to earlier and faster runoff. Managing water storage can become more difficult, as reservoir operators must balance flood control with the need to store water for future use. This would have impacts to surface water irrigation availability.	Not identified	Not identified
Spring Temperatures (Warmer)	Longer growing seasons increase the demand for irrigation water and impact water quality. Ice conditions combined with winter melt and spring precipitation can contribute to flooding.	This can cause an earlier start to the growing season, higher ET values, reduced soil moisture, an increased need for supplemental irrigation beginning earlier in the season, and reduced aquifer recharge.	Use soil health best practices to reduce field runoff of nutrients and chemicals and improve soil water holding capacity and infiltration. Maintain and expand wetland acres for water quality and flood protection. Manage excess flows by diverting or pumping into off-channel wetlands or lakes for groundwater recharge. Maintain and improve levees and other flood protection. Implement riparian buffers to reduce erosion and filter contaminants.

HAZARD	POTENTIAL IMPACT—SURFACE WATERS	POTENTIAL IMPACT—GROUNDWATER	ADAPTATION CONSIDERATIONS
Summer Temperatures (Warmer)	Declining water levels due to increased evaporation can reduce the amount of water available for drinking, irrigation, hydropower, and other uses. Wetlands could dry up earlier, impacting wildlife habitat. Contribute to an increased risk of wildfire.	This may cause higher ET values, requiring more supplemental irrigation to produce the same yield and reduce aquifer recharge.	Nebraska NRD regulations limit the amount of water pumped from aquifers, limiting the impact on groundwater levels. Use soil cover to reduce temperature and evaporation. Create deep pools in streams for cool-water aquatic life.
Annual Precipitation (Increased)	Changing flow conditions and water quality impacts would result.	Beneficial groundwater recharge would occur if allowed to infiltrate.	Use soil health best practices to reduce field runoff of nutrients and chemicals and improve soil water holding capacity and infiltration. Maintain and expand wetland acres for water quality and flood protection. Manage excess flows by diverting or pumping into off-channel wetlands or lakes for groundwater recharge.
Winter Precipitation (Increased)	Increased potential for large flood events.	If soil is frozen, more rainfall will run off, with decreased recharge. If the soil stays unfrozen, there will be potential for more recharge.	Minimize pre-season agrichemical application through precision application in-season. Use soil health best management practices to reduce field runoff of nutrients and chemicals and improve soil water-holding capacity and infiltration. Use additional agriculture conservation practices.

HAZARD	POTENTIAL IMPACT—SURFACE WATERS	POTENTIAL IMPACT—GROUNDWATER	ADAPTATION CONSIDERATIONS
Spring Precipitation (Increased)	Increased potential for large flood events.	Increase in spring soil moisture, possibly increasing aquifer recharge. Increased potential for more leaching and runoff of early applied fertilizers and other agrichemicals, degrading surface and groundwater quality.	Minimize pre-season agrichemical application through precision application in-season. Maintain and expand wetland acres for water quality and flood protection. Use soil health best management practices to reduce field runoff of nutrients and chemicals, improve soil water holding capacity and infiltration. Use additional agriculture conservation practices.
Summer Precipitation (Decreased)	Reduced streamflow and reservoir refilling.	Decreased soil moisture values and increased need for supplemental irrigation to produce the same crop yield could result in lower groundwater levels.	Nebraska NRD regulations limit the amount of water pumped from aquifers, limiting the impact on groundwater levels. Use soil health best management practices to improve soil water holding capacity and infiltration. Plant native landscape species that require less irrigation.
Fall Precipitation (Decreased)	Reduced streamflows and reservoir refilling.	Less potential for aquifer recharge. Longer landscape irrigation season, increasing total groundwater use.	Use soil health best management practices to improve soil water holding capacity and infiltration. Plant native landscape species that are more drought tolerant.

HAZARD	POTENTIAL IMPACT—SURFACE WATERS	POTENTIAL IMPACT—GROUNDWATER	ADAPTATION CONSIDERATIONS
Extreme Precipitation (Increased)	Greater erosion and runoff damaging agricultural and other land would occur, as would water quality impacts due to sediments, nutrients, and other pollutant runoff. There could be fluctuations in river and stream flow. There would be additional risks of flooding and damage or failure of dams and levees. Runoff contributes to the warming of water resources, impacting cold-sensitive species and the biological integrity of rivers and streams. River travel would be more unsafe or unsuitable. Additional risk of damage to infrastructure and agriculture. Property damage costs and associated costs of recovery would rise. Impacts to wetland hydrology.	Precipitation would be delivered too quickly to infiltrate and recharge the groundwater system.	Use soil health best practices to reduce field runoff of nutrients and chemicals and improve soil water holding capacity and infiltration. Maintain and expand wetland acres for water quality and flood protection. Implement additional agriculture conservation practices. Manage excess flows by diverting or pumping into off-channel wetlands or lakes for groundwater recharge. Maintain and improve levees and other flood protection. Use riparian buffers to reduce erosion and filter contaminants. Upgrade urban stormwater infrastructure.

HAZARD	POTENTIAL IMPACT—SURFACE WATERS	POTENTIAL IMPACT—GROUNDWATER	ADAPTATION CONSIDERATIONS
Drought (Increased)	Reduce flow to hydroelectric power generation sites. Increase fluctuations in river and stream flows. Impacts to wetland hydrology. Cause a loss of habitat areas for species that depend on wetland ecosystems. Reduced natural filtration capacity would lead to poorer water quality downstream. Lower water volumes would concentrate pollutants in rivers, lakes, and reservoirs, making water unsafe for drinking, recreation, or agriculture. Increased temperatures in water bodies can exacerbate pollution and algal blooms, creating unhealthy conditions for aquatic life and making water unsafe for drinking, recreation, and wildlife. The loss of habitats and food sources for fish and other wildlife could lead to declining biodiversity. Vegetation loss, especially in riparian zones, reduces habitat for wildlife and can contribute to soil erosion.	Decreased groundwater recharges from rivers and lakes. Decreased soil moisture values with an increased need for supplemental irrigation to produce the same crop yield, likely resulting in lower groundwater levels.	Nebraska NRD regulations limit the amount of water pumped from aquifers and limit the impact on groundwater levels. Use soil health best practices to improve soil water holding capacity and infiltration. Plant native landscape species that require less irrigation.

HAZARD	POTENTIAL IMPACT—SURFACE WATERS	POTENTIAL IMPACT—GROUNDWATER	ADAPTATION CONSIDERATIONS
Drought (Increased)	Disrupt Indigenous communities and local populations that rely on water bodies for fishing, agriculture, or cultural practices. Reduced opportunities for recreational activities like boating, swimming, and fishing may affect the quality of life and local economies. Increase legal and political conflicts over water rights, tensions between urban and rural users, or upstream and downstream communities, and cross-border disputes over shared rivers.	Not identified	Not identified
Wildfires (Increased)	Burned areas include wetland resources, reducing recreational utility in burned and immediate post-burn years while resources recover. Wildfires can degrade water quality by increasing sediment, ash, and pollutants in water supplies. Water is often diverted for firefighting efforts, straining limited resources even further. Long-term loss of vegetation affects watershed health and can lead to more erosion and poorer water infiltration	Not identified	Not identified
Hailstorms (Increased)	Deterioration in water quality in rivers, lakes, and reservoirs due to the sudden influx of debris and contaminants. Increased crop damage, leading to increased loading of debris and sediment from agricultural landscapes.	This may degrade groundwater quality with excess agrichemicals not taken up by damaged crops, increasing leaching risk.	Minimize pre-season agrichemical application through precision application in-season.

Energy

Climate hazard risk assessment

Table SR 3. Summary of the energy and climate hazard risk assessment

HAZARD	CONFIDENCE IN FUTURE CHANGE (Trends + Projections)	IMPACT LEVEL (Sensitivity Summary)	TIMEFRAME	RISK (Confidence x Impact x Timeframe)
Annual Temperatures (Warmer)	Very High	Low	Short-term	Moderate
Winter Temperatures (Warmer)	Very High	Low	Short-term	Moderate
Spring Temperatures (Warmer)	Very High	Low	Short-term	Moderate
Summer Temperatures (Warmer)	High	Moderate	Short-term	High
Fall Temperatures (Warmer)	Very High	Low	Short-term	Moderate
Heat Waves (More intense)	High	High	Medium-term	High
Cold Waves (Fewer)	High	Low	Short-term	Moderate
Nighttime Temperature (Warmer)	Very High	Low	Short-term	Moderate
Extreme Precipitation (Increased)	High	High	Medium-term	High
Drought (Increased)	Medium-High	Moderate	Long-term	Low

HAZARD	CONFIDENCE IN FUTURE CHANGE (Trends + Projections)	IMPACT LEVEL (Sensitivity Summary)	TIMEFRAME	RISK (Confidence x Impact x Timeframe)
Wildfires (Increased)	Medium-High	High	Long-term	Low
Severe Thunderstorms (Increased)	Medium	High	Long-term	Low
Hailstorms (Increased)	High	High	Long-term	Moderate
Tornado Impacts	Low	High	Not known	Not known

