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Ameren Water Resilience Assessment

Final Report

October 9, 2018

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Acronyms and Abbreviations

CICS-NC	North Carolina Institute for Climate Studies
CMIP3	Coupled Model Intercomparison Project Phase 3
CMIP5	Coupled Model Intercomparison Project Phase 5
CY	calendar year
ECB	Engineering and Construction Bulletin
EPA	U.S. Environmental Protection Agency
FAQ	Frequently Asked Questions
GCM	Global Circulation Model
GHG	greenhouse gas
GIS	geographic information system
HUC	Hydrologic Unit Code
IL	Illinois
in/day	inch per day
IPCC	Intergovernmental Panel on Climate Change
km	kilometer
km^2	square kilometer(s)
MO	Missouri
MT	Montana
NASA	National Aeronautics and Space Administration
NC3	Third National Climate Assessment
NC4	Fourth National Climate Assessment
NCA	National Climate Assessment
NCEI	National Centers for Environmental Information
NOAA	National Oceanic and Atmospheric Administration
PDSI	Palmer Drought Severity Index
PRB	Powder River Basin
RCP	Representative Concentration Pathway
U.S.	United States
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USDM	U.S. Drought Monitor
USGCRP	U.S. Global Change Research Program

USGS	U.S. Geological Survey
WRI	World Resources Institute
WY	Wyoming

Executive Summary

Global climate change can impact temperatures, precipitation, streamflow and drought across the United States, including in the Midwest and Great Plains regions. The effects of climate change will vary depending on location, and the implications of these effects will be different for different parts of the Ameren organization and supply chain.

This report assesses the current and future availability of water resources across a broad region, including the Midwest and Great Plains (Section 2, Review of Climate Science for the Region) under a variety of potential climate change scenarios. The report focuses on natural factors and how changes in temperature and precipitation as a result of climate change may influence water resources and water availability. A study area was defined for this report to include the Upper Mississippi Water Resources Region and the lower Missouri Water Resources Region, which represents Ameren's service area, as well as specific portions of the Powder River Basin in Wyoming, which represents a key portion of Ameren's supply chain. Scientific literature and available online tools and datasets were reviewed in order to assess historical climate observations and projected climate trends for all three of these focus regions. Significant climate change factors, including temperature, precipitation, extreme weather events, drought and streamflow were used to document how historical trends relate to future projections incorporating climate models.

Research was conducted in order to inform Ameren of available tools and datasets for use in considering the implications of climate change, as well as in understanding drought and flood projections and how this information can be utilized. An overview of four tools and datasets is provided (Section 3, Overview of Selected Climate Change Tools and Datasets); including a description of purpose, as well as a description of what specific variables can be obtained and used from each source.

Based on the literature review and through use of tools described, an overview assessment is conducted on the potential implications of climate change factors on the three focus regions within the study area (Section 4, Focus on Watersheds). Findings are presented in tables for each of the focus regions reflecting historic trends and projections of key characteristics related to water resources and water availability.

Water stress is projected to be near normal for most areas within Ameren's service area in the time period around 2030. With precipitation projected to see a slight increase, the Upper Mississippi and the lower portion of Missouri Regions are anticipated to see an increasing trend for maximum monthly flow and flooding events. Precipitation is also expected to have seasonal variability, with specific increases seen in the spring. However, the projected increase in temperature and evaporation and potentially lower streamflow in the summer is anticipated to outweigh a projected increase in average annual precipitation, and contribute to an increase in drought events by midcentury, particularly in summer months.

The Powder River Basin, already considered an arid region, may experience increased water stress. The potentially higher temperatures, higher evaporation and lower summer streamflows are likely to contribute to a potential future increase in drought severity and frequency. The projections for the future flooding trend are mixed as the historical instantaneous peak flows in this area has been steadily decreasing, while projected maximum monthly flow is shown to increase in the future.

Overall, the three regions within the study area are projected to have increased seasonal precipitation variability, future drought and potential water stress for the study horizon through 2030, which are important when considering the need for consistent reliable water resources.

In Summary, this Water Resource Resilience Assessment

- Considered a study area of the Upper Mississippi Water Resources Region and the lower Missouri Water Resources Region, as well as specific portions of the Powder River Basin in Wyoming.
- Reviewed available climate change literature and data, with a focus on information concerning the study area. All three watersheds have experienced and are projected to continue to experience increasing average annual temperatures and seasonal variability in precipitation. The study area has seen an overall increase in annual precipitation, which has been primarily concentrated in heavy precipitation events. Average streamflows across the study area have generally increased; however, projections show a mix of increases and reductions in streamflow across the area. The study area's soil moisture content has experienced both wetting and drying trends, though is projected to further dry across the study area. Droughts are projected to increase in frequency and duration regardless of increasing precipitation, due to higher temperatures and evapotranspiration rates.
- Evaluated four different publicly available climate change tools and datasets: the World Resources Institute's Aqueduct and Water Risk Atlas, the U.S. Army Corps of Engineers' Climate Hydrology Assessment Tool, the National Oceanic and Atmospheric Administration's Climate Explorer Tool, and the U.S. Drought Monitor.
- Based on the climate change tools and datasets, concluded that for the time period around 2030 water stress is projected to be near normal for most regions within the study area, but is likely to increase in the already arid Powder River Basin. Average annual precipitation has been variable to increasing, but is projected to increase in the future across all three watersheds. Flooding has been increasing and is projected to continue to increase in the study area; however, flooding is more variable both historically and projected in Powder River Basin. Drought has been variable historically, but is projected to increase across all three watersheds.

1. Introduction

1.1 Purpose of the Report

Through its operating companies, Ameren Corporation provides energy, distribution, and transmission services to approximately 2.4 million electric and 900,000 natural gas customers across 64,000 square miles in the states of Missouri and Illinois. To provide these services, Ameren has 17 coal-fired, nuclear, natural gas or oil-fired, hydroelectric, and renewable energy centers across the service area.[1] These energy centers require a number of natural resources to function, one of which is water. An adequate, consistent, and sustainable amount of water is essential for cooling plant operations on a daily basis. As this is a required aspect of Ameren's power generation, it is critical to optimize the use of this resource as well as understand the adequacy of projected water resource conditions currently and into the future. Ameren's generating facilities obtain their water supply from either the Missouri or Mississippi Rivers. Using various assumptions and variables, this report uses specific reports, tools, and datasets to assess the reliability of the future water supply in the areas of operation and identifies processes and procedures that could be used to assess water resources risk.

The effects of global climate change on the Upper Midwest and Great Plains Regions of the United States (U.S.) may influence water availability and river flows in the geography encompassing Ameren's operational footprint and supply chain. The scientific literature and available online tools and datasets were reviewed in order to assess historical climate observations and projected climate trends for all three of these focus regions. Significant climate change factors, including temperature, precipitation, extreme weather events, drought and streamflow, were used to document how historical trends relate to future projections incorporating climate models. This report summarizes historical climate and river flow trends and projected climate change impacts to geographical areas of interest, including potential changes in temperature, precipitation, and extreme weather events (Section 2, Review of Climate Science for the Region). The report will also provide an overview of available tools for evaluating water risks so that Ameren can continue to monitor and assess water resource availability in the future (Section 3, Overview of Selected Climate Change Tools and Datasets). Finally, this report will take a deeper look at the study area of significance to Ameren, which includes: the Upper Mississippi Water Resources Region (Upper Mississippi Region), the lower Missouri Water Resources Region (lower Missouri Region), and specific parts of the Powder River Basin, which is part of the upper Missouri Water Resources Region (Section 4, Focus on Watersheds). The report will assess potential changes in consistent water availability in these three areas in future time periods based on the available information on projected climate change.

1.2 Background

1.2.1 Study Area

The study area of this report includes Ameren's service area in Illinois and Missouri (see Figure 1) and portions of the Powder River Basin (PRB) in Wyoming, which provides the majority of Ameren's coal supply (see Figure 2). Highlighted in Figure 1 are Hancock County, Illinois, (site

[1] https://www.ameren.com/-/media/corporate-site/Files/AboutAmeren/AmerenCorporateFactSheet.pdf

of the Keokuk facility) and Boone County, Missouri, which will serve as representative counties in Section 4, Focus on Watersheds, for assessing climate data.

Ameren's energy centers are located in its service area, which spans most of Illinois and the northern and eastern parts of Missouri. The service area contains 158 counties and is located in the Upper Mississippi and lower Missouri Regions. The U.S. Geological Survey (USGS) divides the U.S. into 21 water resources regions based on two-digit Hydraulic Unit Codes (HUC); these regions are also referred to as HUC2 regions.

Located in southeastern Montana and northeastern Wyoming, the PRB is a geological basin, a lower elevation formed roughly 65 million years ago when the surrounding mountain masses were elevated. Rich in coal deposits, the PRB stretches from the Bighorn Mountains to the Black Hills and includes the watersheds of the Tongue, Little Missouri, Belle Rouche, and Cheyenne Rivers. The area of the PRB included in this study is the southern portion within Converse and Campbell Counties in Wyoming. It is important to understand the climate and water risks to this region, as it is a significant part of Ameren's supply chain. This area of northeastern Wyoming has large deposits of minerals, coal, and petroleum, and therefore mining and energy industries, as well as other land uses, already compete for water.

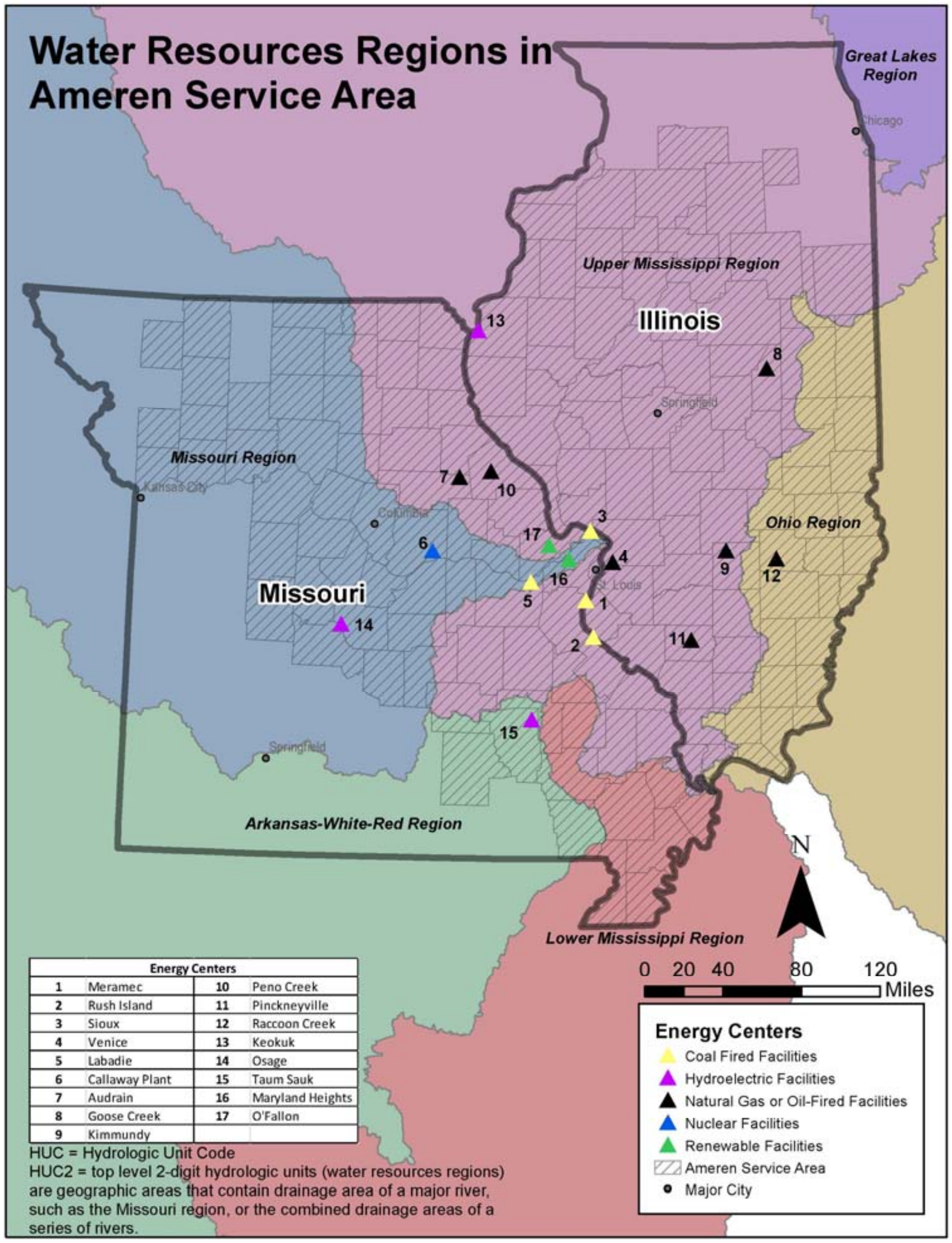

Figure 1: Map of Ameren Service Area and Energy Centers[2]

[2] "Counties of interest" in the map legend refers to those assessed in Section 4.

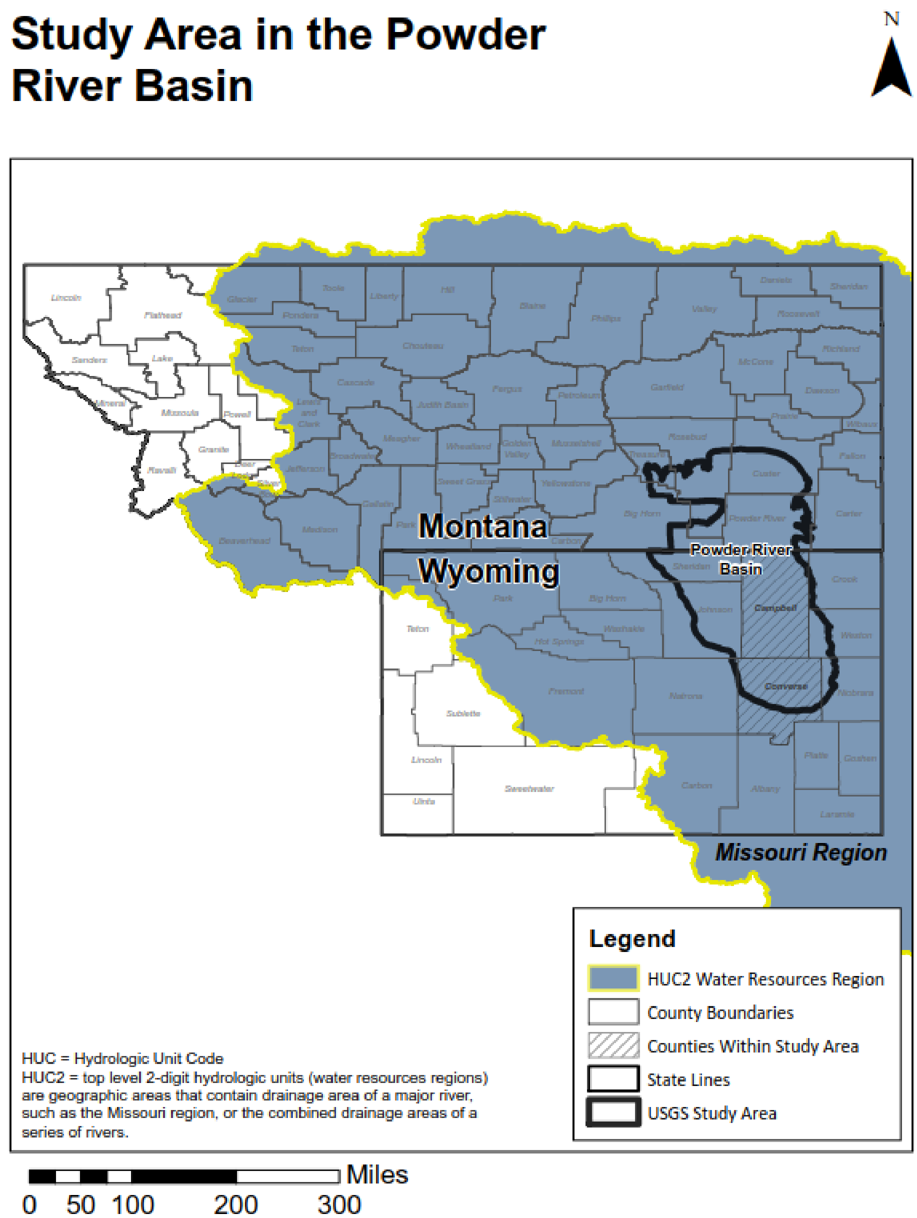

Figure 2: Map of Powder River Basin Study Area

1.2.2 Existing Water Use

Ameren energy centers withdraw and discharge billions of gallons of water per year from the Mississippi and Missouri River Basins, primarily for thermal cooling for energy generation and also to convey ash to ponds. While a snapshot of overall water usage, the information presented in this section is meant to further emphasize the importance of consistent water availability to Ameren, and thus underline the purpose of this study to better understand how climate change may affect water resources in the study area.

Table 1 provides the annual totals for water withdrawals and discharges from the five Ameren energy centers. Coal-fired and nuclear energy centers account for the most significant water usage.

Nearly 100 percent of the water withdrawals are from fresh surface water, with less than 1 percent of the withdrawals coming from groundwater sources. Similarly, nearly 100 percent of the water that is discharged goes back into rivers. Ameren uses larger quantities of water from the Mississippi River Basin than it does from the Missouri River Basin. Based on the totals from CY 2013 to CY 2016, 61 percent of Ameren's withdrawals and 69 percent of its discharges were from and into the Mississippi River Basin, as shown on Figure 3.

Table 1: Annual Water Withdrawals and Discharges from Five Ameren Energy Centers (billion gallons)[3]

	CY 2013	CY 2014	CY 2015	CY 2016
Missouri River Basin				
Withdrawal	437	406	470	451
Discharge	430	399	462	443
Mississippi River Basin				
Withdrawal	664	729	689	641
Discharge	663	728	688	640

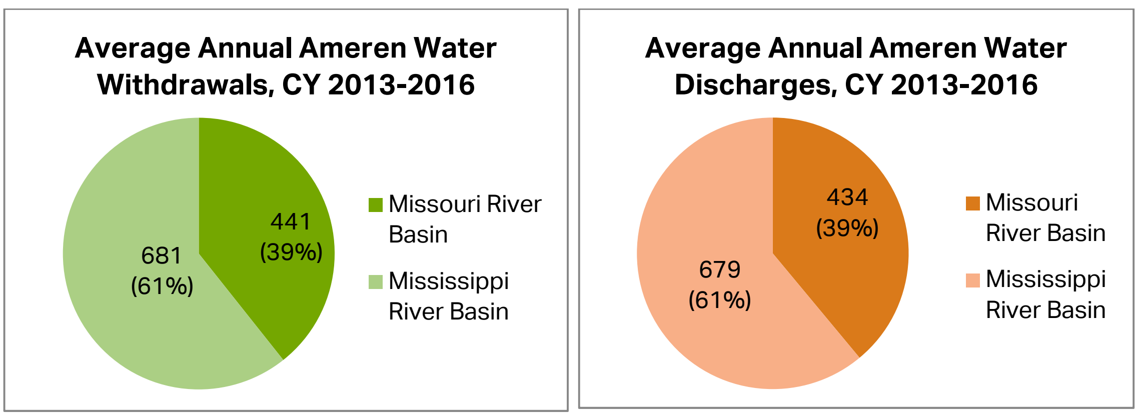

Figure 3: Average Annual Water Withdrawals and Discharges from CY 2013 to CY 2016 (billion gallons)

Ameren also reports its water consumption at these five energy centers to the CDP, which equals the difference between withdrawal and discharge quantities. Generally, nuclear operations have a higher consumption rate, as water is evaporated in its cooling operation using the "natural draft tower" process, while the "once-through" systems at the coal-fired energy centers return most of the water withdrawn to the sources.

For more information on Ameren's water use, see http://amerencsr.com/[4] and https://www.cdp.net/en.

[3] For this report, water data was sourced from Ameren's publicly available Carbon Disclosure Project (CDP) Water Reports. These data represent annual totals from five energy centers, all located in Missouri. The energy centers include four coal-fired energy centers (Labadie, Meramec, Rush Island, and Sioux) and one nuclear energy center (Callaway). Three of the energy centers are located in the Upper Mississippi Region (Meramec, Rush Island, and Sioux), while two are located in the lower Missouri Region (Labadie and Callaway). In addition to these five, there are three hydroelectric generation facilities (Osage, Taum Sauk, and Keokuk). The Osage and Taum Sauk energy centers are located in the lower Missouri Region and the Keokuk energy center is located in the Upper Mississippi Region (Carbon Disclosure Project 2014-2017)

[4] Ameren 2017

1.2.3 Existing Water Supply Sources

Ameren withdraws its water from the portions of the Mississippi and the Missouri Rivers, which are located in the USGS Water Resource Regions, Region 07 - Upper Mississippi and Region 10 - Missouri. The Upper Mississippi Region includes the drainage of the Mississippi River Basin above the confluence with the Ohio River, excluding the Missouri River Basin. The Upper Mississippi Region includes parts of Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, South Dakota, and Wisconsin. The Missouri River Region includes the drainage of: (a) the Missouri River Basin, (b) the Saskatchewan River Basin, and (c) several small closed basins. The Missouri River Region includes all of Nebraska and parts of Colorado, Iowa, Kansas, Minnesota, Missouri, Montana, North Dakota, South Dakota, and Wyoming. As can be seen on Figure 4, both regions are considerably large, covering broad geographic areas.

These watersheds are further described in Section 4, Focus on Watersheds.

Figure 4: Water Resource Regions in the United States[5]

[5] https://water.usgs.gov/wsc/map_index.html

2. Review of Climate Science for the Region

When considering factors that may influence water resources, the primary factors include temperature and precipitation, which both influence snowmelt, as well as water consumption from upstream users. This report focuses solely on natural factors and how changes in temperature and precipitation as a result of climate change may influence water resources and water availability. The report does not consider how future consumption from other water users in the region may affect Ameren's access to water resources, as such information is not known or otherwise publicly available.

Potential climate change impacts across the study area may vary due to the wide range of topographies and geographies. For this section, four climate factors are considered: temperature, precipitation, extreme events, and drought/water availability. Each of these factors can impact regional water resources, and therefore affect consistent and reliable water availability. Each climate factor is explained further in the sections that follow.

2.1 Climate Change Resources

Multiple climate science resources were assessed that cover various geographical scales associated with Ameren's service area and the PRB. The publications and data sources used in this report were selected based on their wide use in peer-reviewed publications and general acceptance, having been produced by thought-leading institutions and organizations within the climate science community. Most of the organizations that produced the publications and data sources referenced below and used to perform the analysis described in this report include leading climate scientists and related technical experts. Several of the publications represent comprehensive analysis of many scientific papers, studies, and models relevant to climate scienceg. The resources reviewed cover climate impacts at the regional (Midwest, Great Plains), water resource region (Upper Mississippi, Missouri), and state (Illinois, Missouri, and Wyoming) levels.

2.1.1 Recent U.S. Climate Change and Hydrology Literature Applicable to U.S. Army Corps of Engineers Missions

The U.S. Army Corps of Engineers (USACE) report, *Recent US Climate Change and Hydrology Literature Applicable to the US Army Corps of Engineers Missions,* covers 21 water resource regions of the U.S. Each of the 21 regional reports summarizes observed and projected climate and hydrological patterns sourced from reputable peer-reviewed literature and authoritative national and regional reports. The regional reports for Region 7 – Upper Mississippi and Region 10 – Missouri were reviewed for this project, as these encompass both the service and the major coal supply chain areas for Ameren (USACE 2015a, 2015b).

The USACE literature review reports are based on the HUC2 regions that cover the entire U.S. The large regional approach is helpful for understanding general trends in climate data. Specific sources are cited that can offer state-specific information; however, the approach of the report remains at this higher, regional level. As Ameren moves forward with assessing water risk, it would be important to remember that these sources do not offer detailed information on smaller geographical areas.

2.1.2 National Climate Assessment

The U.S. Global Change Research Program (USGCRP) is the federal program consisting of 13 departments and agencies[6] tasked with studying and reporting on climate science and global changes in the environment. Among other initiatives, the USGCRP produces the National Climate Assessment (NCA) every 4 years. This report focuses solely on the U.S. and provides an assessment of climate impacts and projections for individual regions and sectors.

The USGCRP produced its third NCA report, titled *Climate Change Impacts in the United States: The Third National Climate Assessment* (NC3). Of direct relevance to this study, the 2014 NCA report includes specific chapters (Chapters 18 and 19) on climate change in the Midwest and the Great Plains. Each chapter provides an overview of the observed regional climate trends as well as climate projection scenarios downscaled specifically for the region featured in the chapter. The Midwest region of the NCA consists of Ameren's service area in Missouri and Illinois along with the surrounding states of Iowa, Minnesota, Wisconsin, Michigan, Indiana, Michigan, and Ohio (Pryor et al. 2014). The Great Plains region of the NCA consists of the PRB in Wyoming along with the surrounding states of Montana, North and South Dakota, Nebraska, Kansas, Oklahoma, and Texas (Shafer et al. 2014).

Chapter 4 ("Energy, Supply, and Use") of the NCA report provides detailed suggestions on appropriate adaptation actions for the energy sector in response to anticipated climate change (Dell et al. 2014). Lastly, Chapter 2 of the report ("Water Resources") assesses the water cycle, supply, use, and management in a changing climate (Georgakakos et al. 2014). The fourth NCA report is expected to be published in late 2018.

The NCA reports reflect a user-friendly approach to climate change science, trends and projections, which could be helpful to Ameren when the company communicates climate information externally or internally. The USGCRP also offers more-focused regional reports, which can be useful when narrowing in on a specific geographical area in the Midwest. The NCA report also covers the energy sector (see the report's Chapter 4, "Energy, Supply, and Use"), which Ameren could use when considering the energy sector as a whole and potential future impacts. Since the initial draft of this report, the USGCRP has released their *Climate Science Special Report*, which provides the foundation for Volume II of the Fourth National Climate Assessment (NC4). Information from this update is not included in this report.

2.1.3 The National Oceanic and Atmospheric Administration's National Centers for Environmental Information

The National Oceanic and Atmospheric Administration (NOAA) is an American scientific governmental agency that focuses on the conditions of past, present, and future climate, weather, oceans, and coasts. The NOAA includes the National Centers for Environmental Information (NCEI), which provides public access to environmental data, including atmospheric, coastal, oceanic, and geophysical data. The NCEI regularly updates their "State of the Climate" website,[7] which provides monthly summaries of climate-related occurrences on both a global and national scale. Recent national temperature and precipitation information from this website was reviewed for this report. The NOAA's regularly updated maps are useful when tracking climate data and recent trends (NOAA NCEI 2017b).

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[6] Agency for International Development; U.S. Department of Agriculture; National Oceanic and Atmospheric Administration; U.S. Department of Defense; U.S. Department of Energy; National Institutes of Health; U.S. Department of State; U.S. Department of Transportation; U.S. Geological Survey; Environmental Protection Agency; National Aeronautics and Space Administration; National Science Foundation; Smithsonian Institution

[7] https://www.ncdc.noaa.gov/sotc/

The NCEI and the North Carolina Institute for Climate Studies (CICS-NC) produced State Climate Summaries following the 2014 NCA report. These summaries covered data on historical climate variations and trends, future climate model projections of climate conditions during the 21st century, and past and future conditions of sea levels and coastal flooding by state. The state reports for Illinois and Wyoming (Frankson, Kunkel, et al. 2017a, 2017b) and the state report for Missouri (Frankson, Kunkel, Champion, and Stewart 2017) were reviewed for this assessment.

As the State Climate Summaries are similar to the NCA reports, they also offer a user-friendly approach to state-specific historical and projected climate information. This smaller geographical approach is useful when narrowing in on changes near specific Ameren Energy Centers and parts of the service area. The NOAA's external website does not currently state whether these will be updated with the NC4 release.

2.1.4 Intergovernmental Panel on Climate Change

The Intergovernmental Panel on Climate Change (IPCC) is an international body established by the United Nations Environmental Program to summarize and present the current state of climate change science and information. IPCC reports are collaborative efforts with contributions from thousands of scientists and experts from around the world. Assessment reports are regularly updated (roughly every 6 years) to provide the most current information regarding climate change. The IPCC reports also provide consensus in terms of confidence levels of climate change observed and projected effects. The most recent report, the Synthesis Report of the IPCC Fifth Assessment Report (AR5), was released in 2014 and reviewed for this assessment. This report provides an overview of the state of knowledge concerning the science of climate change (IPCC 2014).

The IPCC AR5 used four Representative Concentration Pathways (RCPs) emissions scenarios to discuss and project potential future conditions and to describe how each will generate different levels of climate change. Each of the four unique RCPs describes a different climate future depending on how much greenhouse gases are emitted in future years; the scenarios used are RCP2.6, RCP4.5, RCP6.0, and RCP8.5 (Table 2). Figure 5 presents a summary of the CO_2 emissions in the RCPs and their associated Working Group III (WGIII) scenario categories. Published in the scientific literature, the scenarios represent a set of possible future developments of complex systems such as climate change policies and technological advancements (IPCC 2014).

Table 2: RCPs used in AR5

IPCC RCP	Description
RCP2.6	Stringent mitigation scenario; representative of a scenario that aims to keep global warming likely below a 2°C increase above preindustrial temperatures. Ambitious reduction of greenhouse gas (GHG) emissions peaking around 2020, then declining and becoming net negative before 2100.
RCP4.5	Intermediate mitigation scenario consistent with relatively ambitious emissions reductions and GHG emissions increasing slighting before starting to decline ~2040. This falls short of the 2°C limit agreed upon in the Paris Agreement.
RCP6.0	High-to-intermediate emissions scenario with emissions peaking at 2060 and declining for the rest of the century.
RCP8.5	Very high GHG emissions; consistent with no policy changes to reduce emissions (current policies or business as usual)

Source: IPCC, 2014.

C = centigrade

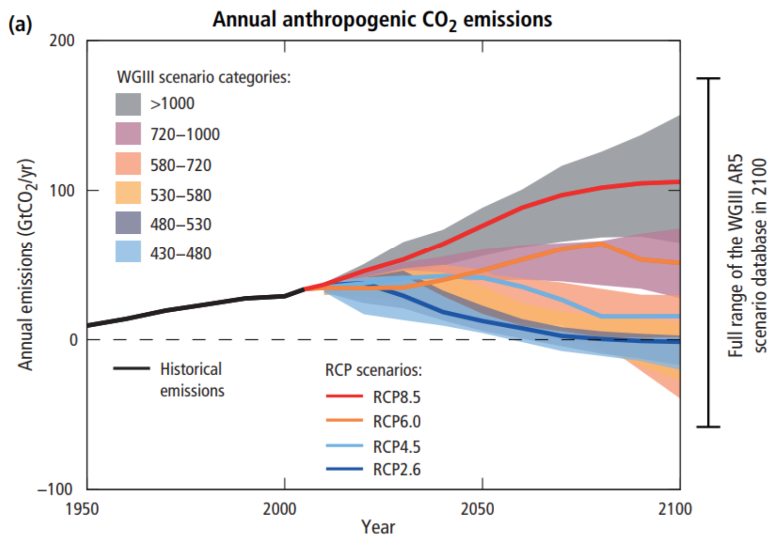

Figure 5: CO_2 Emissions in the RCPs and Associated Working Group III Scenario Categories

RCP2.6 represents the "2 degrees Celsius (°C) scenario" that is now referenced in the CDP. The scenario aligns with the objectives in the Paris Agreement, an agreement adopted by consensus of representatives of member countries of the United Nations Framework Convention on Climate Change (UNFCCC) in December 2015 and aimed at reducing countries' GHG emissions and thus keeping global temperature rise below 2 degrees °C, and will support the evaluation and comparison of individual organizations and sectors. The IPCC shows this as being achievable, in part, if the power sector is decarbonized by mid-century by electrifying as many energy services as possible, by substituting residual fossil fuels with biofuels in transport, building, and industry sectors , and by achieving negative emissions in the land-use sector by the end of the century (Task Force on Climate-Related Financial Disclosures 2017).

The IPCC is currently in its sixth assessment cycle, which is projected to be finalized in 2022. In the meantime, the IPCC AR5 offers a comprehensive scientific overview of climate change from a global perspective. Ameren can look to IPCC resources to consider the global standards for emissions scenarios and to learn more about the goals of the Paris Agreement.

2.2 Climate Change Overview

Worldwide trends have shown a warming climate system since the 1950s. The atmosphere and oceans have warmed, snow and ice cover have decreased, and sea levels have risen on average. Global average trends show a decrease in cold temperature extremes, an increase in warm temperature extremes, an increase in sea levels, and an increase in the number of heavy precipitation events.

It is projected that across emissions scenarios, surface temperatures will continue to increase. Increasing temperatures will make more frequent and intense heat waves and extreme precipitation events very likely. It is also projected that the ocean will continue to warm and acidify; as a result, sea levels are projected to continue to rise (IPCC 2014). The effects of climate change are projected to have a ripple effect on water availability and quality, ecosystems, public health, agriculture, infrastructure, and much more.

This section describes each of the climate change indicators assessed in this report: temperature, precipitation, extreme weather events, and drought/water availability. For each indicator, observed trends and projected trends per region are noted. The descriptions of observed trends include historical measured data, while the descriptions of projected trends include data and narratives based on models.

2.2.1 Temperature

The IPCC AR5 report states that almost the entire globe experienced surface warming between 1901 and 2012 (Figure 6), and that in the Northern Hemisphere, the 30-year period from 1983 to 2012 was very likely the warmest period of the last 800 years (IPCC 2014). Temperatures described here and throughout the report refer to surface temperature.[8] Annual average temperatures in the U.S. have increased by 1.3 degrees Fahrenheit (°F) to 1.9°F since 1895, with most of the increase occurring after 1970. The most recent decade was the warmest on record (Walsh et al. 2014).

Temperatures are of concern with respect to Ameren's water resources because increasing temperatures have impacts on evaporation and transpiration (evapotranspiration), causing water to be returned to the atmosphere instead of staying on the Earth's surface. Increases in temperature or a decrease in the number of cooling days per year may also have implications for energy use, and may cause an increase in water demand for energy production. In addition, high air temperatures may eventually result in higher surface water temperatures, which may affect water quality during low flow periods.

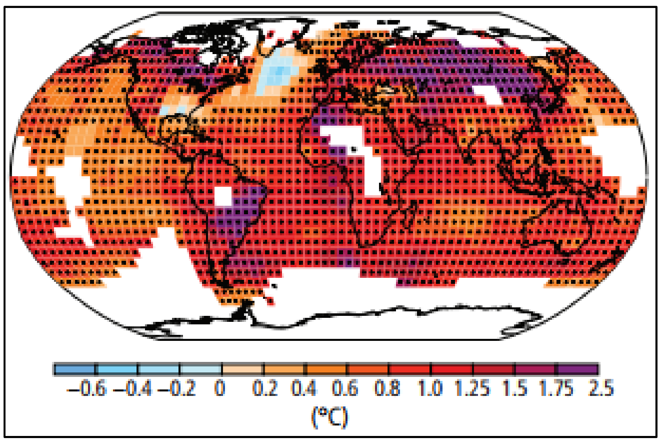

Figure 6: Observed Change in Surface Temperatures, 1901-2012 (IPCC 2014)

2.2.1.1 Ameren Service Area

Observed Trends

According to the NOAA's regularly updated National Temperature Map, the Ameren service area has seen increasing temperatures over the past 100 years. So far in 2017,[9] the service area has seen "above to much above average" temperatures (Figure 7) (NOAA NCEI 2017a). The service area spans Illinois and Missouri, which have both observed temperature increases over the past decade (Figure 8). The average temperature in Illinois has increased by 1°F since 1900. There has been seasonal variation in this trend, with the average spring temperature increasing by about 2°F and with summer temperature increasing very little (Frankson, Kunkel, et al., "Illinois

[8] The average of near surface air temperature over land
[9] With a ranking period from 1895-2017

State Summary," 2017a). Missouri's average temperature has increased 0.5°F since 1900, with temperatures in the 2000s being higher than any historical period on record aside from the Dust Bowl era of the 1930s. There has also been a below average number of cooling days, which is a characteristic of winter warming (Frankson, Kunkel, Champion, and Stewart, "Missouri State Summary," 2017).

The broader watersheds encompassing the service area have seen increases in temperature as well. The Missouri River Region (Region 10) has seen a mild increase in average temperature, with increases in winter and spring and slight decreases in summer and fall (USACE 2015a). The Upper Mississippi Region (Region 7) has seen a moderate increase in average temperature, with increasing temperatures in winter, spring, and summer and a slight decrease in fall (USACE 2015b).