Climate impacts summary

Table SR 4. Summary of the potential impacts on energy

HAZARD	POTENTIAL IMPACT #1	POTENTIAL IMPACT #2	ADAPTATION CONSIDERATIONS
Annual Temperatures (Warmer)	Reduced efficiency of thermal energy systems	Slightly reduced efficiency of solar PV systems	Not identified
Heat Waves/ Extremely Hot Temperatures (More intense)	Reduced efficiency of thermal energy systems	Rising peak demand for cooling	Testing for availability during extreme temperatures
Cold Waves/ Extremely Cold Temperatures (Fewer)	Ice risk to thermal power systems	Ice risk to transmission and distribution systems	Testing for availability during extreme temperatures
Nighttime Temperatures (Warmer)	Reduced efficiency of thermal energy systems	Not identified	Not identified
Winter Temperatures (Warmer)	Reduced efficiency of thermal energy systems	Not identified	Not identified

HAZARD	POTENTIAL IMPACT #1	POTENTIAL IMPACT #2	ADAPTATION CONSIDERATIONS
Spring Temperatures (Warmer)	Reduced efficiency of thermal energy systems	Not identified	Not identified
Summer Temperatures (Warmer)	Reduced efficiency of thermal energy systems	Not identified	Not identified
Fall Temperatures (Warmer)	Reduced efficiency of thermal energy systems	Not identified	Not identified
Extreme Precipitation (Increased)	Flood risk to thermal power systems	Not identified	Not identified
Drought (Increased)	Water availability risk for thermal power systems	Water temperature risk for thermal power systems	Not identified
Wildfires (Increased)	Risk to all generation, transmission, and distribution facilities	Not identified	Prepare for disruptions with robust grid system
Hailstorms (Increased)	Large hail is a risk to solar facilities and other energy infrastructure	Not identified	Not identified
Tornado Events	Risk to all generation, transmission, and distribution facilities	Not identified	Prepare for disruptions with robust grid system

Ecosystems

Climate hazard risk assessment

Table SR 5. Summary of the ecosystem and climate hazard risk assessment

HAZARD	CONFIDENCE IN FUTURE CHANGE (Trends + Projections)	IMPACT LEVEL (Sensitivity Summary)	TIMEFRAME	RISK (Confidence x Impact x Timeframe)
Annual Temperatures (Warmer)	Very High	High	Short-term	Very High
Winter Temperatures (Warmer)	Very High	High	Short-term	Very High
Spring Temperatures (Warmer)	Very High	High	Short-term	Very High
Summer Temperatures (Warmer)	High	High	Short-term	Very High
Fall Temperatures (Warmer)	Very High	High	Short-term	Very High
Heat Waves (More intense)	High	High	Medium-term	High
Cold Waves (Fewer)	High	High	Short-term	Very High
Nighttime Temperatures (Warmer)	Very High	High	Short-term	Very High
Annual Precipitation Changes	Low	High	Not known	Not known

HAZARD	CONFIDENCE IN FUTURE CHANGE (Trends + Projections)	IMPACT LEVEL (Sensitivity Summary)	TIMEFRAME	RISK (Confidence x Impact x Timeframe)
Winter Precipitation (Increased)	High	High	Short-term	Very High
Spring Precipitation (Increased)	Medium	High	Long-term	Low
Summer Precipitation (Decreased)	Medium	High	Long-term	Low
Fall Precipitation Changes	Low	High	Not known	Not known
Extreme Precipitation (Increased)	High	High	Medium-term	High
Drought (Increased)	Medium-High	High	Long-term	Low
Wildfires (Increased)	Medium-High	High	Long-term	Low
Severe Thunderstorms (Increased)	Medium	Moderate	Long-term	Very Low
Hailstorms (Increased)	High	Moderate	Long-term	Low
Tornado Impacts	Low	Not Known	Not known	Not known
Snow Cover (Decreased)	High	High	Short-term	Very High

Climate impacts summary

Table SR 6. Summary of the potential impacts on ecosystems

HAZARD	POTENTIAL IMPACT #1	POTENTIAL IMPACT #2	ADAPTATION CONSIDERATIONS
Annual Temperatures (Warmer)	Changes in animal phenology	Not identified	Not identified
Heat Waves/ Extremely Hot Temperatures (More intense)	Exceeds critical thermal maximum for fishes	Not identified	Not identified
Cold Waves/ Extremely Cold Temperatures (Fewer)	Increase in disease	Not identified	Not identified
Nighttime Temperatures (Warmer)	Increased heat stress	Not identified	Not identified
Winter Temperatures (Warmer)	Changes in animal phenology	Not identified	Not identified
Spring Temperatures (Warmer)	Changes in animal phenology	Not identified	Not identified
Summer Temperatures (Warmer)	Changes in animal phenology	Not identified	Not identified
Fall Temperatures (Warmer)	Changes in animal phenology	Not identified	Not identified
Annual Precipitation (Increased)	Increased availability of water depending on timing and magnitude	Not identified	Not identified
Winter Precipitation (Increased)	Changes in animal phenology	Not identified	Not identified

HAZARD	POTENTIAL IMPACT #1	POTENTIAL IMPACT #2	ADAPTATION CONSIDERATIONS
Spring Precipitation (Increased)	Changes in animal phenology	Not identified	Not identified
Summer Precipitation (Decreased)	Changes in animal phenology	Not identified	Not identified
Fall Precipitation (Decreased)	Changes in animal phenology	Not identified	Not identified
Extreme Precipitation (Increased)	Increased flooding and habitat change in streams	Not identified	Not identified
Drought (Increased)	Drying of streams and loss of connectivity	Not identified	Not identified
Wildfire (Increased)	Habitat loss or gain dependent on species	Not identified	Not identified
Hail (Increased)	Reduced survival of nesting birds	Not identified	Not identified
Tornado Events	Unknown impact on wildlife	Not identified	Not identified

Agriculture

Climate hazard risk assessment

Table SR 7. Summary of the agriculture and climate hazard risk assessment

HAZARD	CONFIDENCE IN FUTURE CHANGE (Trends + Projections)	IMPACT LEVEL (Sensitivity Summary)	TIMEFRAME	RISK (Confidence x Impact x Timeframe)
Annual Temperatures (Warmer)	Very High	High	Short-term	Very High
Winter Temperatures (Warmer)	Very High	High	Short-term	Very High
Spring Temperatures (Warmer)	Very High	High	Short-term	Very High
Summer Temperatures (Warmer)	High	High	Short-term	Very High
Fall Temperatures (Warmer)	Very High	High	Short-term	Very High
Heat Waves/ Extremely Hot Temperatures (More intense)	High	High	Medium-term	High
Cold Waves/ Extremely Cold Temperatures (Fewer)	High	High	Short-term	Very High
Nighttime Temperatures (Warmer)	Very High	High	Short-term	Very High
Annual Precipitation Changes	Low	High	Not known	Not known

HAZARD	CONFIDENCE IN FUTURE CHANGE (Trends + Projections)	IMPACT LEVEL (Sensitivity Summary)	TIMEFRAME	RISK (Confidence x Impact x Timeframe)
Winter Precipitation (Increased)	High	Moderate	Short-term	High
Spring Precipitation (Increased)	Medium	High	Long-term	Low
Summer Precipitation (Decreased)	Medium	High	Long-term	Low
Fall Precipitation Changes	Low	High	Not known	Not known
Extreme Precipitation (Increased)	High	High	Medium-term	High
Drought (Increased)	Medium-High	High	Long-term	Low
Wildfires (Increased)	Medium-High	Moderate	Long-term	Low
Severe Thunderstorms (Increased)	Medium	Moderate	Long-term	Very Low
Hailstorms (Increased)	High	Moderate	Long-term	Low
Tornado Impacts	Low	High	Not known	Not known
Snow Cover (Decreased)	High	High	Short-term	Very High

Climate impacts summary

Table SR 8. Summary of the potential impacts on agriculture

HAZARD	POTENTIAL CROP AGRICULTURE IMPACT	POTENTIAL RANGE & LIVESTOCK IMPACTS	ADAPTATION CONSIDERATIONS
Increased intensity and frequency of drought under all emissions scenarios by mid- and late century. Summer drought is more probable than spring drought (Knapp et al., 2023 p. 11). Analysis of 21st century precipitation data in Nebraska points to a trend of fewer but more intensive droughts (Chapter 3).	Impacts on summer annual crop planting and productivity (corn and soybean). More heavy rain in spring complicates or delays planting, while drought in summer during critical growth periods limits yield potential.	Decreasing livestock production and performance due to declining forage availability and quality with increasing drought frequency and intensity during the summer growing season. Increased wildfire risk, potentially negatively affecting cattle operations. Increased water demand to meet physiological requirements of livestock during times of drought. Changes in rangeland plant communities (i.e., forage base) expected, with potential to impact timing and duration of grazing; along with livestock performance and production. Positive feedbacks between invasive annual grasses and fire are expected to increase the wildfire risk for rangelands, impacting livestock production.	Heterogeneity-based rangeland/grassland management practices can reduce risks and impacts of wildlife—for example, pyric herbivory (literally “fire-driven grazing”)—well known to mitigate the negative effects of drought on livestock weight gain compared to traditional, homogenous, management practices. Reducing seeding rates, optimizing irrigation water use, managing residue for water retention, and planting drought-tolerant varieties or more drought-tolerant crops. Efficient irrigation techniques, such as drip irrigation and soil moisture sensors, can help farmers manage water use more effectively, reducing the impact of higher water demands.

HAZARD	POTENTIAL CROP AGRICULTURE IMPACT	POTENTIAL RANGE & LIVESTOCK IMPACTS	ADAPTATION CONSIDERATIONS
Greater variability in precipitation is very likely to increase in spring, with uncertain change in summer. Across the region, an increase in the heaviest 1% of rainfall days by 24% (Knapp et al., 2023, p. 9; Marvel et al., 2023, fig 2.8 pp. 2–19). The most extreme rainfall events (more than 2 inches per day) are expected to increase across central and eastern Nebraska, especially in the Southeast (Chapter 4). Analysis of 21st century precipitation data in Nebraska points to a lower frequency of extreme precipitation events in summer compared to spring and fall (Chapter 3)	Impacts on summer annual crop planting and productivity (corn and soybean). More heavy rain in spring complicates or delays planting, while drought in summer during critical growth periods limits yield potential.	Not identified	More frequent application of inputs can reduce environmental and profit losses, that is, split application of nitrogen. Residue management can provide erosion prevention and cool soil temperatures in warmer conditions. Shifting planting timing and planting shorter season crops or alternative crops could avoid crop water stress with more variable rainfall. Growing a variety of crops, especially those tolerant to waterlogged conditions, can help farmers spread risk and reduce the overall impact of extreme rainfall on their operations. Installing more effective drainage systems, such as retention ponds or drainage ditches, can help manage excess water and prevent flooding.

HAZARD	POTENTIAL CROP AGRICULTURE IMPACT	POTENTIAL RANGE & LIVESTOCK IMPACTS	ADAPTATION CONSIDERATIONS
There is greater uncertainty in annual precipitation trends compared to temperature trends given Nebraska's intercontinental location and climate. Precipitation is projected to increase in winter and spring, with decreases in summer and no consistent trend for directionality of fall precipitation (Chapter 4). Most climate divisions in Nebraska have seen a short-term decrease in summer precipitation (Chapter 3).	If summer drought increases, it could impact summer annual crops in reproductive or water-critical growth stages. Lower precipitation or drought in fall could impact fall planting conditions and lead to unreliable establishment of winter annual crops.	Forage nutritive value is expected to go down (i.e., %N•kg-2), with increased biomass production from higher rainfall and atmospheric CO_2, with potential for malnutrition in livestock (nutrient dilution effect). Rainfall timing is expected to shift grassland plant communities.	Including more winter annual or cool-season crops in rotation optimizes rainfall utilization: the main crop is harvested before summer drought, and more use of different types of crops diversifies risk of rainfall variability. Disturbances to promote landscape heterogeneity Change animal grazing timing, kin and class of animal, or multispecies grazing to capitalize on changing forage quality in time. Increasing range biodiversity has the potential to improve soil, for example, the relationship between prairie dogs and water infiltration.
Aridity is expected to increase, specifically with an eastward shift of demarcation between a humid east and arid west (Knapp et al., 2023, p. 9).	A potential for shifts and decreases in productivity for a new demarcation line (i.e. central Nebraska), specifically in non-irrigated cropland, with more strain on groundwater resources for irrigated cropland.	Reduced livestock production is expected with increased aridity, via decreased forage productivity. Increased aridity might decrease woody plant cover and invasion, limiting the total area that might be tree dominated as landscapes become more water limited.	This is a more challenging shift for crop production, especially in the east, which may require considering alternative crops that are more drought tolerant, and/or more drought-tolerant varieties of corn, soybean, and wheat. Consider lowering stocking rates to accommodate increasing aridity and subsequent declines in forage production across the state. Consider changing the kind and class of animal to those that are better suited to changing aridity and humidity.

HAZARD	POTENTIAL CROP AGRICULTURE IMPACT	POTENTIAL RANGE & LIVESTOCK IMPACTS	ADAPTATION CONSIDERATIONS
Annual peak streamflow decreased in the west and increased in the east from 1961 to 2020. Larger negatives observed in southwest Nebraska, with slight increases in eastern Nebraska (Knapp et al., 2023, Fig 25.4).	Peak streamflow is a proxy for flooding, which could indicate a potential increase in eastern Nebraska (in addition to shifts in rainfall variability).	Decreased water availability in riparian habitats is likely to negatively impact livestock production in western Nebraska or increase the potential for overgrazing in sensitive riparian ecosystems as arid systems become more water limited.	Many well-known soil management practices can improve soil hydrology and reduce runoff, including conservation tillage, planting cover crops, and residue management. Optimize irrigation resources. Diversify crops or shift to more drought-tolerant options. Lower stocking rates to accommodate fluctuations in streamflow and water availability. Reduce restrictions to animal movement and increase total available area to overcome increased spatial variability in water resources over time.
Decreased runoff is expected from the Colorado River basin, with increased evaporative demand (Knapp et al., 2023, p. 11).	Increased evaporative demand could decrease summer soil moisture. This could increase pressure on groundwater and available irrigation resources, making growing season precipitation even more important and can lead crops to be more vulnerable to drought.	Not identified	Not identified
Decreasing snowpack and snowmelt runoff are projected (Knapp et al., 2023, p. 9; Coles et al., 2017).			

HAZARD	POTENTIAL CROP AGRICULTURE IMPACT	POTENTIAL RANGE & LIVESTOCK IMPACTS	ADAPTATION CONSIDERATIONS
Average temperatures are projected to increase by 5–6°F by the end of the century, or up to 11.5°F under the high emissions scenario. The number of extremely hot days (90°F or higher) is likely to be two to four times larger than during the historical period. Days above 100°F could increase to over 50 days per year (fewer than 10 in the historical period) (Chapter 4). The number of days with a minimum temperature above freezing increased from 1991 to 2000 compared to 1951–1980 (Chapter 3). Most locations in Nebraska have had record warm temperature months since 2000 (Chapter 3, Figure 12).	Temperature stress decreases photosynthesis. This impacts growth and development in corn; water stress is expected to shift to temperature stress after mid-century. There is potential for an increase of winter annual weeds and overwinter pests with fewer frost-free days. This expands the growing season with a related impact of a shift or increase in plant hardiness zones in the state (USDA FSA, 2023).	Cool-season grass productivity could decrease, with the potential for increased reliance on warm-season grasses for forage (which may also be subject to summer drought risk). Domestic livestock will face increased energetic demand because of increased temperature—e.g., cattle start to show symptoms of heat stress at temperatures over 80°F. Livestock movements could be more restricted to parts of the landscape with high soil moisture or standing water—riparian zones, around water tanks, etc.	Diversify crops and minimize summer annual crops, use more drought- and heat-tolerant varieties of corn, soy, and wheat. For livestock, improved ventilation and cooling systems, such as fans, sprinklers, and shade structures, can help animals cope with higher nighttime temperatures and reduce heat stress.

HAZARD	POTENTIAL CROP AGRICULTURE IMPACT	POTENTIAL RANGE & LIVESTOCK IMPACTS	ADAPTATION CONSIDERATIONS
Fewer very cold days could occur (Knapp et al., 2023, pp. 8–9; Marvel et al., 2023, Fig 2.7 pp. 2–18).	Pests that typically die in the winter could survive and cause more damage (i.e., increased winter annual weeds, expanded pathogens).	This could positively impact livestock production, reducing losses due to extreme low temperatures and snowfall. The livestock production schedule (e.g., calving timing, grazing rotation schedules, etc.) that is usually timed in accordance with weather conditions is expected to change.	A risk of increased pests necessitates best management practices such as scouting and timely pest management, which could interfere with vernalization requirements of cool-season crops.
There could be increased wildfire potential, with a longer fire season and decline in the number of snow-cover days (Knapp et al., 2023, p. 13).	A decline in snow-cover days impacts survival of winter pests. It also creates opportunity from an expanded growing season.	The distribution of invasive annual grasses is expected, which will in turn increase fire frequency. Forage availability for livestock may be reduced (i.e., more is burned). Coupled with drought, this will reduce the livestock production capacity of Nebraska rangelands.	Utilize grazing systems that capitalize on increased forage quality following fire (pyric herbivory), but at moderate (i.e., 20–25% harvest use efficiency) stocking rates to avoid steep declines in range condition and heterogeneity.
Hail may increase in frequency and intensity, with the largest projected increases anticipated in summer (July). (Knapp et al., 2023, p. 10)	Potential damage to winter and summer annual crops is expected, plus the potential for increased crop insurance payouts.	Not identified	Diversifying crops could avoid summer water-related stress and damages.

HAZARD	POTENTIAL CROP AGRICULTURE IMPACT	POTENTIAL RANGE & LIVESTOCK IMPACTS	ADAPTATION CONSIDERATIONS
Atmospheric CO_2 increases (USGCRP, 2023).		This is expected to accelerate a shift from grass-dominated to woody-plant-dominated landscapes across Nebraska, with effects being the strongest in the mesic parts of the state (>700 mm rainfall).	Change kind and class of livestock to capitalize on changes to the forage base. Increase the use and frequency of prescribed fire to improve forage conditions and utilize grazing management practices that capitalize on vegetation recovery (and high forage quality) immediately following fire.