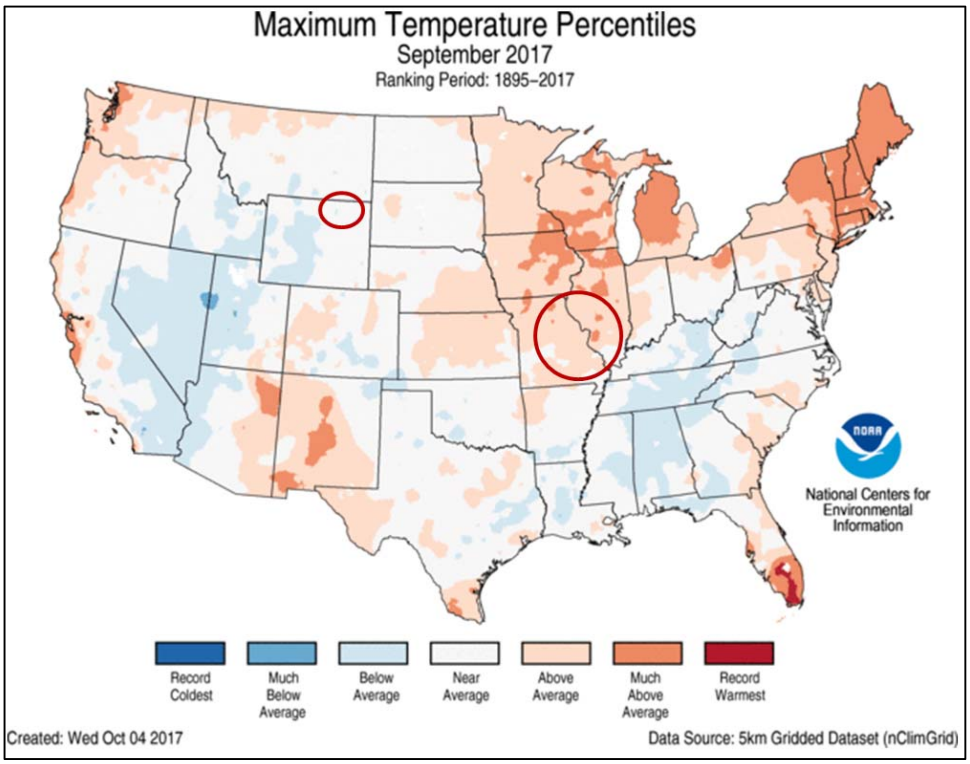

Figure 7: Observed Maximum Temperature Percentiles for January-September 2017 with a ranking period of 1895-2017 (NOAA NCEI 2017a)

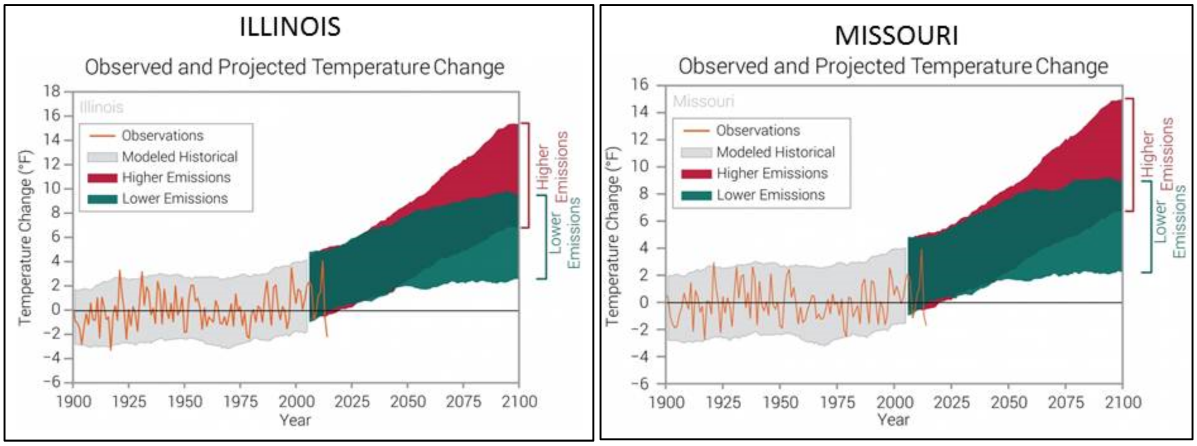

Figure 8: Observed and Projected Temperature Change for Illinois[10] and Missouri[11]

Projected Trends

Illinois and Missouri are both expecting a projected temperature increase at similar rates. Both states are expected to have average annual temperatures that exceed historical record levels by the middle of the 21st century, even at the lowest emissions pathway (Figure 8).

Both of the USACE regions are projected to experience an increase in mean annual air temperature by the latter half of the 21st century, with the Missouri River Region projecting an increase of 7.2 to 14.4ºF and the Upper Mississippi Region projecting an increase of 3.6 to 10.8ºF (USACE 2015a, 2015b). The Midwest region is expecting an increase in days above 95ºF, particularly in the southern part of the region, which includes Missouri and Illinois (Figure 9) (Pryor et al. 2014).

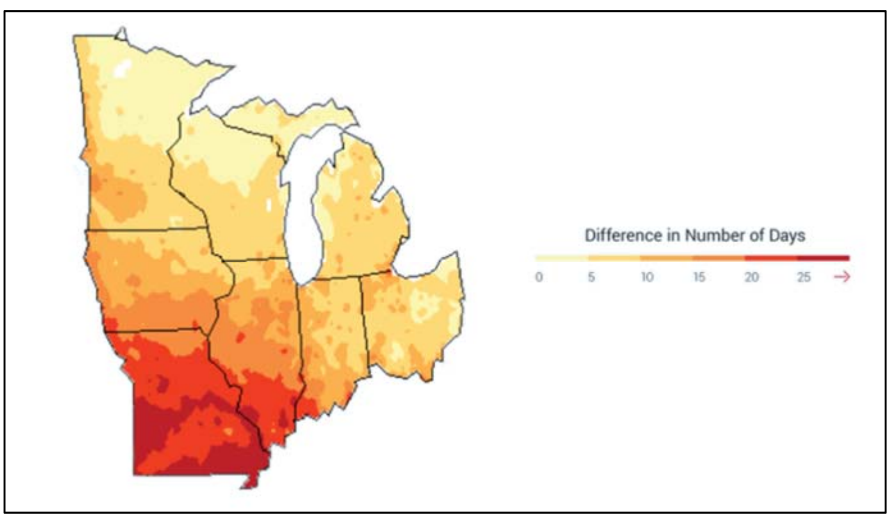

Figure 9: Projected Increase in Days above 95ºF for the Midwest Region[12]

[10] *Illinois State Summary* (Frankson, Kunkel, et al. 2017a).
[11] *Missouri State Summary* (Frankson, Kunkel, Champion, and Stewart 2017).
[12] Projection for 2041-2070 as compared to 1971-2000 under an emissions scenario that assumes continued increases in heat-trapping gases (Pryor et al. 2014).

2.2.1.2 Powder River Basin

Observed Trends

The PRB is located in the Missouri Water Resources Region, which has seen a mild increase in average temperature, with increases in winter and spring and slight decreases in summer and fall (USACE 2015a). The area of the PRB assessed is in the state of Wyoming. Wyoming's average temperature has increased by 1.4°F since 1900, with the 21st century being the warmest period on record for the state. In addition to the overall trend of higher average temperatures, the state has experienced a below average number of very cold days since 2000, which is a characteristic of winter warming (Frankson, Kunkel, et al., "Wyoming State Summary," 2017b).

Figure 10 shows the increase in the historical mean daily maximum temperature in Wyoming's Converse and Campbell Counties.

According to the NOAA's regularly updated National Temperature Map, the PRB area has been seeing "above to much above average" temperatures so far in 2017[13] (Figure 7) (NOAA NCEI 2017a).

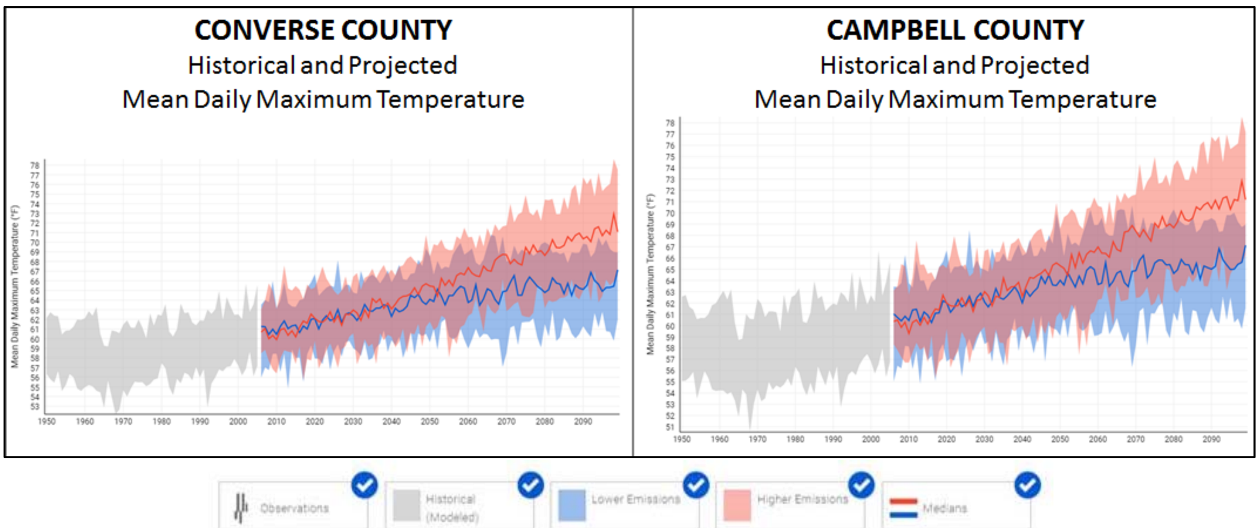

Figure 10: Historical and Projected Mean Daily Maximum Temperature in Converse and Campbell Counties (U.S. Climate Resilience Toolkit 2017)

Projected Trends

Wyoming's temperatures are projected to increase at a fairly fast rate, with the broader Missouri River Region projected to see an increase in mean annual air temperature of approximately 7.2 to 14.4ºF by the latter half of the 21st century.

The Great Plains is rich in resources that the rest of the country, including Ameren and its customers, relies on. Wyoming in particular provides 14 percent of U.S. energy, primarily from the state's coal production. With this increase in the area's temperature, the Great Plains National Climate Assessment (NCA) chapter cites an increased demand for water and energy, which is already causing stress on the area's important natural resources (Shafer et al. 2014).

[13] With a ranking period from 1895-2017.

2.2.2 Precipitation

The IPCC AR5 report states the mid-latitude areas of the Northern Hemisphere have likely had increased precipitation since 1901. Figure 11 shows the change in annual precipitation over land from 1951 to 2010 (IPCC 2014). Annual average precipitation over the continental U.S. increased by close to 2 inches between 1895 and 2011, or approximately 0.16 inches per decade (Georgakakos et al. 2014). More winter and spring precipitation is projected for the northern United States, including Ameren's service and supply chain regions, over this century (Walsh et al. 2014).

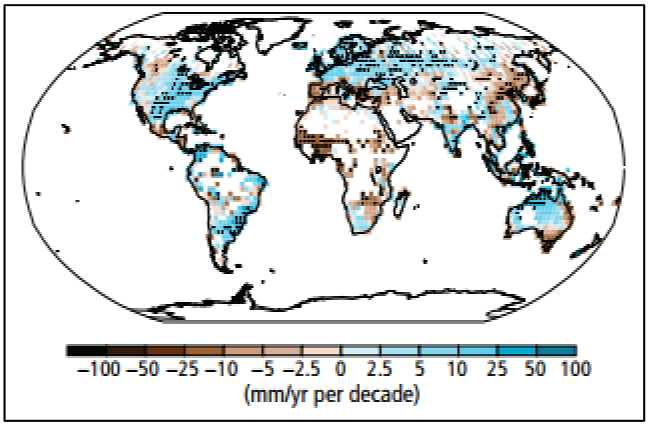

Figure 11: Observed Change in Annual Precipitation over Land, 1951-2010 (IPCC 2014)

2.2.2.1 Ameren Service Area

Observed Trends

According to NOAA's regularly updated National Precipitation Map, the Ameren service area has been seeing increasing precipitation over the past 100 years. So far in 2017[14] the service area has seen "below average and much below average" precipitation (Figure 12) (NOAA NCEI 2017a). The Midwest region has seen increased precipitation in the east, but decreased precipitation in the west. Generally, annual precipitation has increased in the past century (by up to 20 percent in some locations), with much of it driven by heavy precipitation events (Pryor et al. 2014).

Precipitation varies widely across Missouri. The driest 5-year period was in the early 1930s, while the wettest 5-year period was in the early 1990s. Overall, the state has seen above average precipitation in spring and summer in the past two decades. The position of Missouri in the lower parts of several area rivers in combination with increasing precipitation makes flooding a particular hazard for the state (Frankson, Kunkel, Champion, and Stewart, "Missouri State Summary," 2017). Precipitation also varies across Illinois. The driest 5-year period was 1952-1956, and the wettest was 2007-2011. Annual precipitation ranges from 48 inches in the south to less than 32 inches in the north. For Illinois, the total precipitation volumes are primarily from extreme precipitation events (Frankson, Kunkel, et al., "Illinois State Summary," 2017a).

The Upper Mississippi Region has seen increasing trends in total annual precipitation. Between 1895 and 2006, there was a positive linear trend for both annual precipitation and the soil moisture index for multiple sites within the region. Increases in precipitation were most significant in the summer and fall, with a mild decreasing trend for winter and spring in the

[14] With a ranking period from 1895-2017

northern portion (USACE 2015b). The Missouri River Region had more variation in the historical precipitation data presented in the USACE report. There were increasing trends in total annual precipitation for the lower Missouri River Region (which includes the Ameren service area) and decreasing trends for the upper Missouri River Region (USACE 2015a).

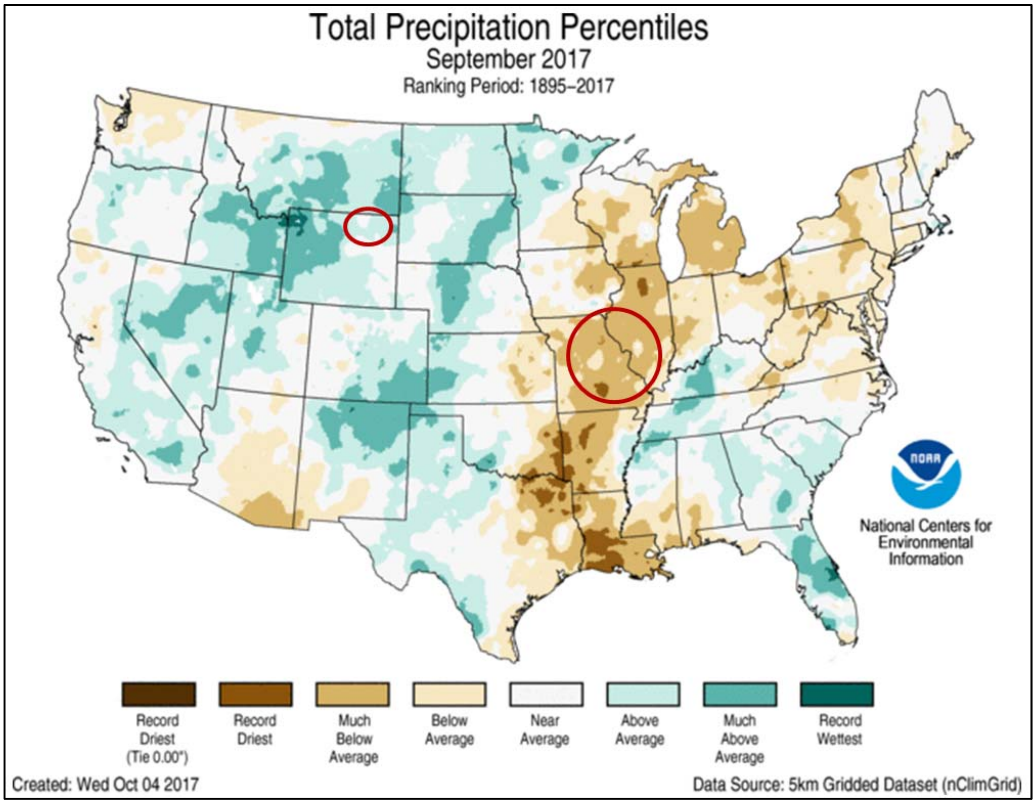

Figure 12: Observed Total Precipitation Percentiles for January-September 2017 with a Ranking Period of 1895-2017 (NOAA NCEI 2017a)

Projected Trends

Illinois is projected to have an increase in precipitation. Both Missouri and Illinois are projected to have an increase in spring precipitation ranging from 5 to over 15 percent (Figure 13). Both states also project an increase in winter precipitation and a decrease in summer precipitation (Frankson, Kunkel, et al., "Illinois State Summary," 2017a). Missouri's projection of overall annual increases in precipitation is slightly less certain (Frankson, Kunkel, Champion, and Stewart 2017).

The Missouri River Region on the whole is projected to have wetter, rather than dryer, future climatic conditions and an increase in annual precipitation and frequency of large storm events (USACE 2015a). The Upper Mississippi Region projects an increase in annual precipitation and frequency of large storm events. However, some parts of the northern Upper Mississippi Region will have a slight decrease in precipitation. Seasonal variation in precipitation, particularly drier summers, is also expected (USACE 2015b).

Projected precipitation for the Midwest region is expected to increase 10 to 20 percent relative to 1971 to 2000, while changes for summer and fall are not expected to differ much from their natural variations. Southern portions of the Midwest region, which includes the Ameren service area, project increased spring precipitation (9 percent in the period from 2041 to 2062 relative to

1979 to 2000) and decreased summer precipitation (by an average of 8 percent from 2041 to 2062 relative to the period from 1979 to 2001) (Pryor et al. 2014).

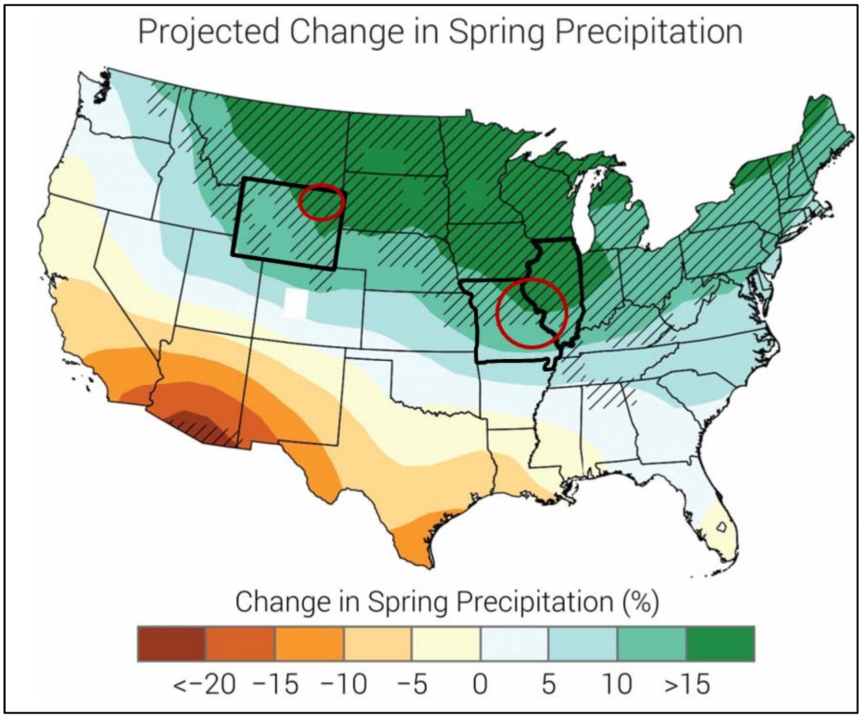

Figure 13: Projected Change in Spring Precipitation for the U.S. with States in the Study Areas Circled in Red (2017 Illinois State Summary)[15]

Figure 14 shows the observed and projected mean daily precipitation for Converse and Campbell Counties.