Human Health

Climate hazard risk assessment

Table SR 9. Summary of the human health and climate hazard risk assessment

HAZARD	CONFIDENCE IN FUTURE CHANGE (Trends + Projections)	IMPACT LEVEL (Sensitivity Summary)	TIMEFRAME	RISK (Confidence x Impact x Timeframe)
Annual Temperatures (Warmer)	Very High	Moderate	Short-term	High
Heat Waves/ Extremely Hot Temperatures (More intense)	High	High	Medium-term	High
Nighttime Temperatures (Warmer)	Very High	High	Short-term	Very High
Extreme Precipitation (Increased)	High	High	Medium-term	High
Drought (Increased)	Medium-High	High	Long-term	Low
Wildfires (Increased)	Medium-High	Moderate	Long-term	Low

Climate impacts summary

Table SR 10. Summary of the potential impacts on human health

HAZARD	POTENTIAL IMPACT #1	POTENTIAL IMPACT #2	ADAPTATION CONSIDERATIONS
Annual Temperatures (Warmer)	Change in vector-borne and zoonotic disease due to changing seasons, ecology, and so on.	Not identified	Implement better surveillance of vectors and related diseases. Improve education regarding risks and prevention measures.
Heat Waves/ Extremely Hot Temperatures (More intense)	Increase in heat-related illnesses.	Increases in other negative health outcomes (e.g., cardiovascular diseases, respiratory diseases, mental health impacts)	Increase green spaces and heat-reducing features in urban areas. Improve weatherization and energy efficiency in under-resourced and vulnerable communities. Improve access to cooling centers. Improve messaging regarding heat-health risks for populations with greater vulnerability and risk and increased education regarding behavioral modifications. Encourage development of heat action plans in communities and cities across the state.
Nighttime Temperatures (Warmer)	Increase in heat-related illnesses.	Increases in other negative health outcomes (e.g., cardiovascular diseases, respiratory diseases, mental health impacts).	Increase green spaces and heat-reducing features in urban areas. Improve weatherization and energy efficiency in under-resourced and vulnerable communities. Improve access to 24-hour cooling centers. Improve messaging regarding nighttime heat-health risks for populations with greater vulnerability and risk and education regarding nighttime behavior modifications (e.g., cool sleep, sleep hygiene tips).

HAZARD	POTENTIAL IMPACT #1	POTENTIAL IMPACT #2	ADAPTATION CONSIDERATIONS
Extreme Precipitation (Increased)	Increase in flood-related illnesses and injuries (e.g., drowning, respiratory impacts from mold, mental health outcomes).	Risk of contaminated water sources leading to increased risk of gastrointestinal illnesses.	Implement better surveillance for injury and other flood-related health outcomes, including increased use of syndromic surveillance for flood events. Improve messaging around flood-related health risks and contaminated drinking water. Encourage development of community flood action plans. Improve community preparedness, including educating residents about evacuation route planning and having emergency water and power supplies. Implement community tetanus vaccination campaigns semi-annually. Develop post-flood vector control plans. Offer immediate and long-term mental health support.
	Disruptions to the healthcare system and healthcare access.	Not identified	Improve health system resilience to floods (e.g., elevated power source and back-up generators, waterproof barriers). Improve transportation system resilience to floods (e.g., improve road and bridge infrastructure to maintain emergency vehicle access). Deploy mobile health clinics. Expand telehealth services.

Communities and the Built Environment

Climate hazard risk assessment

Table SR 11. Summary of the communities and the built environment and climate hazard risk assessment

HAZARD	CONFIDENCE IN FUTURE CHANGE (Trends + Projections)	IMPACT LEVEL (Sensitivity Summary)	TIMEFRAME	RISK (Confidence x Impact x Timeframe)
Annual Temperatures (Warmer)	Very High	Moderate	Short-term	High
Heat Waves (More intense)	High	High	Medium-term	High
Annual Precipitation Changes	Low	Low	Not known	Not known
Extreme Precipitation (Increased)	High	High	Medium-term	High
Drought (Increased)	Medium-High	Moderate	Long-term	Low
Wildfires (Increased)	Medium-High	High	Long-term	Low
Severe Thunderstorms (Increased)	Medium	High	Long-term	Low
Hailstorms (Increased)	High	High	Long-term	Moderate
Tornado Impacts	Low	High	Not known	Not known

Climate impacts summary

Table SR 12. Summary of the potential impacts on communities and the built environment

HAZARD	POTENTIAL IMPACT #1	POTENTIAL IMPACT #2	ADAPTATION CONSIDERATIONS
Heat waves/Extremely Hot Temperatures (More intense)	Health, lives	Energy, infrastructure	Services to disadvantaged populations, Infrastructure improvement
Annual Precipitation (Increased)	Infrastructure	Human activities	Monitoring, design standards
Extreme Precipitation (Increased)	Lives, property	Infrastructure, transportation	Land-use planning, zoning, design standard, public education
Drought (Increased)	Economy, health	Infrastructure	Water infrastructure, water conservation education
Wildfire (Increased)	Lives	Property	Warning system, evacuation plan
Hail (Increased)	Property	Human activities	Insurance
Tornado Events	Property, lives	Infrastructure	Design standards, building codes

Indigenous Peoples

Climate hazard risk assessment

Table SR 13. Summary of the Indigenous peoples and climate hazard risk assessment

HAZARD	CONFIDENCE IN FUTURE CHANGE (Trends + Projections)	IMPACT LEVEL (Sensitivity Summary)	TIMEFRAME	RISK (Confidence x Impact x Timeframe)
Annual Temperatures (Warmer)	Very High	Moderate	Short-term	High
Winter Temperatures (Warmer)	Very High	Low	Short-term	Moderate
Spring Temperatures (Warmer)	Very High	Low	Short-term	Moderate
Summer Temperatures (Warmer)	High	Moderate	Short-term	High
Fall Temperatures (Warmer)	Very High	Low	Short-term	Moderate
Heat Waves/ Extremely Hot Temperatures (More intense)	High	High	Medium-term	High
Cold Waves/ Extremely Cold Temperatures (Fewer)	High	Low	Short-term	Moderate
Nighttime Temperatures (Warmer)	Very High	High	Short-term	Very High
Annual Precipitation Changes	Low	Moderate	Not known	Not known

HAZARD	CONFIDENCE IN FUTURE CHANGE (Trends + Projections)	IMPACT LEVEL (Sensitivity Summary)	TIMEFRAME	RISK (Confidence x Impact x Timeframe)
Winter Precipitation (Increased)	High	Moderate	Short-term	High
Spring Precipitation (Increased)	Medium	High	Long-term	Low
Summer Precipitation (Decreased)	Medium	Moderate	Long-term	Very Low
Fall Precipitation Changes	Low	Moderate	Not known	Not known
Extreme Precipitation (Increased)	High	High	Medium-term	High
Drought (Increased)	Medium-High	High	Long-term	Low
Wildfires (Increased)	Medium-High	High	Long-term	Low
Severe Thunderstorms (Increased)	Medium	Moderate	Long-term	Very Low
Hailstorms (Increased)	High	Moderate	Long-term	Low
Tornado Impacts	Low	High	Not known	Not known

Climate impacts summary

Table SR 14. Summary of the potential impacts on Indigenous peoples

HAZARD	POTENTIAL IMPACT #1	POTENTIAL IMPACT #2	ADAPTATION CONSIDERATIONS
Annual Temperatures (Warmer)	Disruption in cultural resource availability	Interference with ceremonial practices	Vulnerability assessment Climate adaptation plan
Heat Waves/ Extremely Hot Temperatures (More intense)	Exacerbated negative health outcomes	Interference with ceremonial practices	Vulnerability assessment Climate adaptation plan
Cold Waves/ Extremely Cold Temperatures (Fewer)	Disruption in cultural resource availability	Interference with ceremonial practices	Vulnerability assessment Climate adaptation plan
Nighttime Temperatures (Warmer)	Exacerbated negative health outcomes in summer	Not identified	Educational awareness Enhanced local health services
Winter Temperatures (Warmer)	Disruption in cultural resource availability	Interference with ceremonial practices	Vulnerability assessment Climate adaptation plan
Spring Temperatures (Warmer)	Disruption in cultural resource availability	Interference with ceremonial practices	Vulnerability assessment Climate adaptation plan
Summer Temperatures (Warmer)	Disruption in cultural resource availability	Interference with ceremonial practices	Vulnerability assessment Climate adaptation plan
Fall Temperatures (Warmer)	Disruption in cultural resource availability	Interference with ceremonial practices	Vulnerability assessment Climate adaptation plan
Annual Precipitation (Increased)	Disruption in cultural resource availability	Interference with ceremonial practices	Vulnerability assessment Climate adaptation plan
Winter Precipitation (Increased)	Elevated flood risk, condition-dependent	Not identified	Local environmental condition tracking Flood insurance assessment and education

HAZARD	POTENTIAL IMPACT #1	POTENTIAL IMPACT #2	ADAPTATION CONSIDERATIONS
Spring Precipitation (Increased)	Elevated flood risk, condition-dependent	Not identified	Environmental condition tracking =Flood insurance assessment and education
Summer Precipitation (Decreased)	Disruption in cultural resource availability	Interference with ceremonial practices	Vulnerability assessment Climate adaptation plan
Fall Precipitation (Decreased)	Disruption in cultural resource availability	Interference with ceremonial practices	Vulnerability assessment Climate adaptation plan
Extreme Precipitation (Increased)	Disruption in cultural resource availability	Interference with ceremonial practices	Vulnerability assessment Climate adaptation plan
Drought (Increased)	Water security	Not identified	Drought plan
Wildfire (Increased)	Exacerbated negative health outcomes	Infrastructure damage	Strengthen community-based air quality alert systems Increase household air quality mitigation measures
Hail (Increased)	Infrastructure damage	Amplified community housing shortage	Provision of pathways for hazard insurance New construction design for increased hazard resilience
Tornado Events	Infrastructure damage	Amplified community housing shortage	Provision of pathways for hazard insurance New construction design for increased hazard resilience

Climate Justice and Equity

Climate hazard risk assessment

Table SR 15. Summary of the climate justice and equity and climate hazard risk assessment

HAZARD	CONFIDENCE IN FUTURE CHANGE (Trends + Projections)	IMPACT LEVEL (Sensitivity Summary)	TIMEFRAME	RISK (Confidence x Impact x Timeframe)
Annual Temperatures (Warmer)	Very High	Moderate	Short-term	High
Heat Waves/ Extremely Hot Temperatures (More intense)	High	High	Medium-term	High
Cold Waves/ Extremely Cold Temperatures (Fewer)	High	Low	Short-term	Low
Nighttime Temperatures (Warmer)	Very High	Low	Short-term	Moderate
Extreme Precipitation (Increased)	High	High	Medium-term	High
Drought (Increased)	Medium-High	Moderate	Long-term	Low
Wildfires (Increased)	Medium-High	High	Long-term	Low
Hailstorms (Increased)	Medium	Moderate	Long-term	Very Low
Tornado Events (Increased)	High	Moderate	Long-term	Low
Extreme Precipitation (Increased)	Low	High	Not known	Moderate

Climate impacts summary

Table SR 16. Summary of the potential impacts on climate justice and equity

HAZARD	POTENTIAL IMPACT #1	POTENTIAL IMPACT #2	ADAPTATION CONSIDERATIONS
Annual Temperatures (Warmer)	Increased energy burdens.	Increased air conditioning use undermining emissions reductions.	Expand and accelerate weatherization and efficiency improvements for vulnerable communities. Ensure building codes address extreme weather risks.
Heat Waves/ Extremely Hot Temperatures (More intense)	Increased health risk to vulnerable workers.	Increased health risk in vulnerable communities.	Improve enforcement of worker-related environmental protections and create protections for state employees where absent. Address land-use and infrastructure that are disproportionate risks for minority and low-income communities. Expand and accelerate weatherization and efficiency improvements for vulnerable communities. Increase access to cooling centers. Ensure building codes address extreme weather risks.
Nighttime Temperatures (Warmer)	Increased health risks to vulnerable households.	Not identified	Expand and accelerate weatherization and efficiency improvements for vulnerable communities. Expand cooling center availability and hours in at-risk communities.
Spring Temperatures (Warmer)	Increased health risks to vulnerable households.	Not identified	Not identified
Summer Temperatures (Warmer)	Increased health risks to vulnerable households.	Not identified	Not identified
Fall Temperatures (Warmer)	Increased health risks to vulnerable households.	Not identified	Not identified

HAZARD	POTENTIAL IMPACT #1	POTENTIAL IMPACT #2	ADAPTATION CONSIDERATIONS
Extreme Precipitation (Increased)	Reductions in affordable housing.	Disproportionate exposure and impact on vulnerable communities with increased racial and class inequalities.	Improve zoning and create equitable managed retreat plans. Improve equity in disaster planning and response policies. Regulate insurance costs and provide competition from public insurance.
Drought (Increased)	Losses for agricultural communities.	Not identified	Diversify rural economies to be less dependent on commodity crop monocultures by equitably sharing benefits of climate mitigation strategies.
Wildfire (Increased)	Strains on rural community resources.	Exacerbation of air-quality-related illnesses.	Manage fire risk. Reduce sources of additional respiratory disease vulnerability.
Hail (Increased)	Reductions in affordable housing.	Disproportionate exposure and impact on vulnerable communities with increased racial and class inequalities.	Regulate insurance costs and provide competition from public insurance. Ensure building codes address extreme weather risks. Improve equity in disaster planning and response policies.
Tornado and High Wind Events (Increased)	Reductions in affordable housing.	Disproportionate exposure and impact on vulnerable communities with increased racial and class inequalities.	Regulate insurance costs and provide competition from public insurance. Ensure building codes address extreme weather risks. Improve equity in disaster planning and response policies. Increase electrical grid resiliency, for example, with distributed generation and storage.

Appendix A

About the Authors

Heather Akin is an Assistant Professor of Strategic Communication. Her research and service focus on understanding the social and psychological dynamics underlying the public's attitudes and behaviors related to scientific issues and risks. She received a Fulbright Teaching Fellowship in Indonesia and maintains a strong interest in issues and politics in Southeast Asia. She received her PhD in Mass Communications from the University of Wisconsin–Madison and was the Howard Deshong Postdoctoral Fellow at the University of Pennsylvania's Annenberg Public Policy Center.

Andrea Basche is an Associate Professor in the Department of Agronomy and Horticulture at the University of Nebraska–Lincoln. Her research team studies several aspects of diversified cropping systems, including carbon and nitrogen cycling, water and weed dynamics, and policy and human decision-making. In her role, she also teaches several undergraduate courses in crop management. She has expertise in cover crops, soil health, and climate change and was a co-author on the Northern Great Plains chapter of the 5th National Climate Assessment, published in 2023. Dr. Basche received her PhD in Crop Production and Physiology and Sustainable Agriculture from Iowa State University.

Deborah Bathke is the Nebraska State Climatologist and an Associate Professor in the School of Natural Resources. She was a climatologist with the National Drought Mitigation Center for 16 years, and during that time, she authored the U.S. Drought Monitor, served as the coordinator for the center's education and engagement activities, and worked to develop decision-support tools for drought risk management. Dr. Bathke was the lead author of the state's 2014 climate change impact assessment, *Understanding and Assessing Climate Change: Implications for Nebraska*. Before working at UNL, she served as the Assistant State Climatologist for New Mexico. Dr. Bathke is a native Nebraskan and grew up in Ponca. She earned her BS and MS from the University of Nebraska–Lincoln and a PhD in Atmospheric Sciences from The Ohio State University.

Jesse E. Bell is the Claire M. Hubbard Professor of Water, Climate, and Health in the Department of Environmental, Agricultural, and Occupational Health at the University of Nebraska Medical Center and the School of Natural Resources of the Institute of Agriculture and Natural Resources at the University of Nebraska–Lincoln. He is the director of the Water, Climate, and Health Program at UNMC and the Director of Water, Climate, and Health at the University of Nebraska's Daugherty Water for Food Global Institute. These programs aim to develop interdisciplinary research, education, and collaborative solutions to public health challenges associated with environmental issues in Nebraska and worldwide. As the founding director, he has helped grow these programs and to lead 25 faculty, staff, and students. His expertise and research are focused on understanding how human and natural processes are connected to environmental and climate changes. Dr. Bell is a native Nebraskan and received his PhD from the University of Oklahoma.

Daniel R. DiLeo is a Catholic moral theologian, Associate Professor, Justice and Peace Studies Program Director, and Chair of the Department of Cultural and Social Studies at Creighton University. Since 2009, he has been a consultant with Catholic Climate Covenant, founded with support from the U.S. Conference of Catholic Bishops. Dr. DiLeo earned his PhD in Theological Ethics with a minor in Systematic Theology from Boston College.

Ross Dixon is an Assistant Professor in the Department of Earth & Atmospheric Sciences at the University of Nebraska–Lincoln. His research is focused on climate modeling, regional climate dynamics, and precipitation projections. Dr. Dixon joined UNL in 2021 after obtaining a PhD from the University of Wisconsin–Madison, followed by postdoctoral positions at the Centre National de Recherches Météorologiques in Toulouse, France, and the University of Arizona. He has worked on various projects that focused on understanding uncertainty in projections of West African climate. He has recently been involved with research on rain-on-snow events across the central United States. To further this research, he regularly designs and runs simulations with a wide range of complexities and applies statistical techniques to model output and observations.

Martha Durr is an Applied Climatologist Faculty in the Math and Science Department at Nebraska Indian Community College. Her specialization areas are meteorology, climatology, and climate change impacts. Before NICC, she was an Applied Climatologist at the Alaska Climate Research Center, Director of the NOAA High Plains Regional Climate Center, and most recently served as the Nebraska State Climatologist. Dr. Durr earned her PhD in Soils and Climate from the University of Minnesota.

F. John Hay is an Extension Educator for the University of Nebraska–Lincoln Extension. Based in the Department of Biological Systems Engineering, his teaching focuses on energy issues, including biofuels, renewable energy, and farm energy management. John has taught extensively about economic analysis for behind-the-meter solar applications for farms, residences, and businesses. He received a BS in Agronomy from the University of Nebraska–Lincoln and an MS in Agronomy from Texas A&M University.

Tonya Haigh is a Research Assistant Professor and Social Science Coordinator of the National Drought Mitigation Center at the University of Nebraska–Lincoln. Her research focuses on the adaptive capacity of agricultural producers, rural communities, and others to cope with drought. Her research connects social science with climate science by informing the development of stakeholder-driven resources and tools. Dr. Haigh received her PhD in Natural Resource Sciences, specializing in Human Dimensions, from the University of Nebraska–Lincoln.

Eric Hunt is an Assistant Extension Educator of Agricultural Meteorology and Climate Resilience for the University of Nebraska–Lincoln Extension. He is based in the Nebraska State Climate Office and the School of Natural Resources. Dr. Hunt provides routine weather and climate updates for the agricultural community across the state. He received his PhD in Natural Resource Sciences with a specialization in Bio-Atmospheric Interactions from the University of Nebraska–Lincoln.

Kristina W. Kintziger is the Claire M. Hubbard Professor of Health and Environment and Associate Director of the Water, Climate, and Health Program at the University of Nebraska Medical Center, College of Public Health. Dr. Kintziger also has an appointment with the National Center for Environmental Health at the Centers for Disease Control and Prevention. She is an environmental and disaster epidemiologist with experience in academia and public health practice. Her research focuses on the impacts of climate change on human health and applying advanced and interdisciplinary methods to improve public health practice in environmental, climate, and disaster epidemiology. Dr. Kintziger received an MPH in Epidemiology from Emory University and a PhD in Epidemiology from the University of South Carolina.