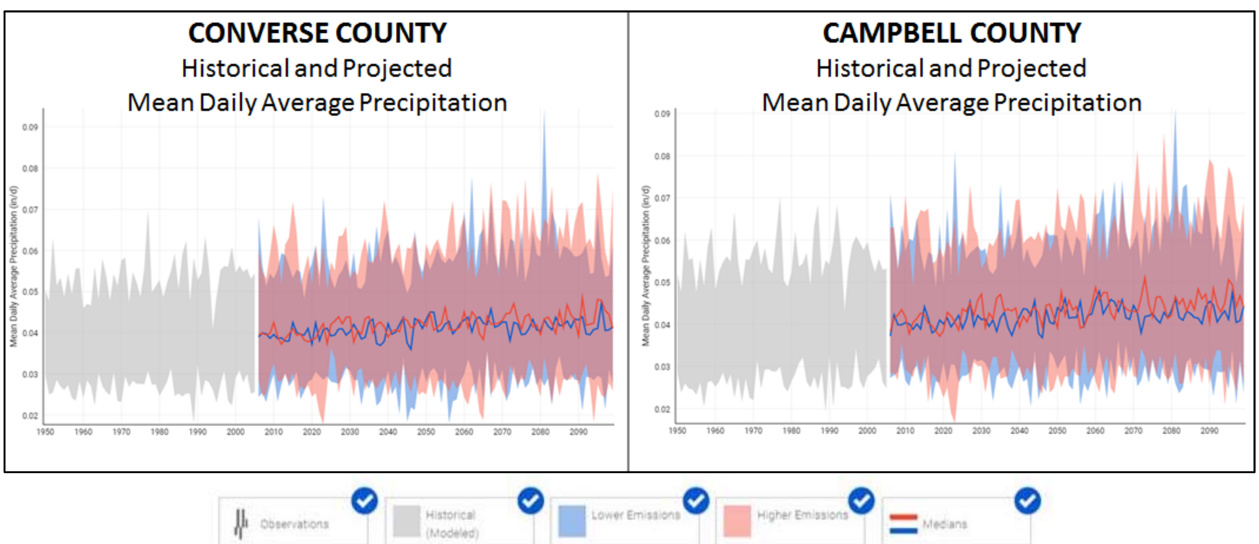

Figure 14: Observed and Projected Mean Daily Average Precipitation for Converse and Campbell Counties (U.S. Climate Resilience Toolkit 2017)

[15] *Illinois State Summary* (Frankson, Kunkel, et al. 2017a.

2.2.2.2 Powder River Basin

Observed Trends

According to the NOAA's regularly updated National Precipitation Map, the PRB has seen "near to above average" precipitation in 2017[16] (Figure 12). The Missouri Region had more variation in the historical precipitation. Generally, there were decreasing trends in total annual precipitation for the upper region (which includes the PRB) and increasing trends for the lower region (USACE 2015a).

Wyoming's rivers flow into major river basins of the U.S., including the Missouri and Mississippi River Basins. Therefore, variation in Wyoming's snowpack depth and precipitation is likely to have impacts on water availability beyond the state. Years with heavy snow cover that are followed by heavy spring precipitation and thaw have been associated with severe flooding (Frankson, Kunkel, et al., "Wyoming State Summary," 2017b).

Projected Trends

Winter and spring precipitation is projected to increase in the state of Wyoming. Spring precipitation in particular is projected to increase by 5 percent to over 15 percent (Figure 13). Projected rising temperatures will increase the lowest elevation at which snow falls in Wyoming. This will increase the likelihood that some of the precipitation events now occurring as snow will fall as rain instead, which will reduce water storage in the snowpack at lower elevations. Higher spring temperatures will also result in earlier melting of the snowpack. This will further decrease water availability during the drier summer months. Heavier spring precipitation, combined with a shift from snow to rain, could also increase the potential for flooding (Frankson, Kunkel, et al., "Wyoming State Summary," 2017b).

The PRB is in the Missouri River Region, which as a whole is projected to have wetter, rather than dryer, future climatic conditions and an increase in annual precipitation and frequency of large storm events (USACE 2015a).

2.2.3 Extreme Weather Events

The IPCC AR5 report states that many extreme weather events have been observed in the past 60 years, including more frequent hot days and heat waves, fewer cold days, and increases in heavy precipitation events (IPCC 2014). The number and intensity of very heavy precipitation events[17] have been increasing significantly across most of the U.S, and the amount of precipitation falling in the heaviest daily events has also been increasing (Georgakakos et al. 2014).

2.2.3.1 Ameren Service Area

Observed Trends

The NCA's *Midwest Region Report* cites an observed increase in extreme rainfall events across the entire region (Pryor et al. 2014).

Illinois has also had a dramatic increase in extreme precipitation events, causing flooding and major impacts to agriculture, infrastructure, homes, and businesses (Frankson, Kunkel, et al., "Illinois State Summary," 2017a). Missouri has seen an increase in heavy rain events. A scientific study has found that Missouri is ranked fourth in the U.S. for state losses due to

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[16] With a ranking from period from 1895-2017.

[17] Defined as the heaviest 1 percent of all daily events from1901 to 2012.

flooding in the period from 1955 to 1997, with major floods including the 1993 Mississippi River flood, the 1973 Mississippi River flood that crested 20 feet above flood stage in St. Louis, and the 2011 Mississippi River and Missouri River floods, which resulted in more than $320 million in damages (Frankson, Kunkel, Champion, and Stewart, “Missouri State Summary,” 2017). The lower portion of the Missouri River (Region 10), which includes Ameren’s service area, has shown increasing trends for extreme precipitation events and an increased frequency in storm event occurrences (USACE 2015a). Figure 15 shows the increasing number of extreme precipitation events observed in both states, primarily after 1984.

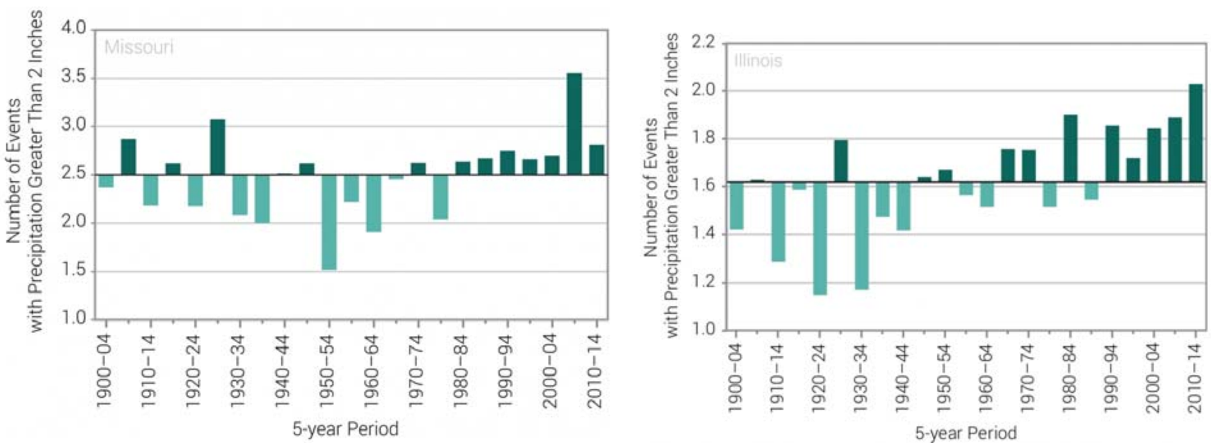

Figure 15: Observed Number of Extreme Precipitation Events in Missouri (left) and Illinois (right) (2017 Missouri State Summary[18] and 2017 Illinois State Summary[19])

Projected Trends

The Midwest region as a whole is projected to have increased extreme rainfall events and associated flooding at a larger magnitude than the expected increase for overall precipitation. These rainfall events in the region are expected to result in increased erosion and declining water quality (Pryor et al. 2014). The Upper Mississippi Region also projects an overall increase in the frequency of large storm events, with some variation across the region.

Future heat waves in both Illinois and Missouri are likely to be more intense if temperature increases continue, coupled with periods of high humidity. These heat waves will pose risks to human health, particularly in the Chicago, Kansas City, and St. Louis metro areas due to urban heat island effect. Cold wave intensity is projected to decrease across both states as well (Frankson, Kunkel, Champion, and Stewart, “Missouri State Summary,” 2017; Frankson, Kunkel, et al., “Illinois State Summary,” 2017a).

2.2.3.2 Powder River Basin

Observed Trends

Wyoming’s number of extreme precipitation events has been above average during recent years (Frankson, Kunkel, et al., “Wyoming State Summary,” 2017b)

Projected Trends

The Missouri Region is projected to see an increase in extreme temperature events, such as heat waves (USACE 2015a). The Great Plains region as a whole is also projected to have

[18]Frankson, Kunkel, Champion, and Stewart 2017.
[19]Frankson, Kunkel, et al. 2017a.

future heat waves and severe rainfall events. The increased seasonal precipitation and heavy precipitation events are projected to increase runoff and flooding, reduce water quality, and erode soils. The northern part of the region, including the PRB area, is projected to experience a double in the number of days over 100ºF per year. The increases in extreme heat will have a number of negative consequences for the region, including surface water losses, heat stress, and an increased regional demand for water and energy. These consequences will in turn increase the competition for water in communities and across agriculture, energy production, and ecological sectors (Shafer et al. 2014).

Heat wave intensity is projected to increase in Wyoming, while the intensity of cold waves is projected to decrease (Frankson, Kunkel, et al., “Wyoming State Summary,” 2017b).

2.2.4 Droughts and Streamflow

The IPCC AR5 report cannot directly state observed drought conditions worldwide due to a lack of direct observations, dependencies on inferred trends on the choice of the definition of drought, and the geographical inconsistencies of drought trends. However, streamflows have been observed as having earlier spring peak flows, and changes have been observed in discharge patterns in waterways (IPCC 2014). Short-term droughts are expected to intensify in most of the U.S., with longer droughts expected in the Southwest, southern Great Plains, and the Southeast. This section also discusses the changes in soil moisture in the regions, as soil moisture plays a major role in the water cycle, regulating the exchange of water, energy, and carbon between the land surface and the atmosphere, the production of runoff, and the recharge of groundwater aquifers (Georgakakos et al. 2014).

It is important to evaluate droughts in this assessment because there is a direct relationship between droughts and the streamflow and water availability to Ameren’s service area and supply chain.

2.2.4.1 Ameren Service Area

Observed Trends

According to USGS stations in the area, average streamflow conditions have generally increased 20 percent to more than 50 percent, based on the long-term rate of change from 1940 to 2014 (Figure 16). The Midwest area has seen an increase in 7-day low flows during the past 75 years, meaning streams in the areas are carrying more water than before during their lowest flow days (EPA 2016b). Both the Missouri River Region and the Upper Mississippi Region have seen a mild increase in average streamflow over the last century (USACE 2015a, 2015b).

Drought conditions across the country have varied since 1895, with most widespread droughts occurring in the 1930s and 1950s. From 2000 to 2015, 20 percent to 70 percent of the U.S. experienced abnormally dry conditions at any given time (EPA 2016a). Missouri saw extreme drought conditions during the summers of the 1930s, the Dust Bowl era (Frankson, Kunkel, Champion, and Stewart, “Missouri State Summary,” 2017). Illinois was impacted during a major drought in 2012, which ranked as the third driest period for the area in 120 years of recordkeeping. This drought was considered extreme and had major impacts on the state’s crops (Frankson, Kunkel, et al., “Illinois State Summary,” 2017a).

Based on a study of tree ring data for the entire Central Plain region, both the Upper Mississippi and the Missouri Regions saw a decline in drought frequency (droughts per century) over the past 1,000 years and an increase in soil moisture over the same time period (USACE 2015a, USACE 2015b). Ameren’s service area, as shown on Figure 17, has experienced both wetting and drying trends. The area in Missouri appears to exhibit more drying trends, while the area in Illinois appears to have more wetting trends (Georgakakos et al. 2014).

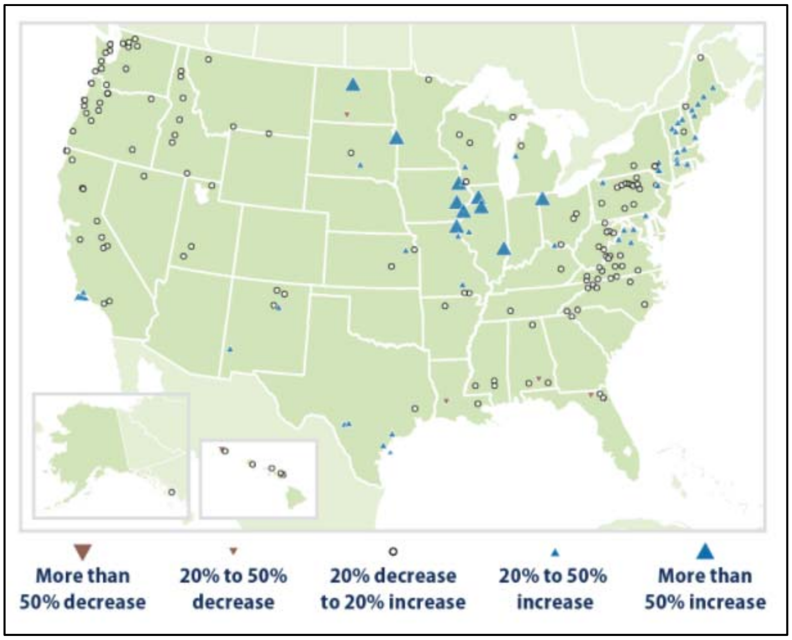

Figure 16: Annual Average Streamflow in the United States, 1940–2014[20] (EPA 2016b)

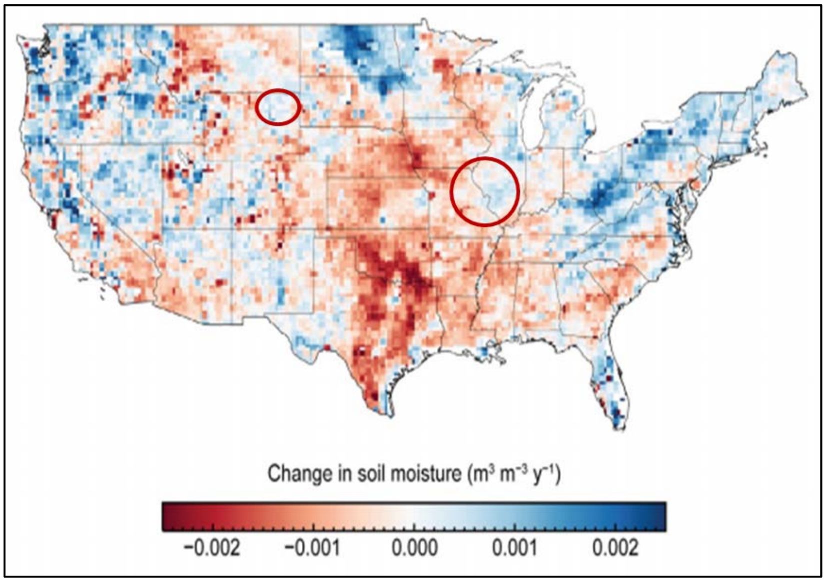

Figure 17: Annual Surface Soil Moisture Trends in the Study Areas Circled in Red, 1988-2010 (Georgakakos et al. 2014)

Projected Trends

Despite projected precipitation increases in the Upper Mississippi Region, droughts are also expected to increase due to increased temperatures and evaporation rates. Projections show both an increase and a reduction in future streamflows (USACE 2015b).

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[20] Percentage changes in the annual average streamflow for rivers and streams across the country, based on the long-term rate of change from 1940 to 2014. This map is based on daily streamflow measurements, averaged over the entire year.

Missouri and Illinois both experience summer droughts, which are likely to increase in frequency and intensity due to rising temperatures, evaporation, and loss of soil moisture, regardless of precipitation changes (Frankson, Kunkel, et al., “Illinois State Summary,” 2017a). Future increases in evaporation rates due to higher temperatures create adverse conditions for the agriculture-dependent state of Missouri (Frankson, Kunkel, Champion, and Stewart 2017).

Soil moisture is a good indicator of drought, as it decreases during times of drought due to lower precipitation levels and increased evaporation rates. Soil moisture for much of the U.S. is projected to decrease overall. The Ameren service area shows a mid-level reduction in soil moisture at 30 centimeters below surface (Figure 18) (NASA 2015).

Over the past century, there was no apparent change in drought duration in the Midwest region; however, the average number of days without precipitation is projected to increase in the future.

2.2.4.2 Powder River Basin

Observed Trends

According to USGS stations in the area, streamflow conditions have remained relatively neutral, with either a 20 percent increase or a 20 percent decrease based on the long-term rate of change from 1940 to 2014 (Figure 16) (EPA 2016b). The Missouri River Region has seen a mild increase in average streamflow over the last century (USACE 2015a).

Wyoming, like the rest of the Great Plains region, has also experienced severe droughts in the 21st century, which have created water availability issues. The drought in 2012 exacerbated Wyoming’s worst wildfire season, which burnt over half a million acres (seven times the yearly average) (Frankson, Kunkel, et al., “Wyoming State Summary,” 2017b). Historical drought information and examples are further described in Section 4, Focus on Watersheds.

Average rainfall for the Great Plains region is less than 30 inches, with some parts of Montana, Wyoming, and far west Texas receiving less than 15 inches a year. With annual water loss from transpiration by plants and from evaporation being higher than annual precipitation, this region is particularly susceptible to drought (Shafer et al. 2014).

Based on a study of tree ring data for the entire Central Plain region (USACE 2015a), the Missouri River Region saw a decline in drought frequency (droughts per century) over the past 1,000 years and an increase in soil moisture over the same time period. Figure 17 shows a wetting trend in soil moisture in the northern Wyoming area.

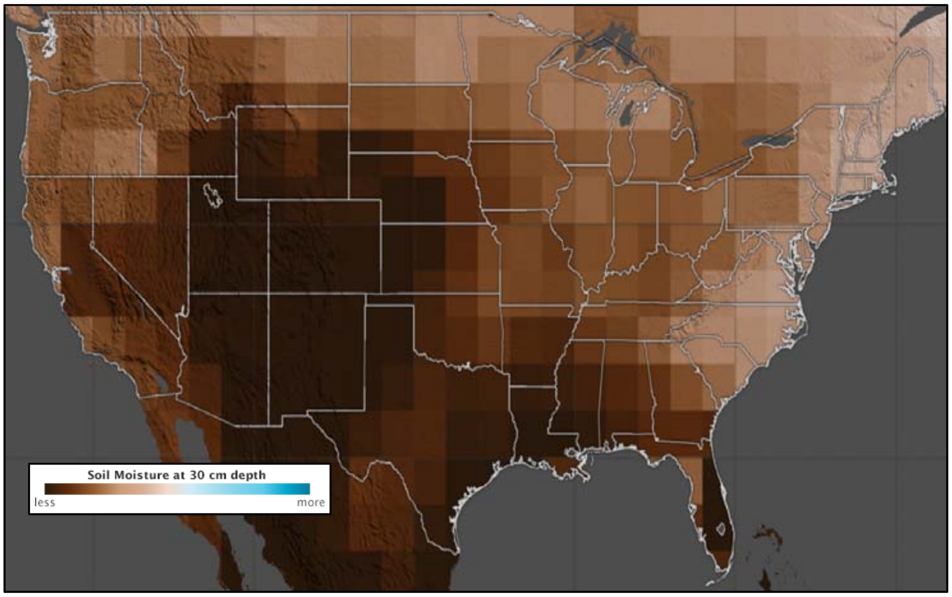


Figure 18: Projected Changes in Soil Moisture, 1950 to 2095 (NASA 2015)

Projected Trends

The Great Plains region as a whole is projected to have frequent and intense droughts that vary across the large region, with dryer conditions in the southern portion and less dry conditions in the north, which includes the PRB (Shafer et al. 2014).