Nicholas McMillan is an Assistant Professor in the Department of Agronomy and Horticulture and the School of Natural Resources. He is the Grazing Lands Ecologist at the University of Nebraska–Lincoln and has plant, landscape, and rangeland ecology expertise. He received his PhD in Natural Resource Ecology and Management from Oklahoma State University.

Henry “Hank” Miller (1962–2025) was an educator and researcher at Nebraska Indian Community College since 2003. He served as the Math and Science division head and led the development and administration of programs. He taught a variety of life science classes and conducted numerous of environmental research projects. Mr. Miller attained a BS and MS in Biology and served on boards for science literacy and science education programs. He was also a member of the Nebraska Academy of Science.

Jerome Okojokwu-Idu is an energy professional and co-founder of a leading communications firm in Nigeria, with expertise spanning energy transition, sustainability, resilience, environmental justice, and Indigenous knowledge systems. He is pursuing a

PhD in Natural Resource Sciences at the University of Nebraska–Lincoln, where he researches the creation of fair and sustainable energy systems in developing countries and tribal nations.

Crystal Powers is an Associate Extension Educator with the University of Nebraska Water Center and the Daugherty Water for Food Global Institute. Her work reaches statewide, focused on water management and science communication. She holds an MS from Cornell University and a BS in Biological Systems Engineering from the University of Nebraska–Lincoln.

Tirthankar Roy is an Assistant Professor in the Department of Civil and Environmental Engineering at the University of Nebraska–Lincoln. His group focuses on a wide range of topics related to hydrology and its intersections with multiple other fields. He received his PhD in Hydrology from the University of Arizona and worked as a postdoc at Princeton before joining UNL in 2019.

Sarah Sonsthagen joined the Nebraska Cooperative Fish and Wildlife Research Unit in 2020 after working at the U.S. Geological Survey Alaska Science Center, where she studied the evolutionary relationships among Arctic vertebrate populations. Dr. Sonsthagen was a post-doctoral fellow at the Smithsonian Institution, National Museum of Natural History, and National Zoo. She was awarded her PhD in Biological Sciences from the University of Alaska Fairbanks. Her research investigates ecological drivers of connectivity and adaptive capacity of species of conservation concern using field- and laboratory-based methods. Movement underlies many key processes in ecology and evolution and is critical for species' responses to environmental change. As such, she applies population- and community-driven approaches to evaluate genomic and demographic connectivity across the landscape, adaptive capacity, and the influence of species biology in shaping spatial and temporal genomic diversity to inform management decisions.

Jonathan Spurgeon received graduate degrees from the University of Missouri and the University of Nebraska–Lincoln, where he studied large-river ecology and conservation and management of fish populations. Before joining the Nebraska Cooperative Fish and Wildlife Research Unit in 2020, Dr. Spurgeon was an Assistant Professor at the University of Arkansas at Pine Bluff. A major focus of his research is quantifying the patchwork of habitat conditions needed by stream fishes across their life history. Research outcomes are intended to inform decisions regarding habitat restoration and conservation strategies, including translocation and suppression of nonnative species. Dr. Spurgeon uses diverse study designs and analytical techniques, including occupancy modeling and mark-recapture methods. Dr. Spurgeon is working across a gradient of systems from small streams in the Nebraska Sandhills and Ouachita Mountains to the largest rivers in North America.

Zhenghong Tang is a Professor and the Community and Regional Planning Program Director at the University of Nebraska–Lincoln. His research focuses on hazard mitigation and environmental planning, promoting an integrated approach to address long-term, uncertain, and strategic environmental and hazard challenges for Nebraska communities and beyond. Dr. Tang received his PhD in Urban and Regional Science from Texas A&M University.

W. Ryan Wishart is an Assistant Professor and Program Director of Sociology in the Department of Cultural and Social Studies at Creighton University. His research and teaching focus on environmental and political sociology, including problems of energy and environmental justice. Dr. Wishart completed his PhD in Sociology at the University of Oregon.

Aaron Young is a geologist with the Conservation and Survey Division (CSD) at the University of Nebraska–Lincoln. The CSD is Nebraska's state geological survey. He has a BS in physical geography from the University of Wisconsin–Platteville and an MS in Natural Resources Science from the University of Nebraska–Lincoln. Aaron has been a geologist with CSD since 2008. He has extensive experience with geologic and aquifer mapping in Nebraska, has overseen the Nebraska Groundwater-Level Monitoring Program, and has published the annual *Groundwater-Level Monitoring Report* since 2011.

Appendix B

Faith-Based Communities Survey

Survey 1: Religious leaders

This survey was open from February 14 to March 13, 2024, and distributed twice through a dataset of 1,782 email addresses. The dataset was constructed using public directories and includes general email addresses for local religious communities and direct email addresses for local religious community leaders. The first email was sent to the complete email list on February 14, 2024, and yielded 203 "undeliverable" bounce-back messages. A reminder survey email was sent on March 1, 2024.

To complete the survey, respondents had to indicate that they had not previously completed the survey, were at least 19 years of age, and were either the most senior appointed/ordained leader in their local religious community or had been authorized by that person to complete this survey on their behalf. Surveys were only considered completed if the respondent answered all required questions. In total, 99 surveys were completed for a 6% response rate among the 1,579 deliverable email addresses.

To analyze findings, the authors used qualitative research methods to conduct a content analysis of the qualitative question responses about why leaders had or had not taken identified steps to address human-caused climate change (Reid et al., 2017; Guest, 2023).

Survey 1 questions

Question 1: The purpose of this study is to assess how local religious community leaders in Nebraska have addressed climate change since the last state climate report in 2014. The results of this survey will be included in the 2024 Nebraska State Climate Report funded by the Nebraska Legislature and led by the Nebraska State Climate Office at the University of Nebraska–Lincoln. This study may help researchers learn more about how religious leaders and communities in Nebraska have responded to climate change since 2014.
For this study, a local religious community is a specific congregation, parish, synagogue, mosque, or other stable grouping of persons within a particular faith tradition. A local religious community leader is the most senior appointed/ordained leader of these communities (e.g., head pastor, rabbi, imam, etc.).
You are being asked to take part in this research because you have been identified as a local religious community leader in Nebraska. If you volunteer to participate in this study, you will be asked to share your experiences through this anonymous survey facilitated through Creighton University. Please note: if you are leader of several local religious communities (for example, you pastor multiple congregations or parishes), we ask that you complete one survey for each community.
The survey is completely voluntary and uncompensated and should only take 15–20 minutes to complete. The survey consists of five background questions and six core questions. All questions will be displayed one at a time. Before beginning the survey, please attempt to gather any unknown information (e.g., you may need to ask your community's facilities manager about actions taken to reduce operational greenhouse gas emissions). The six core questions are:

- Since 2014, how frequently has your most senior appointed/ordained leader spoken publicly to your local religious community about the need to take actions that will address climate change (e.g., sermons, homilies, etc.)?
- Since 2014, how frequently has your local religious community incorporated climate change concerns into communal prayer?
- Since 2014, to what degree has your religious community incorporated climate change concerns into religious education and catechesis (e.g., school curriculum, youth and young adult ministry, adult faith formation, etc.)?
- Since 2014, has your local religious community committed all or part of its operations (e.g., buildings, fleet vehicles, personnel travel, purchasing, etc.) to a comprehensive greenhouse gas reduction target like net zero carbon or net zero greenhouse gas emissions?
    - If yes, please identify the comprehensive greenhouse gas reduction target to which your local religious community has committed all or part of its operations.
- Since 2014, has your local religious community taken any new actions for the purpose of reducing the greenhouse gas emissions associated with its operations (e.g., buildings, fleet vehicles, personnel travel, purchasing, etc.)?
    - If yes, please identify the new actions your local religious community has taken since 2014 for the purpose of reducing the greenhouse gas emissions associated with its operations (e.g., buildings, fleet vehicles, personnel travel, purchasing, etc.).
- Since 2014, how often has your most senior appointed/ordained leader publicly supported to your local religious community international, federal, state, or local policies to address climate change?

Depending on your answer to each question, you may be prompted to answer follow-up questions that ask for additional detail, e.g., what factors you think lead to your answer. During the survey, you can return to any previous question and change your answer by clicking the left blue arrow button. You can leave the survey and resume your progress later, as long as you resume using the same Internet browser. **Please note the survey will close on Wednesday, March 13, at 11:59 pm CT.**

You will not be compensated for your time and there may not be direct benefits to you for your participation in this study. However, you may enjoy the benefit of contributing your community's insights to the 2024 Nebraska State Climate Report.

This study includes only minimal risks. Loss of confidentiality is a potential risk of taking part in this study. Several steps are being taken to ensure confidentiality: the survey is anonymous and does not collect any identifiers (e.g., name, email address); IP tracking is disabled on the online survey; data is stored on Creighton's password protected Qualtrics platform and accessible only to the Principal Investigator who will share select information with the student research assistant; I have completed the required Collaborative Institutional Training Initiative training prior to participating in this research project; no attempt will be made to contact or re-identify respondents; data will only be reported by faith tradition.

Participation in this study is voluntary and you can stop participating at any time.