Higher spring temperatures result in earlier melting snowpack, which will further decrease water availability during the drier summer months. Wyoming typically experiences summer droughts, which due to rising temperatures and evaporation are likely to increase in frequency and intensity (Frankson, Kunkel, et al., “Wyoming State Summary,” 2017b).

Droughts throughout the Central Plains could be longer and dryer than any droughts over the past 1,000 years, according to the National Aeronautics and Space Administration (NASA). Soil moisture in the PRB area is projected to get much dryer, verging on the high end of the scale. The 2015 NASA study predicted that if GHG emissions continue on their upward trajectory for the rest of the 21st century, there is an 80 percent likelihood of a megadrought[21] in the Southwest and Central Plains between 2050 and 2099 (NASA 2015).

2.3 Discussion

The literature review conducted in this section provides a high-level overview of historical trends and future projections considering climate change of significant climate factors in the three regions of the study area. Increasing surface temperatures of 0.5-1.4ºF have been observed since 1900[22] in the study area and are projected to continue to increase in the latter half of the 21st century by 3.6-14.4 ºF.[23] Furthermore, the study area has seen an overall increase in annual precipitation, which has been primarily concentrated in heavy precipitation events. Seasonal variability is expected to increase; there are projected changes to precipitation patterns, with specific increases to winter and spring precipitation and heavy precipitation events. Average streamflows across the study area have generally increased, and projections

[21] A drought lasting more than three decades.
[22] State Climate Summaries for Illinois, Missouri, and Wyoming summarized.
[23] Range from two USACE Region Reports (Upper Mississippi and Missouri).

show a mix of increases and reductions in streamflow across the area. The study area's soil moisture has experienced both wetting and drying trends and is projected to decrease across the study area. The study area as a whole has had historical periods of drought, which are further described in Section 4, Focus on Watersheds. Droughts are projected to increase in frequency and duration regardless of increasing precipitation, due to higher temperatures and evapotranspiration rates.

As discussed in Section 2.1, these sources have varying degrees of usefulness for Ameren's climate research moving forward due to the varying geographic scales and updates. The sources used in this section are based on the most current version as of the writing of this report. Many of the resources used in the literature review conducted for Section 2, Review of Climate Science for the Region, while reliable sources of information, are updated only on a semi-regular basis; they are thus static sources of information and can quickly become somewhat dated. Therefore, assessing these resources should be done regularly as updates occur. Section 3, Overview of Selected Climate Change Tools and Datasets, will consider the value of online climate data and tools, and how information can be used in real time to further understand how climate change may affect water resources and consistent water availability.

3. Overview of Selected Climate Change Tools and Datasets

When considering data sources for information on how climate change will impact water resources, the literature review in Section 2, Review of Climate Science for the Region, provides a good starting point for seeing what trends past researchers have found for certain geographies as well as what reports are presenting from climate models for potential projected future conditions. Another type of data source to consider is online climate change tools and datasets. Rather than primarily being a text-based, static interpretation of a snapshot of future climate conditions, these tools and datasets provide researchers with the underlying data from climate change models directly, allowing more customized and dynamic interpretations. Some of the tools provide access to the direct outputs from Global Circulations Models (GCMs), while other tools include custom-derived and aggregated datasets for specific applications such as water resources. Some of the tools and datasets described below are used in the reports referenced in Section 2.

The following subsections will profile a short list of climate change tools and their associated datasets. This list of tools is not meant to be comprehensive, but is rather a select list that exhibits the variety of tools available from different organizations. The order of the list ranges from tools focused on global and U.S. water resources to climate data sources (historic and future) to detailed GCM outputs.

3.1 WRI Aqueduct and Water Risk Atlas

Utilizing a diverse group of partners, the World Resources Institute (WRI) built the Aqueduct website, shown on Figure 19, to help companies, investors, governments, and communities better understand the global impact of emerging water risks. According to the WRI, water scarcity is one of the defining issues of this century, and the World Economic Forum has identified water supply crises as one of the issues with the greatest risks and potential for impacts around the globe (World Resources Institute 2017).

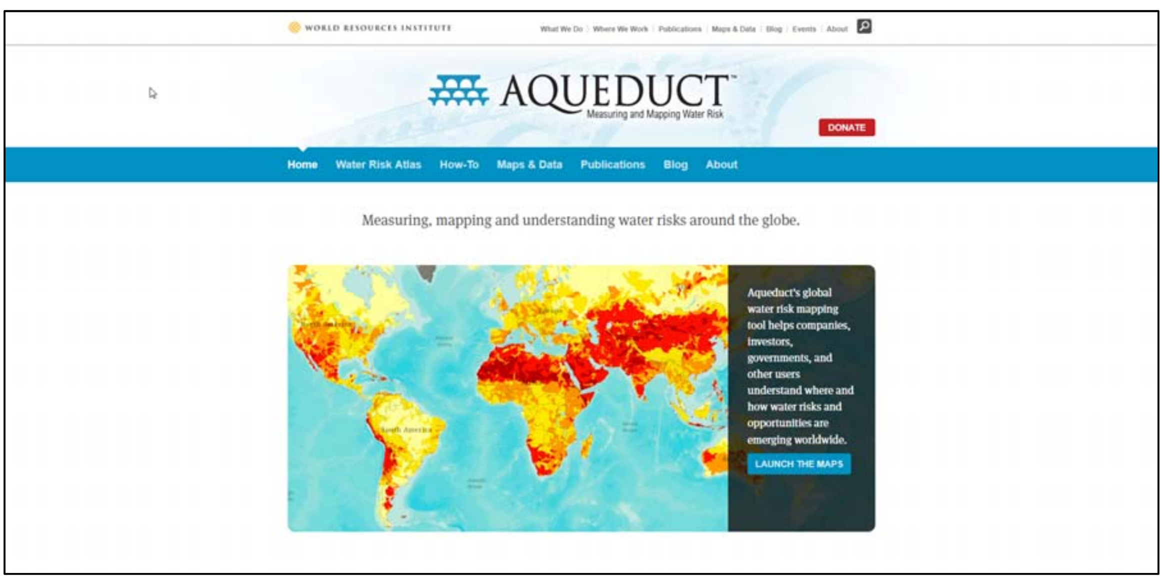


Figure 19: WRI Aqueduct, Measuring and Mapping Water Risk Home Page

Launched in early 2013, the Water Risk Atlas is Aqueduct's primary tool. The tool was developed using a peer-reviewed methodology with globally available high-resolution data to create dynamic, customizable maps of water risks around the world. The Aqueduct Water Risk Atlas provides a publicly available global database and an interactive tool that maps indicators of a range of water-related risks. For current and future conditions, the framework groups 12 indicators for identifying spatial variation in water risks, as shown on Figure 20. Half of the indicators come from pre-existing global datasets, while WRI developed the other half of the indicators to estimate particular values related to seasonal and annual water supply and use. The indicators are placed into three categories related to physical risk quantity, physical risk quality, and regulatory and reputational risk. The scores from these three categories are then used to develop a final weighted overall water risk index. This approach is applied on a watershed basis worldwide.

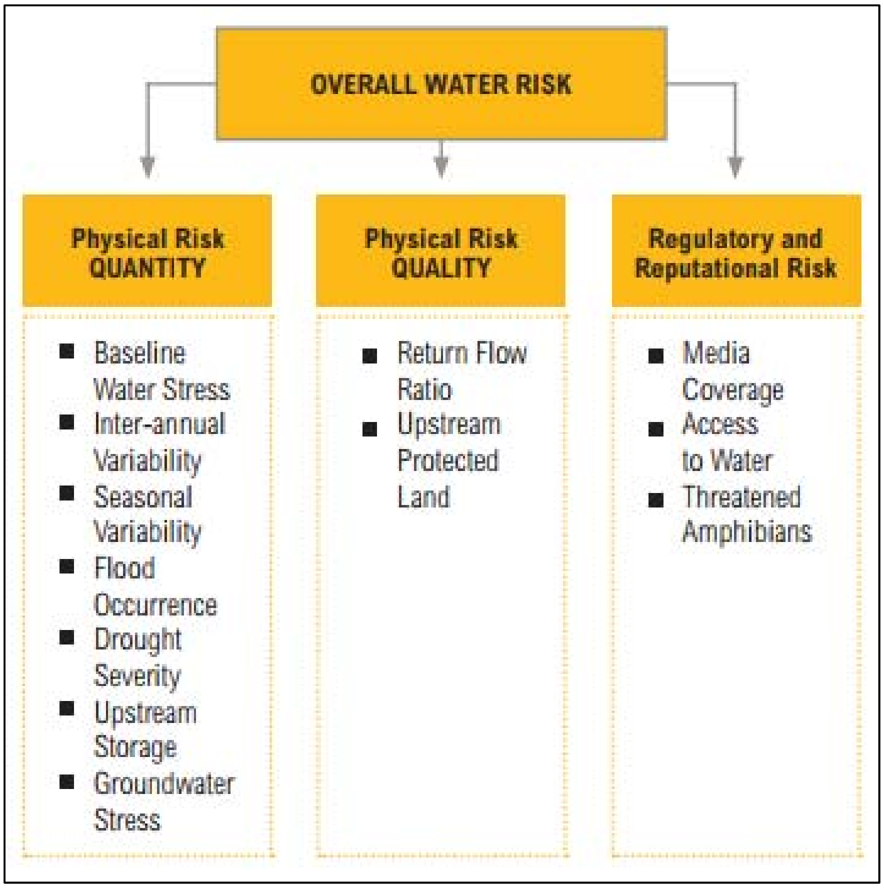


Figure 20: Aqueduct Water Risk Framework

For climate change considerations, the main category of focus should be the physical risk quantity. Conceptually, this category aims to include indicators of how a particular watershed may experience water stress due to changes in water quantity and its availability. In Aqueduct, water stress measures the ratio of total annual water withdrawals to total available annual renewable supply, accounting for upstream consumptive use (i.e., considering demand vs supply). Aqueduct's water stress index is a combination of a variety of sources for water stress including inadequate water supply (low or reduced precipitation), excessive water withdrawal (such as excessive irrigation from groundwater) and consumptive (such as evapotranspiration) uses, and large variations in seasonal or annual water supply (including floods and droughts).

It's important to note that Aqueduct is a useful tool to indicate general future trends on water supply, demand, stress, and other related indicators. However, for drought management and planning, comparing "annual" quantities is not sufficient on its own as water demand tends to be higher in summer and fall while streamflow is lower. The definition of a safe (water supply) yield is the annual average quantity of water guaranteed during a "critical" drought period. Daily data are usually used to assess the "safe yield" of a water supply source. Additional evaluation is required to define the actual water availability, or safe yield, at specific water withdrawal locations. Similarly, critical low flow conditions that may be important for habitats for the threatened and endangered species in the study area, will best be analyzed using daily streamflow data simulated using data sources such as from the USGS in the study area.

3.1.1 Available Site Data

The current version of the tool, Aqueduct Global Maps 2.1, contains Current Conditions and Futures Conditions datasets. The Analyze Locations function allows the user to gather data by clicking on a point map location, entering coordinates, and entering an address or to import location data from a spreadsheet. Once a location is selected, the data specific to that location can be viewed and saved.

On the Current Conditions tab (shown on Figure 21), the user has the ability to view and access data for all 12 indicators shown on Figure 21. The current conditions dataset also contains access to some of the underlying datasets used for calculations. For example, in the calculations of water withdrawals, data about the list of industries and their associated modeling weights can be accessed for various categories, including agriculture, chemicals, electric power, oil & gas, mining, and textiles.

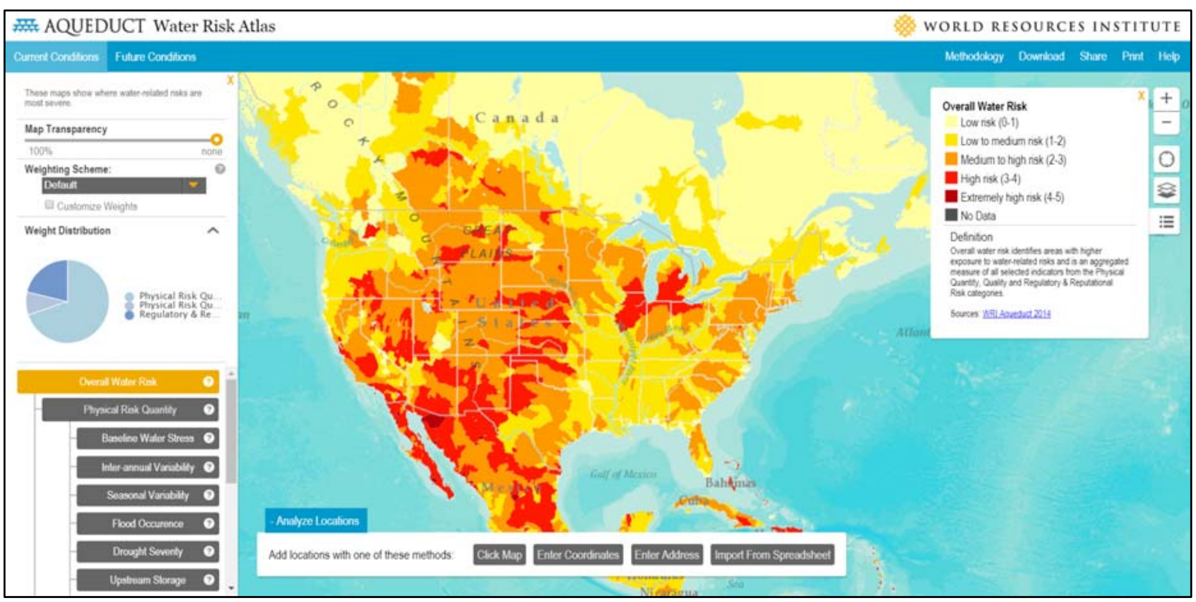


Figure 21: Water Risk Atlas Tool, Current Conditions Page

On the Future Conditions tab (shown in Figure 22), the tool only provides information related to changes in water stress, water supply, water demand, and seasonal variability.

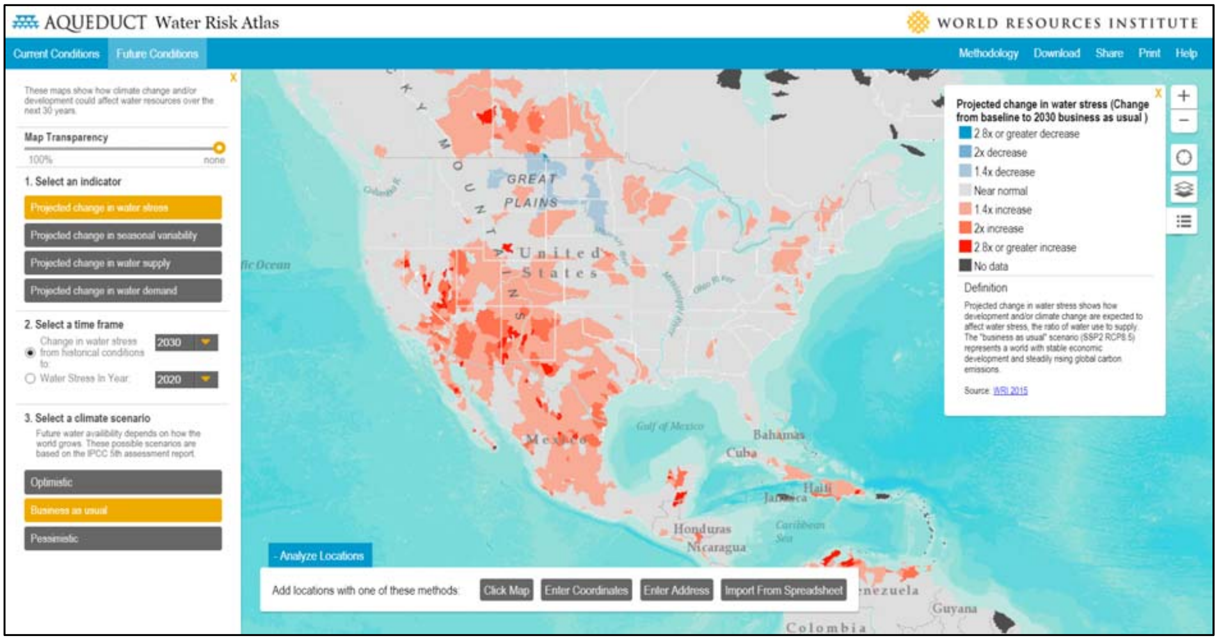


Figure 22: Water Risk Atlas Tool, Future Conditions Page

These changes are projected for 21-year time periods centered on 2020, 2030, and 2040. The projections take into account not only predictions for changes to climate factors, such as temperature and precipitation, but also population and economic growth and the associated increase to water withdrawals by certain industries. Table 3 summarizes the three climate scenarios shown in the tools. Note that the Aqueduct tool does not include the RCP2.6 scenario, which is associated with the reducing GHG emissions so as to avoid a 2 degrees °C increase.

Table 3: Aqueduct Climate Scenario Definitions

Aqueduct Climate Scenario	Climate Model Scenario	Economic Scenario	Description
Optimistic	RCP4.5	SSP2	Stable economic development and carbon emissions peaking and declining by 2040
Business as Usual	RCP8.5	SSP2	Stable economic development and steadily rising global carbon emissions
Pessimistic	RCP8.5	SSP3	Fragmented world with uneven economic development and steadily rising global carbon emissions

RCP = Representation Concentration Pathway, SSP = Shared Socioeconomic Pathways

3.1.2 Data Available for Download

All data under the Current Conditions or Future Conditions tabs may be downloaded from the site. Data are available in spreadsheet or geographic information system (GIS) format (ESRI Geodatabase files or shapefiles). Maps may also be printed directly from the site. The current data were updated in 2015 from an original 2013 dataset.

3.1.3 Tool's Relevance to Ameren's Water Resiliency

Aqueduct can be a useful tool for Ameren by providing projections on future water availability that can inform prioritization of actions aimed at achieving necessary sustainable and consistent water use across time periods. The tool provides usable and user-friendly information for both current and future conditions of water risk in Ameren's geographies of operation. Aqueduct's data takes into account many varying factors that affect water quantity and stress, such as water supply, water withdrawal, consumptive uses, and large variations in seasonal or annual water supply. This comprehensive approach to the complexity of water stress culminates in an accessible tool that can be another resource considered in Ameren's decision-making processes. There is also a measurement for media coverage of water issues, which could be used to consider where companies could face greater public image risks if water is not managed sustainably. Media data are only available on a country-scale at this time, but could be on a finer scale in future iterations of Aqueduct's data and potentially useful to Ameren.

Limitations to this tool would include model accuracy due to the lack of data availability for major infrastructure and in-situ water quality and river gauge measurements, and the need for additional evaluation to define actual water availability. The data featured in this tool were from their 2015 release; therefore a new dataset may be released in the coming years for Ameren to revisit.

3.2 USACE Climate Hydrology Assessment Tool

For the U.S., there are a number of websites with information related to past and future climate data and trends for water resources. One website from the U.S. Army Corps of Engineers (USACE) gives detailed qualitative information about past and future flooding trends.

The USACE Engineering and Construction Bulletin (ECB) 2016-25, Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects, helped to develop USACE policy around observed and projected changes to climate hydrology (USACE 2016). In support of that publication, the USACE established the Climate Hydrology Assessment Tool website, shown on Figure 23, to provide access to data for assessing how water resources, especially flooding, may change in the future (USACE 2017).

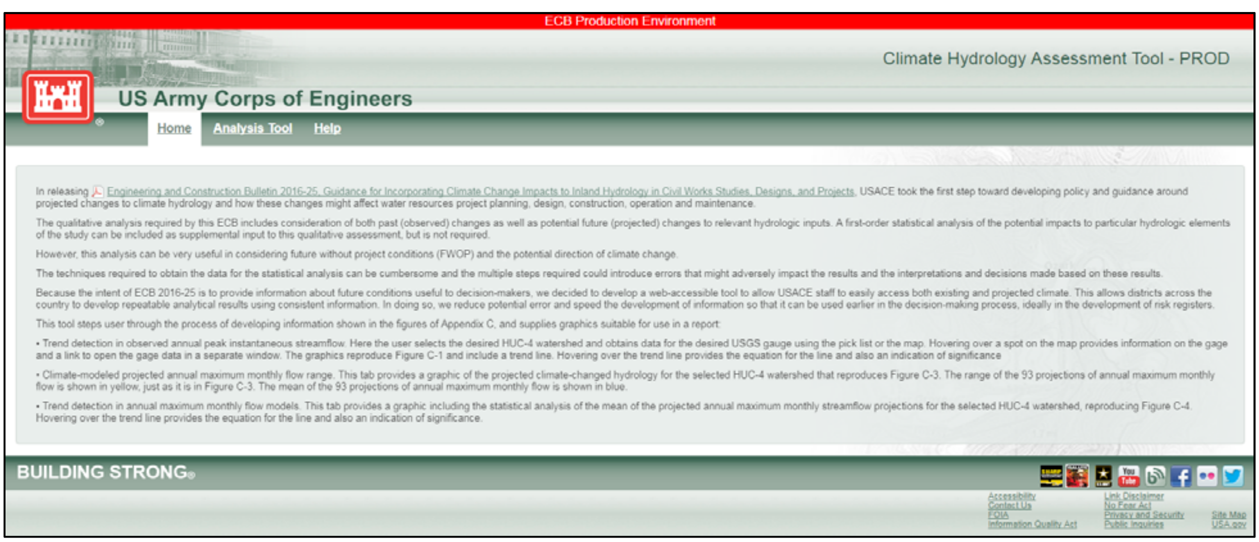


Figure 23: USACE Climate Hydrology Assessment Tool Home Page

The USACE guidance includes information on how to perform a qualitative hydrologic analysis that takes into account past (observed) changes as well as potential future (projected) changes. The USACE Climate Hydrology Assessment Tool website includes an Analysis Tool, shown on Figure 24, which supports such a qualitative analysis. This tool allows USACE districts and other users across the country to develop repeatable analytical results using consistent information, thus reducing potential error and speeding the development of information so that it can be used earlier in the decision-making process.

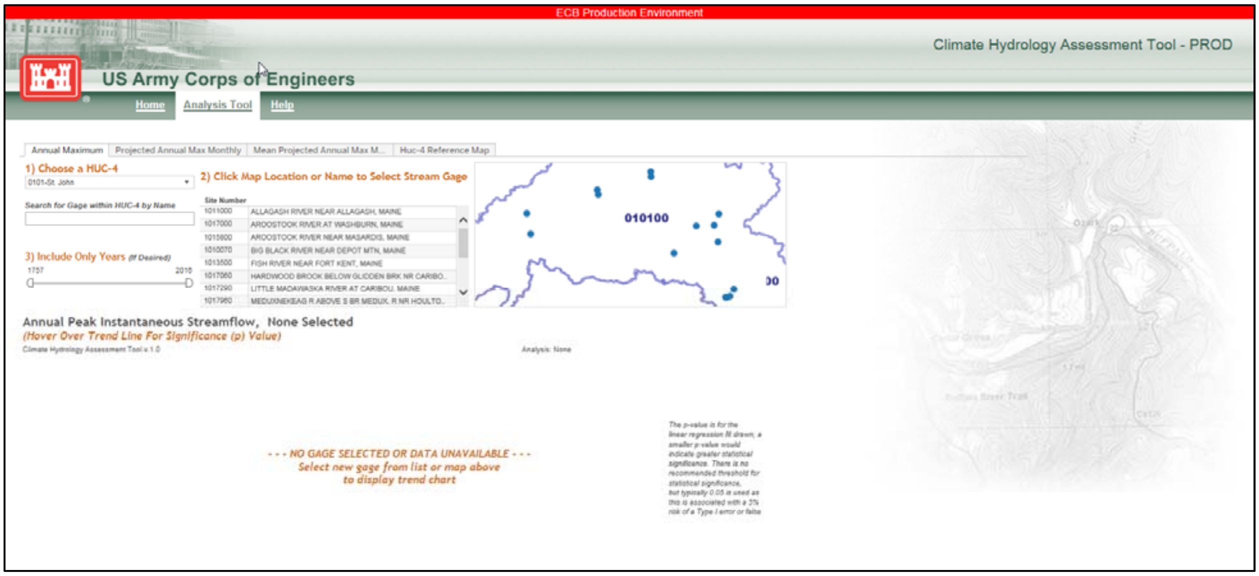


Figure 24: Climate Hydrology Assessment Tool, Analysis Tool

3.2.1 Available Site Data

The Climate Hydrology Assessment Tool under the Analysis Tool link uses four tabs to display information regarding trend detection in observed annual peak instantaneous streamflow, climate-modeled projected annual maximum monthly flow range, and trend detection in annual maximum monthly flow models.

- **Annual Maximum** – Under this tab (Figure 25), the user chooses a HUC4 watershed, then selects and obtains data for the desired USGS gage using the provided list or the map. Hovering over a spot on the map provides information on the gage and a link to open the gage data in a separate window. Available gage data include current/historical observations, daily data, daily statistics, monthly statistics, annual statistics, peak streamflow, field measurements, field/lab water-quality samples, and water-year summary data. Back on the tool page, graphics produce a trend line for the selected gage, and hovering over the trend line provides the equation for the line as well as an indication of significance.

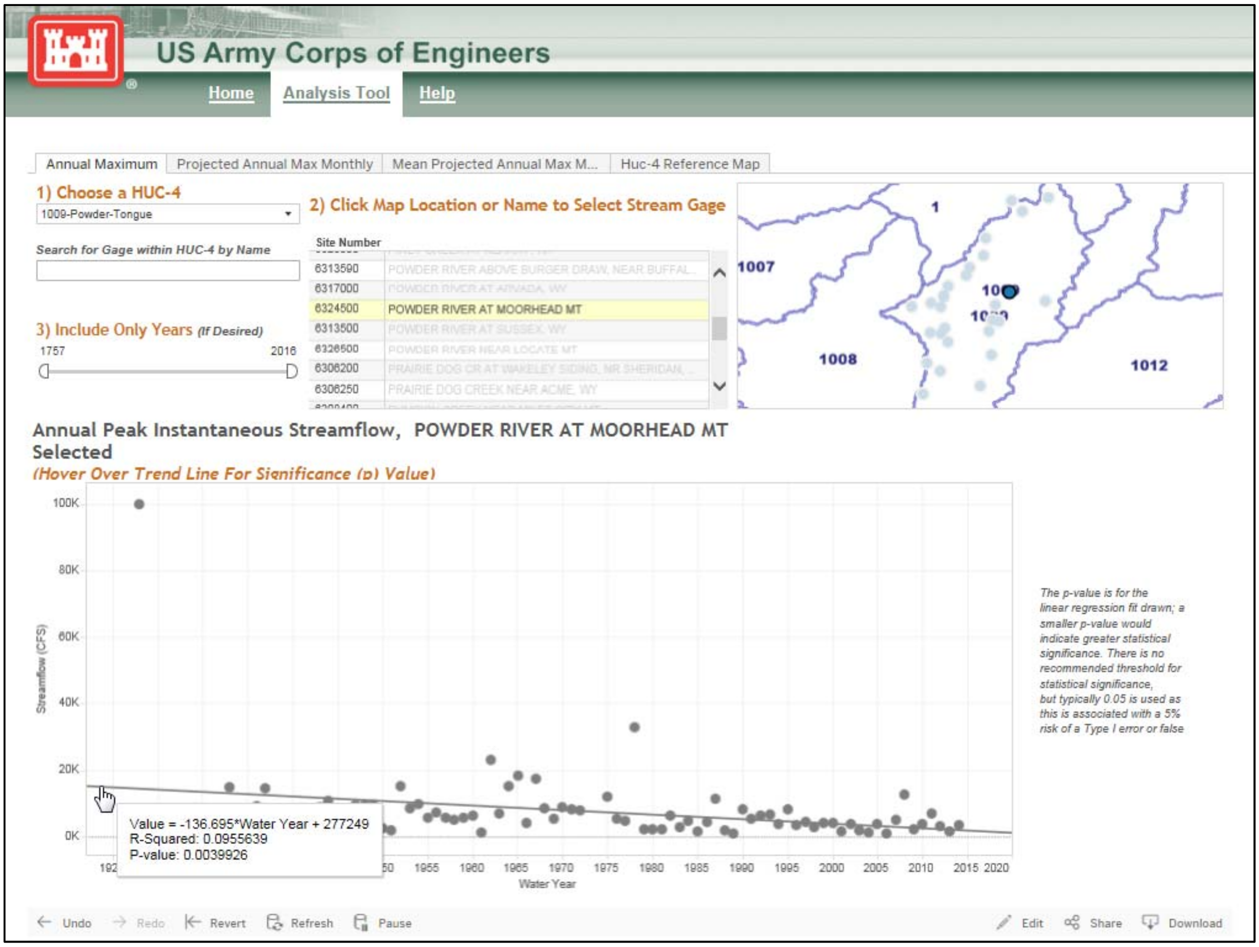


Figure 25: Annual Maximum Tab

- **Projected Annual Max Monthly -** This tab provides a graphic of the projected climate-changed hydrology for the selected HUC4 watershed (Figure 26). The range of 93 climate-changed hydrology models for the selected watershed shows the average annual maximum monthly flow in blue and the range of the values in yellow. The user can use a slide bar to customize the year range for observations and projections.

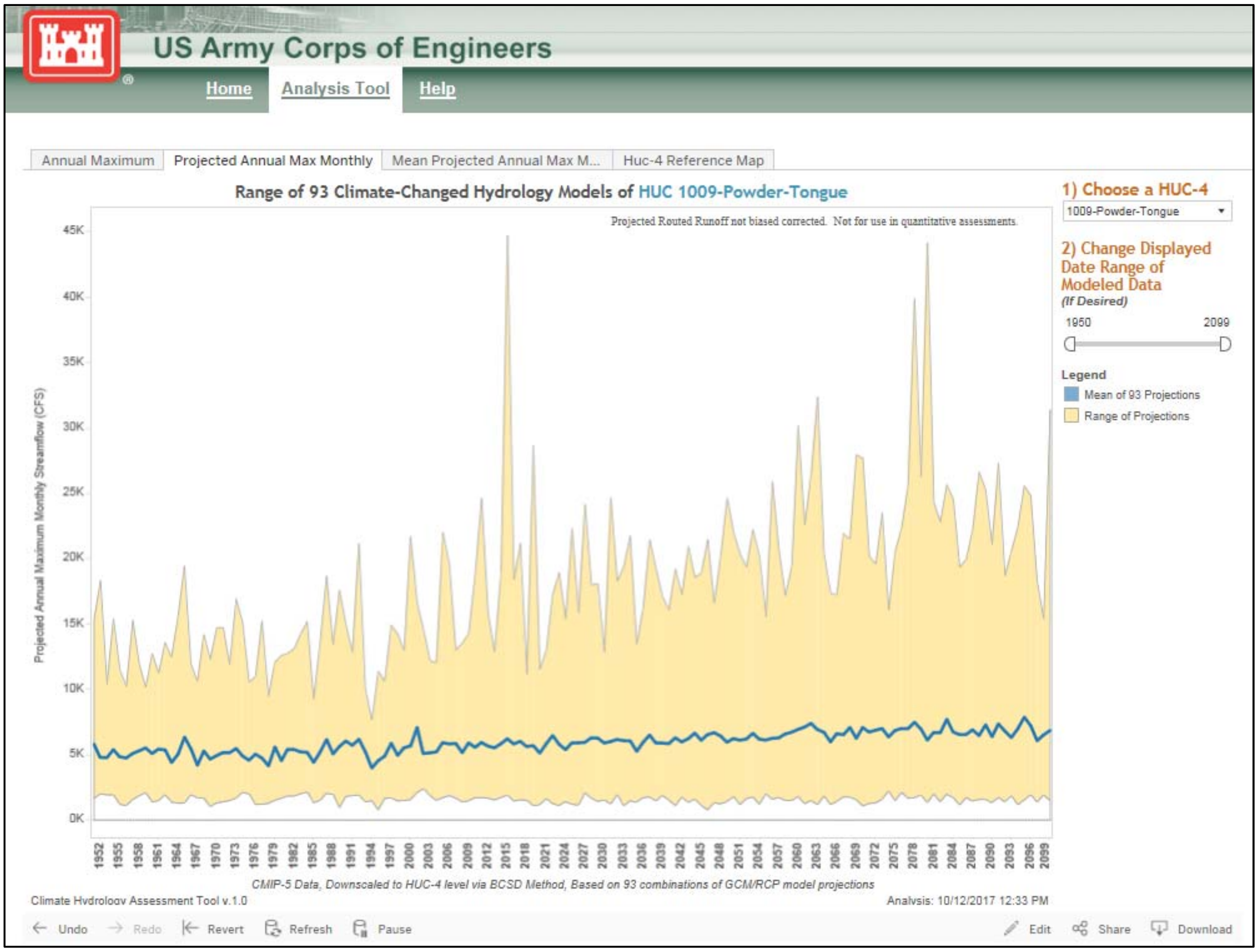


Figure 26: Projected Annual Max Monthly Tab

- **Mean Projected Annual Max Monthly -** This tab provides a graphic of the trends in mean of 93 climate-changed hydrology models for the selected watershed (Figure 27), showing a statistical analysis of the mean of the projected annual maximum monthly streamflow projections. Hovering over the trend line provides the equation for the line and also an indication of significance.

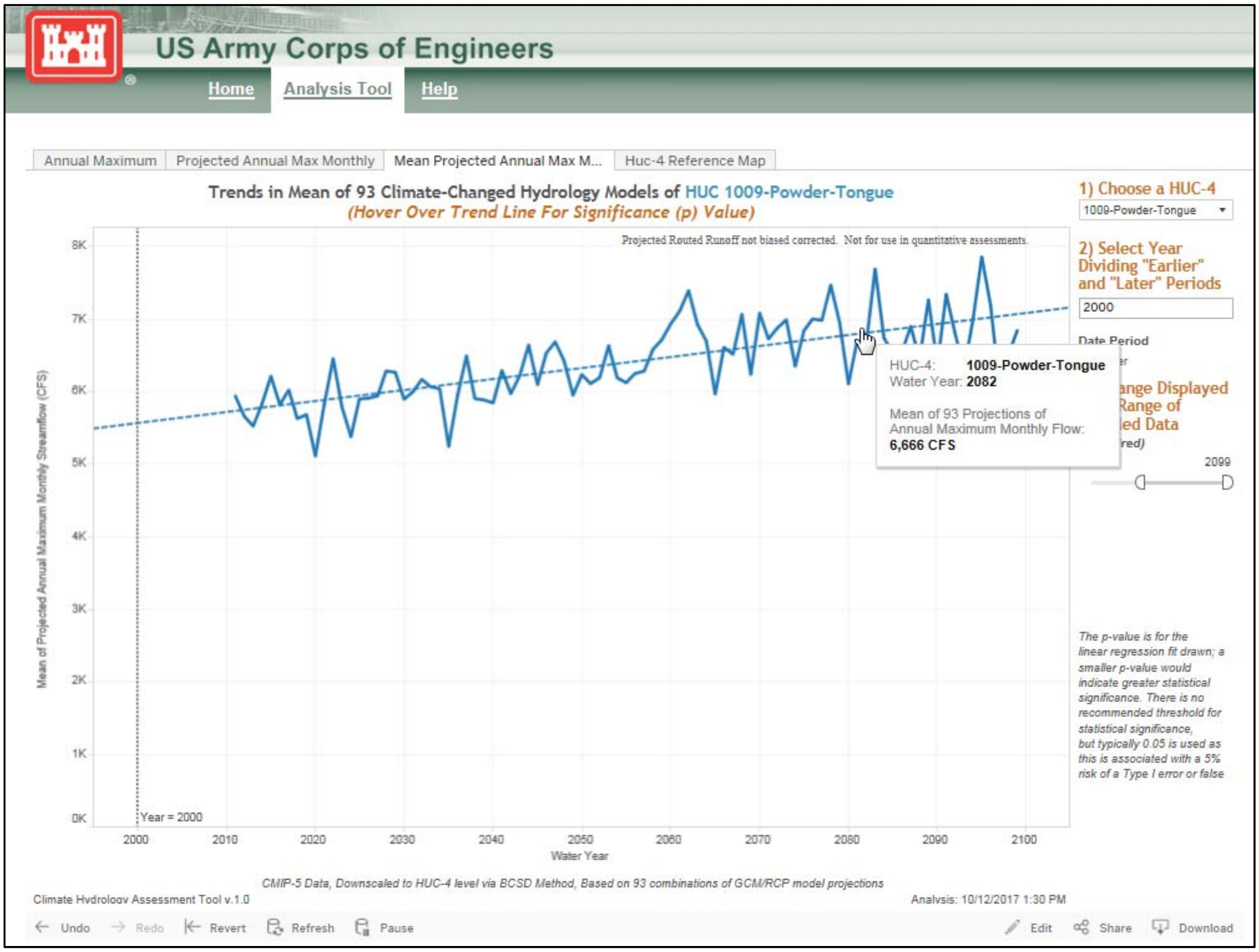


Figure 27: Mean Projected Annual Max Monthly Tab

- **HUC-4 Reference Map** – This fourth tab identifies each of the HUC4 watersheds, grouped by HUC2 (Figure 28). Hovering over individual watersheds will indicate the basin name and HUC4 number. The user may click on a watershed to isolate the specific selection from other watersheds. Additionally, there is an option to sort by state, which will display each full watershed located within state boundaries (Figure 29).