If you have questions or concerns about this study, please contact Daniel R. DiLeo, PhD, associate professor and director of the Justice and Peace Studies Program at Creighton University. If you have questions about research participants' rights, contact the Creighton University Institutional Review Board (CU IRB) at 402-280-2126.
By choosing to participate in this online survey, you consent to participating in this study. Click here to read the Bill of Rights for Research Participants.

Question 2: For this survey, a local religious community is a specific congregation, parish, synagogue, mosque, or other stable grouping of persons within a particular faith tradition.

Have you previously completed this survey on behalf of this local religious community?

- ☐ No
- ☐ Yes (selecting this option will end the survey)

Question 3: Are you at least 19 years of age?

- ☐ Yes
- ☐ No (selecting this option will end the survey)

Q4 For this survey, a local religious community is a specific congregation, parish, synagogue, mosque, or other stable grouping of persons within a particular faith tradition.

Are you the most senior appointed/ordained leader in your local religious community or have you been authorized by that person to complete this survey on their behalf?

- ☐ Yes
- ☐ No (selecting this option will end the survey)

Question 4: For this survey, a local religious community is a specific congregation, parish, synagogue, mosque, or other stable grouping of persons within a particular faith tradition.

Are you the most senior appointed/ordained leader in your local religious community or have you been authorized by that person to complete this survey on their behalf?

- ☐ Yes
- ☐ No (selecting this option will end the survey)

Question 5: For this survey, a local religious community is a specific congregation, parish, synagogue, mosque, or other stable grouping of persons within a particular faith tradition.

Of which tradition is your local religious community a part?

- ☐ Buddhist
- ☐ Catholic
- ☐ Hindu
- ☐ Jewish
- ☐ Mormon
- ☐ Muslim
- ☐ Orthodox Christian
- ☐ Protestant - Evangelical
- ☐ Protestant - Mainline
- ☐ Other (please specify)

Question 6: Do you believe the Earth is getting warmer mostly because of human activity?

- ☐ Yes
- ☐ No
- ☐ Unsure

Question 7: For this survey, a local religious community is a specific congregation, parish, synagogue, mosque, or other stable grouping of persons within a particular faith tradition.

Since 2014, how frequently has your most senior appointed/ordained leader spoken publicly to your local religious community about the need to take actions that will address climate change (e.g., sermons, homilies, etc.)?

- ☐ Never
- ☐ Rarely
- ☐ Sometimes
- ☐ Often
- ☐ Unsure

Question 8: Since 2014, what factors have contributed to your most senior appointed/ordained leader speaking publicly to your local religious community about the need to address climate change?

Question 9: Since 2014, what factors have contributed to your most senior appointed/ordained leader not often (i.e., never, rarely, or sometimes) speaking publicly to your local religious community about the need to address climate change?

Question 10: For this survey, a local religious community is a specific congregation, parish, synagogue, mosque, or other stable grouping of persons within a particular faith tradition.

Since 2014, how frequently has your local religious community incorporated climate change concerns into communal prayer?

- ☐ Never
- ☐ Rarely
- ☐ Sometimes
- ☐ Often
- ☐ Unsure

Question 11: Since 2014, what factors have contributed to your local religious community often incorporating climate change concerns into communal prayer? [Text box]

If "Never, Rarely, or Sometimes" selected, display:

Question 12: Since 2014, what factors have contributed to your local religious community not often (i.e., never, rarely, or sometimes) incorporating climate change concerns into communal prayer?

Question 13: For this survey, a local religious community is a specific congregation, parish, synagogue, mosque, or other stable grouping of persons within a particular faith tradition.

Since 2014, to what degree has your religious community incorporated climate change concerns into religious education and catechesis (e.g., school curriculum, youth and young adult ministry, adult faith formation, etc.)?

- ☐ Not at All
- ☐ Little
- ☐ Moderately
- ☐ Significantly
- ☐ Unsure

Question 14: Since 2014, what factors do you think have contributed to your local religious community significantly incorporating climate change concerns into religious education and catechesis?

Question 15: Since 2014, what factors do you think have contributed to your local religious community not significantly (i.e., not at all, little, or moderately) incorporating climate change concerns into religious education and catechesis?

Question 16: For this survey, a local religious community is a specific congregation, parish, synagogue, mosque, or other stable grouping of persons within a particular faith tradition.

Since 2014, has your local religious community committed all or part of its operations (e.g., buildings, fleet vehicles, personnel travel, purchasing, etc.) to a comprehensive greenhouse gas reduction target like net zero carbon or net zero greenhouse gas emissions?

- ☐ Yes
- ☐ No
- ☐ Unsure

Question 17: Please identify the comprehensive greenhouse gas reduction target to which your local religious community has committed all or part of its operations.

Question 18: What factors do you think contributed to your local religious community committing all or part of its operations to a comprehensive gas reduction target?

Question 19: What factors do you think contributed to your local religious community not committing all or part of its operations to a comprehensive greenhouse gas reduction target like net zero carbon or net zero greenhouse gas emissions?

Question 20: For this survey, a local religious community is a specific congregation, parish, synagogue, mosque, or other stable grouping of persons within a particular faith tradition.

Since 2014, has your local religious community taken any new actions for the purpose of reducing the greenhouse gas emissions associated with its operations (e.g., buildings, fleet vehicles, personnel travel, purchasing, etc.)?

- ☐ Yes
- ☐ No
- ☐ Unsure

Question 21: Please identify the new actions your local religious community taken since 2014 for the purpose of reducing the greenhouse gas emissions associated with its operations (e.g., buildings, fleet vehicles, personnel travel, purchasing, etc.)

Question 22: What factors do you think contributed to your local religious community taking new actions since 2014 for the purpose of reducing the greenhouse gas emissions associated with its operations?

Question 23: What factors do you think contributed to your local religious community not taking new actions since 2014 for the purpose of reducing the greenhouse gas emissions associated with its operations?

Question 24: For this survey, a local religious community is a specific congregation, parish, synagogue, mosque, or other stable grouping of persons within a particular faith tradition.

Since 2014, how often has your most senior appointed/ordained leader publicly supported to your local religious community international, federal, state, or local policies to address climate change?

- ☐ Never
- ☐ Rarely
- ☐ Sometimes
- ☐ Often
- ☐ Unsure

Question 25: What factors do you think have contributed to your most senior appointed/ordained leader often publicly supporting to your local religious community international, federal, state, or local policies to address climate change since 2014?

Question 26: What factors do you think contributed to your most senior appointed/ordained leader not often (i.e., never, rarely, or sometimes) publicly supporting to your local religious community international, federal, state, or local policies to address climate change?

Survey 2: 2024 Nebraska Annual Social Indicators Survey

Survey 2 used the 2024 Nebraska Annual Social Indicators Survey (NASIS 2024), a representative biannual omnibus (single questionnaire) survey that is generalizable to the Nebraska population and administered by the Bureau of Sociological Research (BOSR) at the University of Nebraska–Lincoln. As an omnibus instrument, the survey includes core demographic questions and those submitted by researchers. To ascertain whether and how Nebraskans experienced their religious leaders discussing and acting on climate change, the lead author for Chapter 13 (Dr. DiLeo) submitted ten questions to NASIS 2024 of which the following seven are used in this chapter.

The NASIS 2024 Methodology Report describes the survey as a mixed-mode mail and web instrument administered to a representative sample of 10,000 Nebraska households between July 12, 2024, and October 25, 2024. Respondents had to be 19 years of age or older, and surveys were considered complete even if some questions were unanswered. 2,232 (902 via web, 1,330 via mail) surveys were completed for a 23.2% response rate.

Survey 2 questions

Question 1: Do you believe the Earth is getting warmer mostly because of human activity?

- ☐ Yes
- ☐ No
- ☐ Unsure

Question 2: Since 2014, how frequently have you experienced your local religious community leaders speaking publicly to your local religious community (e.g., sermon) about the need to address climate change?

- ☐ Never
- ☐ Rarely
- ☐ Sometimes
- ☐ Often
- ☐ Unsure

Question 3: Since 2014, how often have you experienced your local religious community leaders speaking publicly to your local religious community (e.g., sermon) affirming the importance of public policy to address climate change?

- ☐ Never
- ☐ Rarely
- ☐ Sometimes
- ☐ Often
- ☐ Unsure

Question 4: Since 2014, how frequently have you experienced your local religious community incorporating climate change concerns into communal prayer?

- ☐ Never
- ☐ Rarely
- ☐ Sometimes
- ☐ Often
- ☐ Unsure

Question 5: Since 2014, how much has your religious community incorporated climate change concerns into religious education (e.g., school curriculum, youth and young adult ministry, adult faith formation, etc.)?

- ☐ Not at all
- ☐ Slightly
- ☐ Moderately
- ☐ Significantly
- ☐ Unsure

Question 6: Since 2014, has your local religious community taken any new actions to reduce the greenhouse gas emissions from its operations (e.g., buildings, fleet vehicles, personnel travel, purchasing, etc.)?

- ☐ Yes
- ☐ No
- ☐ Unsure

Question 7: As of today, has your local religious community committed all or part of its operations (e.g., buildings, fleet vehicles, personnel travel, purchasing, etc.) to net zero carbon or net zero greenhouse gas emissions?