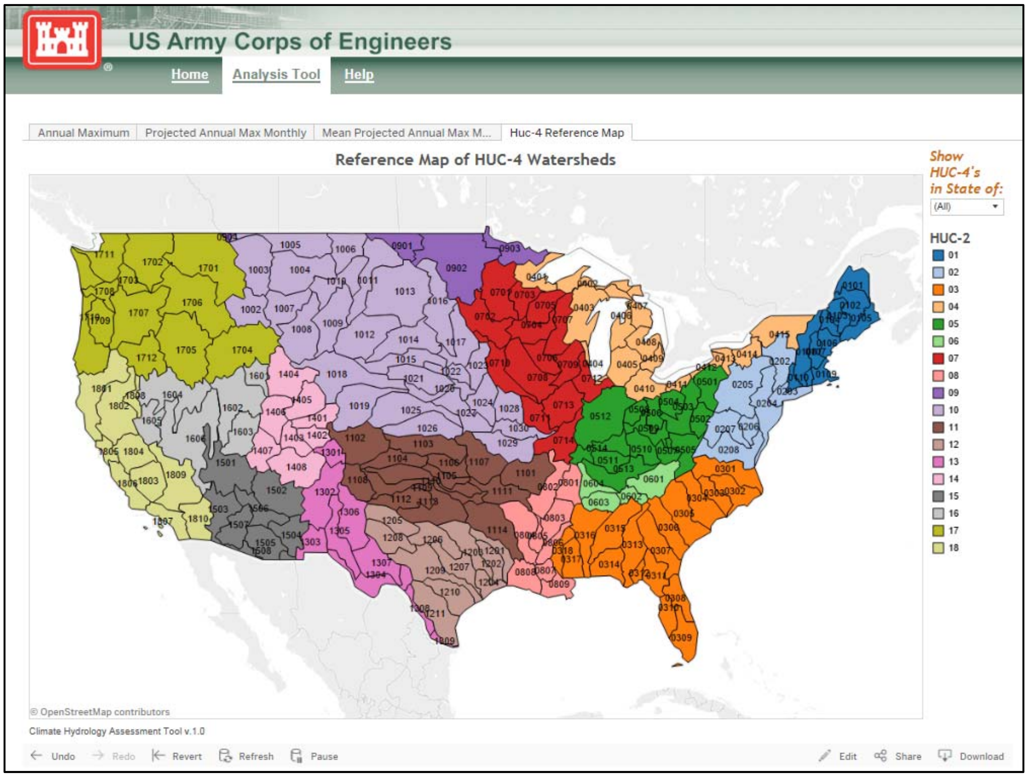


Figure 28: HUC4 Watersheds Reference Map Tab

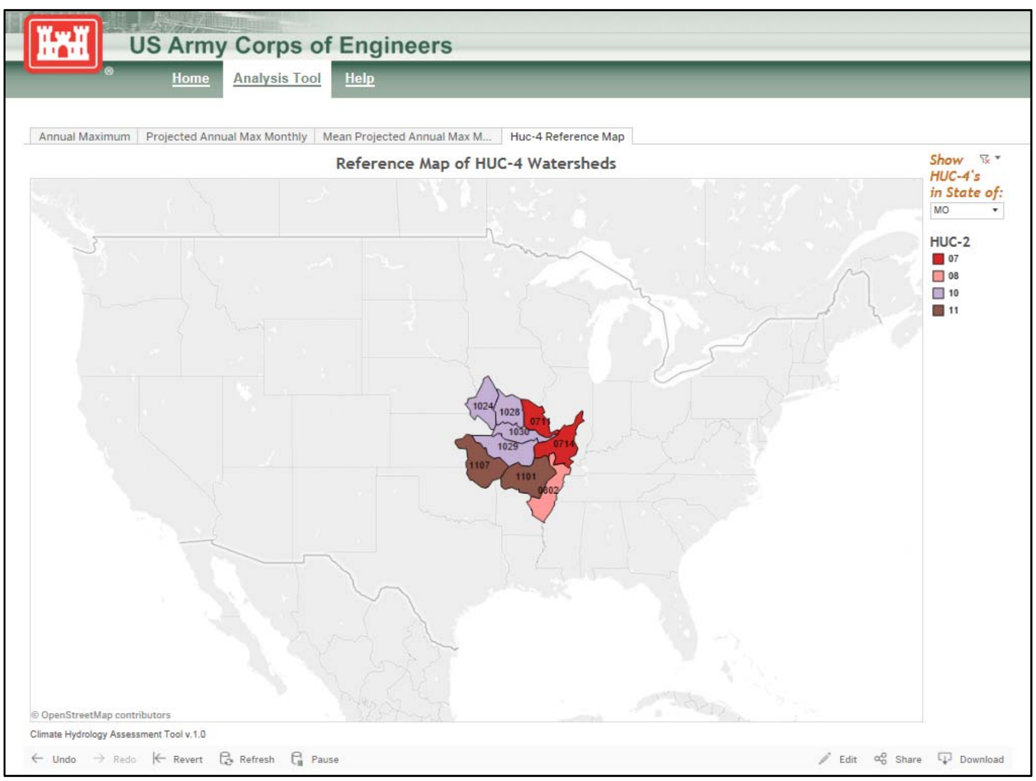


Figure 29: HUC4 Watersheds in Missouri

3.2.2 Data Available for Download

Generated data may be edited by the user or shared with a provided permalink. Depending on the data being obtained, the user may download the data into tables, images, or preformatted pdf files. It is unclear from the website how often the data will be updated or maintained over time.

3.2.3 Tool's Relevance to Ameren's Water Resiliency

The Climate Hydrology Assessment Tool provides existing and projected hydrological data for watersheds. The tool steps the user through the process of developing relevant information and graphs related to trends in streamflow. The tool can be useful to Ameren by providing complex hydrological data and detailed graphs, including for future time periods based on projected climate change scenarios, at a HUC level. At a HUC level, Ameren can focus on geographical areas of interest near energy centers and water intake locations. The data featured in this tool was from their 2016 release; therefore a new dataset may be released in the coming years for Ameren to revisit. Limitations to this tool would be related to the qualitative nature of the tool for streamflow trends, as well as the lack of other climate indicators like temperature or precipitation (i.e., specificity of streamflow analyses). Although the focus on one type of data could be useful, as long as Ameren is coupling it with the use of other tools for a more holistic view of water concerns.

3.3 NOAA – U.S. Climate Resilience Toolkit

The NOAA Climate Resilience Toolkit website and its associated Climate Explorer tool provide access to downscaled observed and projected climate data (Figure 30). The Climate Explorer tool is one of dozens of support tools available on the site; it includes a research application built to support the U.S. Climate Resilience Toolkit. Whether the focus is on rainfall, temperature and drought, or on sea level rise and vulnerable populations, the Climate Explorer tool allows you to look at climate stressors and their impacts at the same time (U.S. Climate Resilience Toolkit 2017).

The tool offers interactive maps and graphs as well as data of observed and projected temperature, precipitation, and related climate variables for every county in the contiguous U.S. Based on global climate models developed for the United Nations Intergovernmental Panel on Climate Change (IPCC), Climate Explorer's graphs and maps show projected conditions for two possible futures: one in which humans make a moderate attempt to reduce global emissions of heat-trapping gases and one in which humans go on conducting business as usual. Decision makers can compare climate projections based on these two scenarios and plan according to their tolerance for risk and the time frame of their decisions.

3.3.1 Available Site Data

The Climate Explorer displays climate observations for temperature, precipitation, and related variables for 1950 to the early 2000s. These averages are calculated from quality-checked, ground-based weather stations across the country. Comparing the range of observations against the simulations for a given period can provide insights on the models' collective ability to capture the range of observed variability for each climate variable. In some cases, the simulations and observations show a good match; in other cases, these comparisons may reveal consistent biases or limitations of the models.

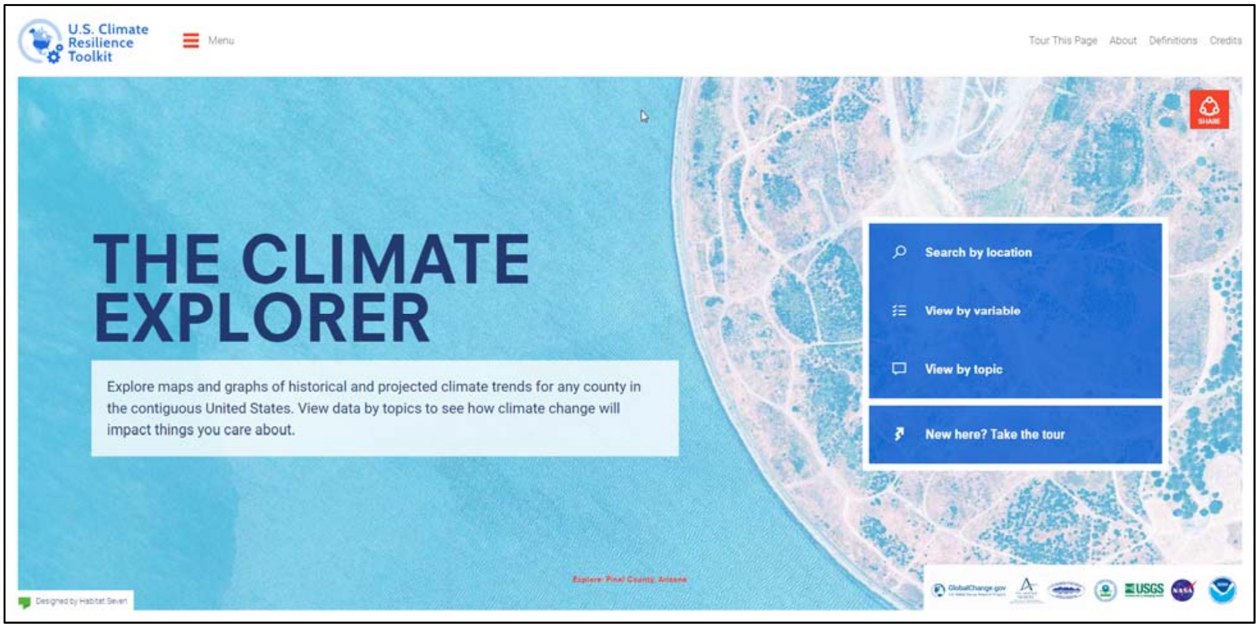


Figure 30: Climate Explorer Tool Home Page

This website provides downscaled climate change model data related to temperature and precipitation. Users can query the website by county, city, or zip code, and view graphics displaying information associated with temperature, precipitation, heating/cooling days, and weather station information (see Figure 31 for a temperature data example). All the climate projection graphs are customizable. Additionally, a Map option on the right of each graph allows the user to view the data in a layer over the selected area.

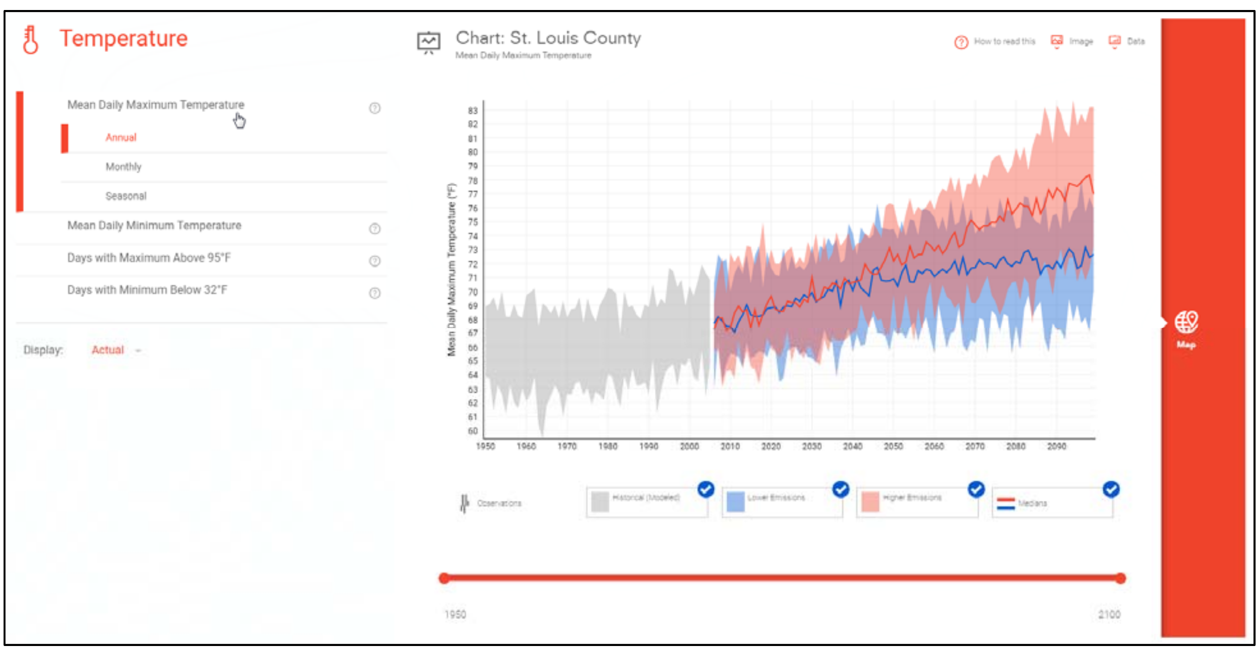


Figure 31: Temperature Data for St. Louis County, Missouri

In addition to searching by location, data can be queried using the Climate Explorer by variable and/or topic. The View by Variable maps (Figure 32) show past observations and future projections for nine different climate variables:

- Mean Daily Maximum Temperature
- Mean Daily Minimum Temperature
- Days With Max Above 95°F
- Days With Min Below 32°F
- Precipitation
- Mean Daily Precipitation
- Days of Precipitation Above 1 Inch
- Heating Degree Days
- Cooling Degree Days

The interface offers a way to select a decade from the 1950s to the 2090s as well as to compare conditions projected for two scenarios: "higher emissions" and "lower emissions."

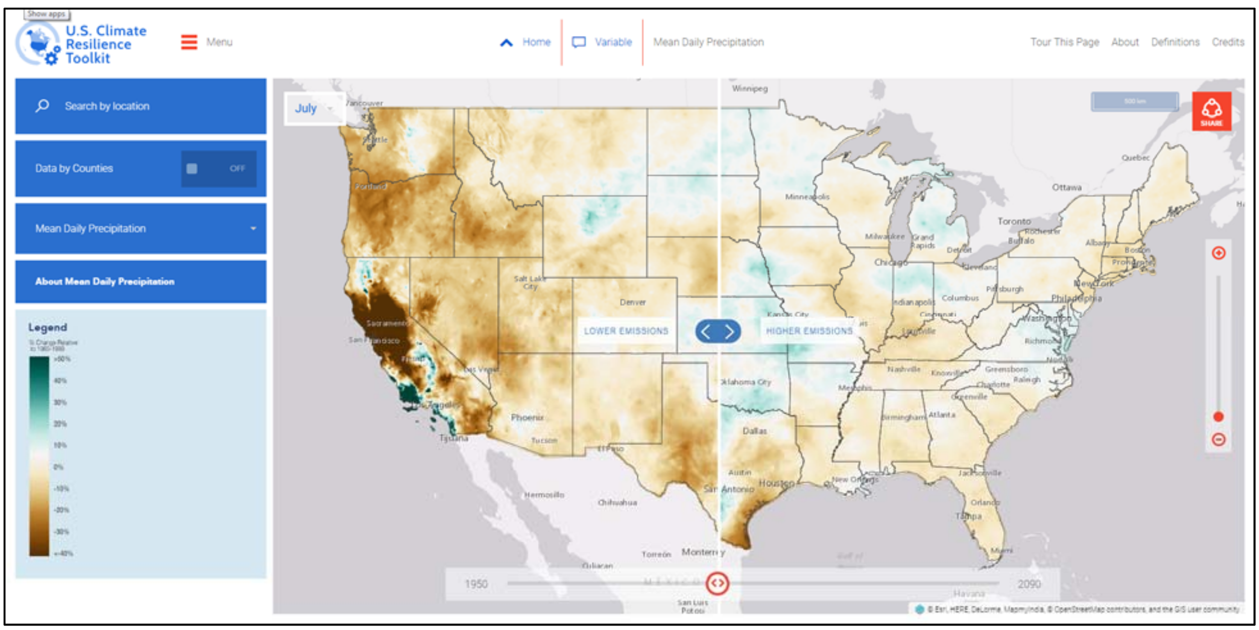


Figure 32: Example View by Variable Page – Mean Daily Precipitation

Figure 33 shows an example of the View by Topic section, which provides an opportunity to explore maps related to several topics, including:

- Development and Sea Level Rise, and River Flooding;
- Coastal Power and Storm Surge, and Sea Level Rise
- Coastal Wetlands and Sea Level Rise
- Pollution Sources and Sea Level Rise

- Transportation and Sea Level Rise, and River Flooding
- Tribal Nations and Sea Level Rise, Storm-Surge, Max Temperatures, Min Temperatures, and River Flooding
- Population Density and River Flooding

The interactive map layers indicate where assets such as power plants, wetlands, and tribal lands intersect with climate threats such as sea level rise, storm surge, or potential flooding.