- ☐ Yes
- ☐ No
- ☐ Unsure

Appendix C

Evaluated Plans and Assessments

This report included an extensive national review of climate resilience actions, trends, and best practices. paleBLUEdot analyzed climate vulnerability assessments and adaptation plans from all 50 states and the District of Columbia, identifying relevant actions across sectors aligned with Nebraska's Focus Topics. Additionally, EOR staff reviewed Nebraska-specific climate guidance documents and reports that address potential climate impacts and adaptation strategies for communities across the state. The plans include the following:

Nationwide state-level plans

Table AC.1. List of state-level plans (and their release date) analyzed for this report. The climate resilience, adaptation, and action plans (column 2) were identified through internet searches of publicly available data. The Priority Climate Action Plans (column 3) are available via a searchable database found at https://www.epa.gov/inflation-reduction-act/climate-pollution-reduction-grants. These plans were developed as part of the U.S. Environmental Protection Agency's Climate Pollution Reduction Grants, authorized and funded under Section 60114 of the Inflation Reduction Act. More information about this program and its current status can be found at: https://www.epa.gov/inflation-reduction-act/climate-pollution-reduction-grants.

STATE	CLIMATE RESILIENCE, ADAPTATION ACTION PLAN	PRIORITY CLIMATE ACTION PLAN
ALABAMA	NA	Priority Climate Action Plan (2024)
ALASKA	NA	State of Alaska: Priority Sustainable Energy Action Plan (2024)
ARIZONA	NA	The Clean Arizona Plan: Priority Climate Action Plan (2024)
ARKANSAS	Energy and Environment Innovation Plan (due July 2025)	Arkansas Energy and Environment Innovation Plan: Priority Action Plan (2024)
CALIFORNIA	California Climate Adaption Strategy (draft 2024)	The State of California's Draft Priority Climate Action Plan (2024)
COLORADO	Colorado Climate Plan (2015)	Colorado Priority Climate Action Plan (2024)

STATE	CLIMATE RESILIENCE, ADAPTATION ACTION PLAN	PRIORITY CLIMATE ACTION PLAN
CONNECTICUT	Connecticut Climate Change Preparedness Plan (2011); Governor's Council on Climate Change (GC3) Policy Recommendation Report (2021); GC3 Policy Recommendation Building a Low Carbon Future for Connecticut (2018); Connecticut Greenhouse Gas Inventory (2023)	EPA Climate Pollution Reduction Grant Planning Grant First Deliverable: A Priority Climate Action Plan (2024)
DELAWARE	Delaware Climate Action Plan (2021)	Delaware Climate Pollution Reduction Plan Submitted to U.S. EPA in partial fulfillment of Assistance Agreement 95316201 (2024)
FLORIDA	Florida's Energy & Climate Change Action Plan (2008)	NA
GEORGIA	Due in 2025 or 2026	Peach State Voluntary Emission Reduction Plan (March 2024)
HAWAI'I	Hawai'i 2050 Sustainability Plan (2021)	Hawai'i Priority Climate Action Plan (2024)
IDAHO	NA	Gem State Air Quality Initiative Priority Plan (2024)
ILLINOIS	Illinois Department of Natural Resources Climate Action Plan (2023)	State of Illinois Priority Climate Action Plan (2024)
INDIANA	Due in 2025	Indiana Priority Climate Action Plan (2024)
IOWA	Iowa Climate Change Advisory Council Final Report (2008)	NA
KANSAS	NA	Kansas Emission Reduction and Mitigation Plan (2024)
KENTUCKY	Final Report of the Kentucky Climate Action Plan Council (2011)	NA
LOUISIANA	Our Land and Water: A Regional Approach to Adaptation (2019)	Louisiana Priority Climate Action Plan (2024)

STATE	CLIMATE RESILIENCE, ADAPTATION ACTION PLAN	PRIORITY CLIMATE ACTION PLAN
MAINE	Maine Won't Wait (2020)	State of Maine Priority Climate Action Plan (2024)
MARYLAND	Maryland Climate Adaptation and Resilience Framework Recommendations: 2021–2030	Priority Climate Action Plan State of Maryland (2024)
MASSACHUSETTS	ResilientMass Plan (2023)	Massachusetts Priority Climate Action Plan (March 2024)
MICHIGAN	Michigan Climate Action Council Climate Action Plan (2009)	Implementing the MI Health Climate Plan: Michigan's Priority Climate Action Plan (2024)
MINNESOTA	Climate Action Framework (2022)	Priority Climate Action Plan (February 2024)
MISSISSIPPI	Due fall 2025	Priority Climate Action Plan (2024)
MISSOURI	Due fall 2025	Missouri Plan for Environmental Improvement Grants (February 2024)
MONTANA	Montana Climate Solutions Plan (2020)	Montana Climate Pollution Reduction Priorities (2024)
NEBRASKA	Due fall 2025	Nebraska Priority Climate Action Plan (2024)
NEVADA	NA	State of Nevada Priority Climate Action Plan (2024)
NEW HAMPSHIRE	The New Hampshire Climate Action Plan: A Plan for New Hampshire's Energy, Environmental and Economic Development Future (2009)	State of New Hampshire Priority Climate Action Plan (2024)
NEW JERSEY	New Jersey Climate Resilience Strategy (2021)	New Jersey's Priority Climate Action Plan (2024)
NEW MEXICO	New Mexico's Climate Adaptation and Resilience Plan (2024)	Priority Climate Action Plan (2024)

STATE	CLIMATE RESILIENCE, ADAPTATION ACTION PLAN	PRIORITY CLIMATE ACTION PLAN
NEW YORK	Climate Act: New York's Scoping Plan (2022)	Climate Pollution Reduction Grants Program Priority Climate Action Plan for New York State (2024)
NORTH CAROLINA	North Carolina Climate Risk Assessment and Resilience Plan (2020)	North Carolina Priority Climate Action Plan (2024)
NORTH DAKOTA	NA	North Dakota Priority Climate Action Plan (2024)
OHIO	NA	Priority Resiliency Plan (March 2024)
OKLAHOMA	NA	Oklahoma's Priority Climate Action Plan (2024)
OREGON	Oregon Climate Change Adaptation Framework (2021)	Oregon's Priority Climate Action Plan (2024)
PENNSYLVANIA	Pennsylvania Climate Action Plan (2021)	Pennsylvania's Priority Climate Action Plan (2024)
RHODE ISLAND	Resilient Rhody: An Actionable Vision for Addressing the Impacts of Climate Change in Rhode Island (2018)	Priority Climate Action Plan (2024)
SOUTH CAROLINA	NA	South Carolina Priority Climate Action Plan (2024)
SOUTH DAKOTA	NA	NA
TENNESSEE	NA	Tennessee Volunteer Emission Reduction Strategy: Priority Climate Action Plan (2024)
TEXAS	NA	Climate Pollution Reduction Grants Priority Action Plan for the State of Texas (2024)
UTAH	NA	Beehive Emission Reduction Plan: Priority Plan (2024)
VERMONT	NA	Climate Pollution Reduction Grant Priority Action Plan (2024)

STATE	CLIMATE RESILIENCE, ADAPTATION ACTION PLAN	PRIORITY CLIMATE ACTION PLAN
VIRGINIA	NA	Commonwealth of Virginia Priority Climate Action Plan (2024)
WASHINGTON	Preparing for a Changing Climate: Washington State's Integrated Climate Response Strategy (2012)	Priority Resiliency Plan (March 2024)
WEST VIRGINIA	NA	EnergyWise West Virginia: Priority Energy Action Plan (2024)
WISCONSIN	NA	Wisconsin Emissions Reduction Roadmap (2024)
WYOMING	NA	NA
WASHINGTON, DC	Clean Energy DC: The District of Columbia Climate and Energy Action Plan (2018)	District of Columbia Priority Climate Action Plan (2024)

State of Nebraska and local plans

Table AC 2. List of plans from Nebraska (and their release date) analyzed for this report

PLAN	AUTHOR/AGENCY	JURISDICTION
Omaha Climate Action and Resilience Plan (2024)	City of Omaha	Municipality
Resilient Lincoln 2021–2027 Climate Action Plan (2021)	City of Lincoln	Municipality
Understanding and Assessing Climate Change: Implications for Nebraska (2014)	University of Nebraska–Lincoln	Higher Education
Comprehensive Plans and Flood Risk: A Resource Guide for Nebraska Communities (2014)	Nebraska Department of Natural Resources	State Agency
Center for Resilience in Agricultural Working Landscapes	University of Nebraska–Lincoln	Higher Education
Nebraska Natural Resource District Master Plans (various)	Various	Natural Resource District
Columbus Comprehensive Plan (2018)	City of Columbus	Municipality
Nāwo Wapānagun Hinmányiwi: Pathways to Climate Resilience (2024)	Iowa Tribe of Kansas and Nebraska	Tribal
How to Support a Climate-Resilient Environment (n.d.)	Nebraska Statewide Arboretum	Private
State Climate Summary: Nebraska 2022	NCICS/NOAA	Higher Education
Implications of Climate Change for Nebraska: Summary Report of Sector-Based Roundtable Discussions (2016)	University of Nebraska–Lincoln	Higher Education
State of Nebraska Disaster Recovery Action Plan (2021)	Department of Economic Development	State Agency

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In compliance with Executive Order 14303 ("Restoring Gold Standard Science"), the White House Office of Science and Technology Policy's June 23, 2025 Memorandum ("Agency Guidance for Implementing Gold Standard Science in the Conduct & Management of Scientific Activities"), 15 USC § 2904 ("National Climate Program"), 15 USC § 2934 ("National Global Change Research Plan"), and 33 USC § 893a ("NOAA Ocean and Atmospheric Science Education Programs"), some of the websites, webpages, and references hosted by U.S. federal agencies have been removed or modified.

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