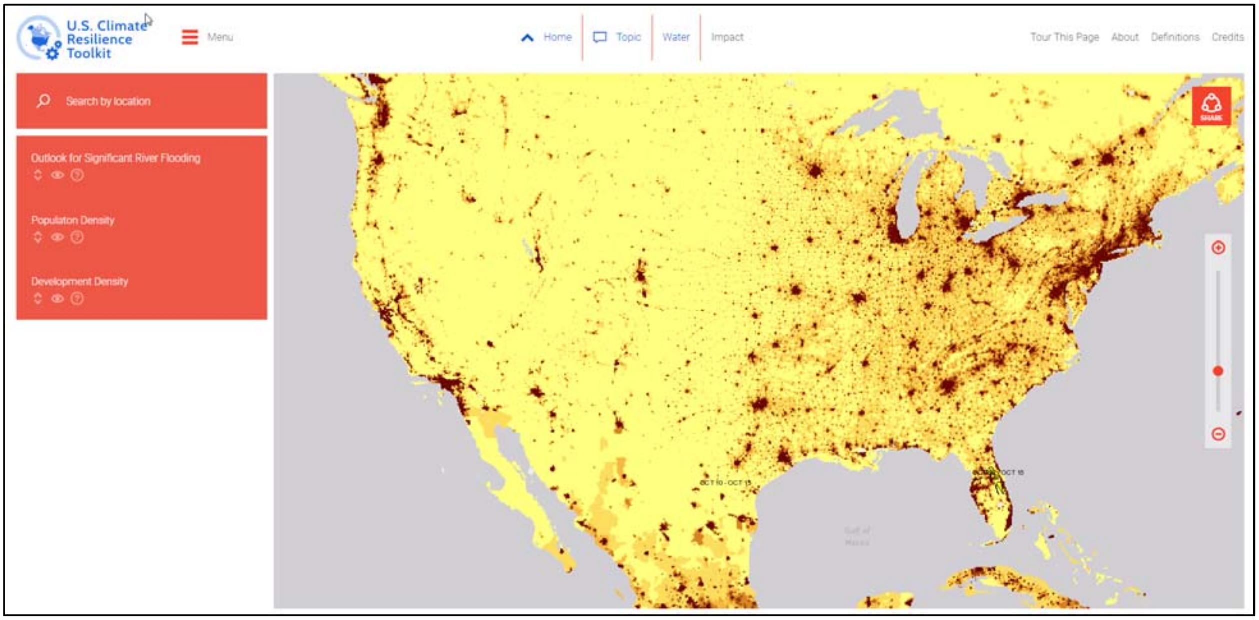


Figure 33: Example View by Topic Page – Outlook for Significant River Flooding associated with Population and Development Density

3.3.2 Data Available for Download

The original version of Climate Explorer has been available on the U.S. Climate Resilience Toolkit website since November 2014, and a new version was released in July 2016. Both versions of the web application are available.

Customized maps or graphs can be downloaded as a .PNG file. Files of observed, historical modeled, and projected modeled data for any location can be downloaded as comma-separated value (.csv) files. Additionally, maps can be posted to Facebook or Twitter, or a copied URL "permalink" can be used or shared to regenerate a specific map at any time.

There is no information indicating updates to the site are in progress; however, due to the availability of data and frequency with which the tool has been updated over the last few years, it is expected that the tool will be available and continually updated for the foreseeable future.

3.3.3 Tool's Relevance to Ameren's Water Resiliency

The Climate Explorer Tool can be useful to Ameren by allowing for county-level assessments of changes to temperature and precipitation. This assessment could be done specifically for counties with key energy centers and/or water intake locations, or other geographical areas of interest. The tool provides user-friendly and informative maps and graphs for both observed and projected data. The data featured in this tool was from their 2016 release; therefore a new dataset may be released in the coming years for Ameren to revisit. The limiting factor of this tool is the potential for model biases or the broad reach of information that could get busy and difficult to focus in on relevant topics for analysis.

The broader U.S. Climate Resilience Toolkit that houses the Climate Explorer is also an excellent resource for Ameren as it has countless additional tools, information, and subject matter expertise on how to build climate resilience. Ameren can utilize information based on sector specific (e.g., water, energy) or regional interests. In addition, this tool provides an easy and efficient platform for data sharing.

3.4 U.S. Drought Monitor

The U.S. Drought Monitor (USDM), established in 1999, is produced through a partnership between the National Drought Mitigation Center at the University of Nebraska-Lincoln, the U.S. Department of Agriculture (USDA), and the NOAA. The USDM website (http://droughtmonitor.unl.edu) presents a weekly map of drought conditions based on climatic, hydrologic, and soil conditions, as well as reported impacts and observations from over 350 contributors (National Drought Mitigation Center and USDA 2017).

A weekly drought summary is prepared by leading climatologists from these partner organizations. The summary includes descriptions of drought conditions by regions in the continental U.S. (Northeast, Southeast, South, Midwest, High Plains, West) and by Alaska, Hawaii, and Puerto Rico (http://droughtmonitor.unl.edu/DroughtSummary.aspx). The drought summary also contains a “looking ahead” section for the following week. The USDM is used by policy makers and media in discussions of drought and in allocations of drought relief. It is also monitored by many water supply providers in the country.

The USDM describes and shows drought in five categories, from D0 - Abnormally Dry (going into drought) to D4 - Exceptional Drought (see Table 4 below).

Table 4: Drought Severity Classification

Drought Severity Classification

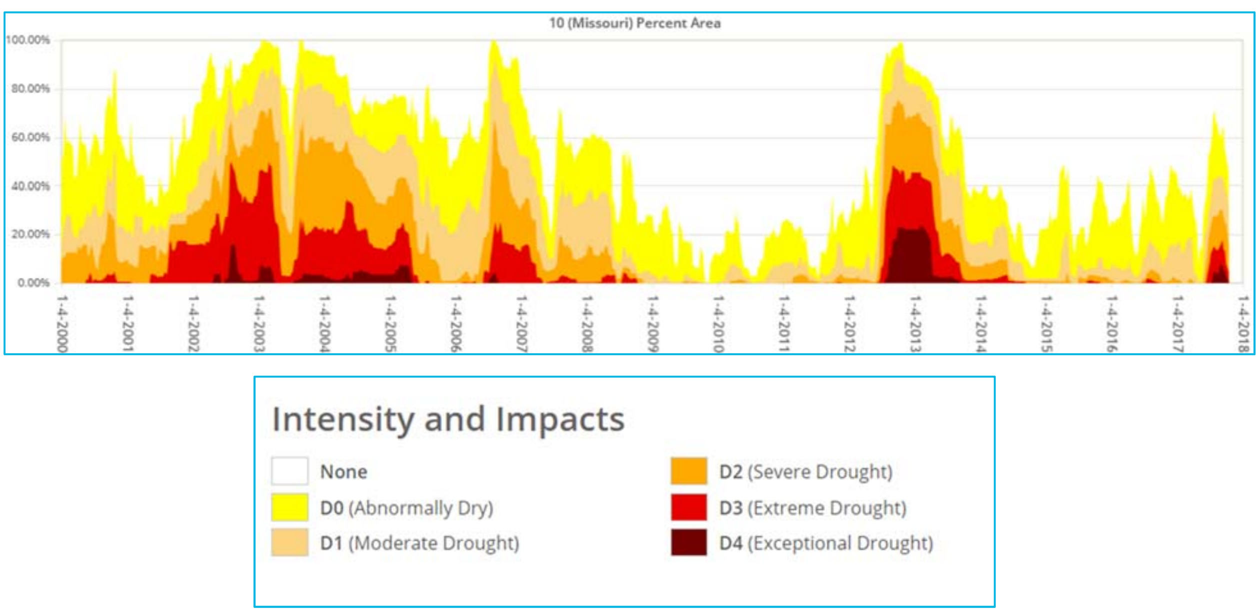
Category	Description	Possible Impacts	Ranges: Palmer Drought Severity Index (PDSI)	Ranges: CPC Soil Moisture Model (Percentiles)	Ranges: USGS Weekly Streamflow (Percentiles)	Ranges: Standardized Precipitation Index (SPI)	Ranges: Objective Drought Indicator Blends (Percentiles)
D0	Abnormally Dry	Going into drought: • short-term dryness slowing planting, growth of crops or pastures Coming out of drought: • some lingering water deficits • pastures or crops not fully recovered	-1.0 to -1.9	21 to 30	21 to 30	-0.5 to -0.7	21 to 30
D1	Moderate Drought	• Some damage to crops, pastures • Streams, reservoirs, or wells low, some water shortages developing or imminent • Voluntary water-use restrictions requested	-2.0 to -2.9	11 to 20	11 to 20	-0.8 to -1.2	11 to 20
D2	Severe Drought	• Crop or pasture losses likely • Water shortages common • Water restrictions imposed	-3.0 to -3.9	6 to 10	6 to 10	-1.3 to -1.5	6 to 10
D3	Extreme Drought	• Major crop/pasture losses • Widespread water shortages or restrictions	-4.0 to -4.9	3 to 5	3 to 5	-1.6 to -1.9	3 to 5
D4	Exceptional Drought	• Exceptional and widespread crop/pasture losses • Shortages of water in reservoirs, streams, and wells creating water emergencies	-5.0 or less	0 to 2	0 to 2	-2.0 or less	0 to 2

Short-term drought indicator blends focus on 1-3 month precipitation. Long-term blends focus on 6-60 months. Additional indices used, mainly during the growing season, include the USDA/NASS Topsoil Moisture, Keetch-Byram Drought Index (KBDI), and NOAA/NESDIS satellite Vegetation Health Indices. Indices used primarily during the snow season and in the West include snow water content, river basin precipitation, and the Surface Water Supply Index (SWSI). Other indicators include groundwater levels, reservoir storage, and pasture/range conditions.

Source: http://droughtmonitor.unl.edu/AboutUSDM/DroughtClassification.aspx

3.4.1 Available Site Data

The website provides time series data starting in January 2010 – Current. The percent area in drought can also be sorted by county, by state, by various HUC levels (HUC2 to HUC8), by climate region, and by USACE district or division. Figure 34 shows the percent area of drought from January 2010 to October 19, 2017, within the Missouri Region (including the PRB) and the Upper Mississippi Region, which are both HUC2 Water Resources Regions.



Source: http://droughtmonitor.unl.edu/Data/Timeseries.aspx

Figure 34: Missouri Region (HUC2) Percent Area by Drought Category

3.4.2 Data Available for Download

Drought monitor data are available in various formats for download on the USDM website (http://droughtmonitor.unl.edu/Data.aspx):

- Times series
- Tabular data
- Drought statistics (comprehensive, by threshold and weeks in drought)
- GIS data
- Metadata
- Farm Service Agency (FSA) Eligibility Tool – Tool to determine if an area qualifies for disaster payments from the FSA

3.4.3 Palmer Drought Severity Index

The Palmer Drought Severity Index (PDSI) is a measurement of dryness that is monitored frequently by policy makers, farmers, and water suppliers. It is based on available precipitation and temperature data. The PDSI is a valuable tool to understand the effects of climate change on drought through changes in evapotranspiration. The PDSI is most effective in determining long-term droughts in low and middle latitudes. PDSI is measured on a scale of -10 to +10. The severity is classified into the categories shown in Table 5 (NOAA NCEI 2017b).

Table 5: Palmer Drought Severity Index — Categories of Severity

Extreme Drought	Severe Drought	Moderate Drought	Mid-range	Moderately Moist	Very Moist	Extremely Moist
-4.00 and below	-3.00 to -3.99	-2.00 to -2.99	-1.99 to +1.99	+2.00 to +2.99	+3.00 to +3.99	+4.00 and above

Section 4, Focus on Watersheds, summarizes the historical trends observed based on the PDSI. The data gathered for this report on trends in Missouri, Illinois, and Wyoming span the period from January 1900 through September 2017. The PDSI was provided for each month during this time frame.

Number of months in each category

Table 6 shows the number of months between January 1900 and September 2017 that fell into each severity category of the PDSI.

Table 6: Months of Dryness between January 1900 and September 2017 based on Palmer Drought Severity Index

Severity	Extreme Drought	Severe Drought	Moderate Drought	Mid-Range	Moderately Moist	Very Moist	Extremely Moist
Missouri	51	69	113	794	196	123	67
Illinois	71	72	118	814	191	103	44
Wyoming	179	106	102	550	166	141	169

For all three states, the majority of the months are historically in the mid-range category. Wyoming has had significantly more months in the extreme drought and extremely moist categories, and fewer months in the mid-range category.

3.4.4 Tool's Relevance to Ameren's Water Resiliency

The USDM tool synthesizes complex climatic, hydrologic and soil conditions, as well as reported impacts and observations from more than 350 contributors around the country into user-friendly and accessible maps and datasets. The USDM provides data in versatile downloadable formats that is updated on a weekly basis. This would be useful to Ameren to assess current and past drought conditions in geographic areas of interest that rely heavily on water resources. The USDM does not provide projected data for future time periods, but does offer monthly outlook data that could help inform decision-making regarding water availability and use.

3.5 Tool Comparison

Table 7 provides a summary of water and climate risk assessment tools and datasets that are available online that were described in Section 3, Overview of Selected Climate Change Tools and Datasets.

Table 7: Online Water and Climate Risk Assessment Tools

Available Data						
Tool	**Owner/ Operator**	**Tool Focus**	**Release Date/Last Update**	**Basis (# of Model, Scenarios)**	**Resolution of Model**	**Projections Available**
Aqueduct Water Risk Atlas	Water Resources Institute (WRI)	Monitoring and mapping water risk	Released 2013; last update 2015	Estimates derived from GCMs from the CMIP5; and mixed-effects regression models based on projected socioeconomic variables from the IIASA's SSP database. Climate scenarios: RCP4.5 and RCP8.5 Socioeconomic pathways: SSP2 and SSP3	Watersheds (approximately HUC4 within US)	Current conditions and future conditions for years 2020, 2030, and 2040
USACE Climate Hydrology Assessment Tool	USACE	Climate hydrology and impacts on water resources	Mainly static with certain components automated daily updates (gage data)	CMIP-5 Data, Downscaled to HUC-4 level via BCSD Method, Based on 93 combinations of GCM/RCP model projections.	HUC4 watersheds or specific USGS flow gages	1950 to 2099

Available Data						
Tool	**Owner/ Operator**	**Tool Focus**	**Release Date/Last Update**	**Basis (# of Model, Scenarios)**	**Resolution of Model**	**Projections Available**
NOAA Climate Explorer	NOAA	Identifying and documenting climate hazards	Original version November 2014; updated version July 2016	CMIP5 using Bias-Corrected Constructed Analogs (BCCA), provided by the U.S. Geological Survey; RCP4.5 and RCP8.5	County-based queries based on NASA Earth Exchange Downscaled Climate Projections at a spatial resolution of 30 arcseconds.	Each decade from 1950 to 2090
U.S. Drought Monitor	National Drought Mitigation Center at University of Nebraska-Lincoln, USDA, and NOAA	Drought conditions	Updated weekly	Historical drought statistics; weekly map with drought severity classifications	County, state, HUC2 to HUC8 watershed, USACE Districts, climate regions, and various other scales	Only qualitative “looking ahead” for the following week

4. Focus on Watersheds

This section discusses the available future predictions for each watershed in Ameren's service area using the preferred tools discussed in Section 3. Based on the tools available and building off of the literature review conducted in Section 2, Review of Climate Science for the Region, this section discusses how future climate conditions could affect a variety of watershed issues, including the frequency and intensity of extreme events such as peak flow events, peak streamflow levels, and drought conditions.

4.1 Introduction to Watershed Analysis and Trend Comparison

The comparison of future climate trends and potential impacts to watersheds are discussed using four of the tools listed in Section 3:

- Aqueduct for predicted water stress
- NOAA Climate Explorer for projected temperature and precipitation changes
- USACE Climate Hydrology Assessment Tool for projected streamflow changes
- U.S. Drought Monitor for historical and current drought conditions

The examples or trend analyses shown are not exhaustive but are representative of the study area (HUC2 water resources regions) because of the resolution of the GCM currently available.

4.2 Maps of Watersheds in the Study Area

This section presents the watershed maps from the Aqueduct Water Risk Atlas for water stress[24] for three time periods: baseline, 2020 and 2030. Further time frames are available; however, these time periods were used for this report to consider near-term conditions to minimize uncertainty that occurs and increases as projections become further away from the baseline period. The maps presented show an area that encompasses the entire study area, including the Upper Mississippi Region, lower Missouri Region and PRB.

The projected conditions for years 2020 and 2030 are compared to baseline water stress for three future scenarios, as defined in Section 3.1.1—Optimistic, Business as Usual, and Pessimistic, using the Aqueduct Water Risk Atlas outputs (see Table 3). The maps generated by the Water Risk Atlas show how climate change and/or development could affect water resources over the next 30 years. The results are summarized based on HUC2 Water Resources Regions (Upper Mississippi and Missouri) and the PRB. The PRB is in the upper Missouri Region and the arid characteristics, including climate, soil, and water resources, are considerably different from those of the lower Missouri Region.

4.2.1 Aqueduct Baseline

In Aqueduct, the "Baseline" water stress measures the ratio of total annual water withdrawals to total available annual renewable supply, accounting for upstream consumptive use (see Figure 35). Higher values indicate more competition for water among users. Baseline water stress in the portion of Missouri that is within Ameren's service area is mostly low (<10 percent) and low to medium (10 to 20 percent). Baseline water stress in Illinois is mostly high (40 to 80 percent),

[24] Aqueduct water stress indicator measures "annual" water withdrawal vs "annual" supply.

while the baseline water stress in the PRB in Wyoming is mostly arid and low water use (World Resources Institute 2017).

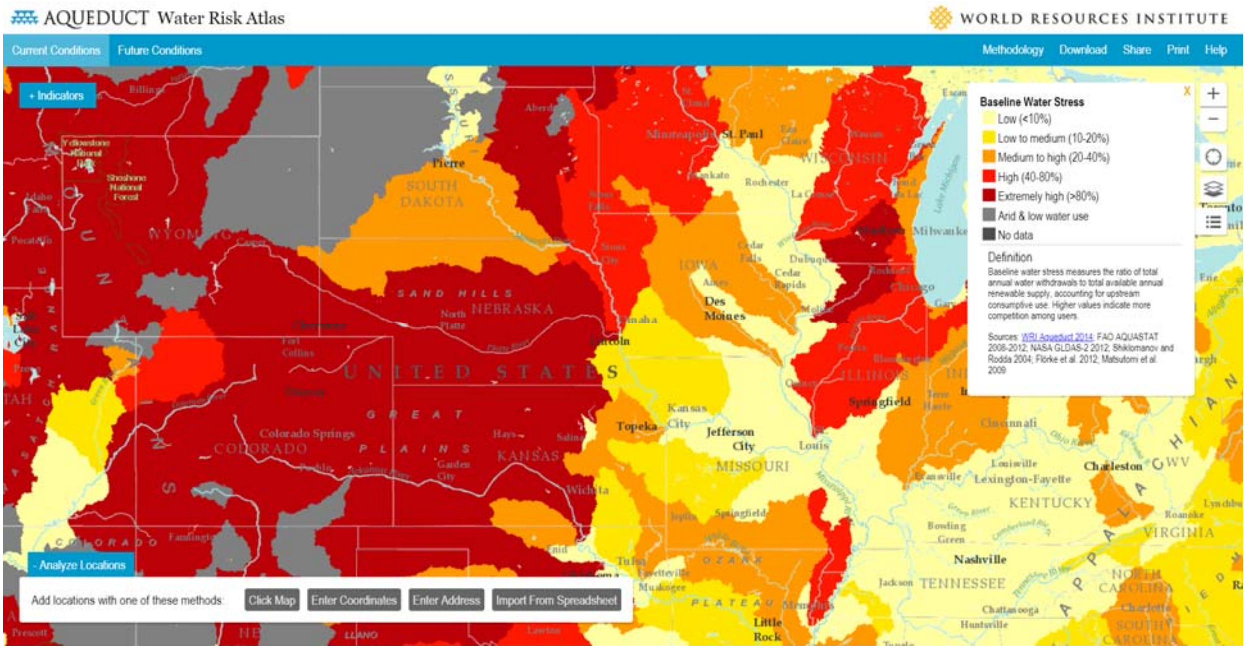


Figure 35: Aqueduct Baseline (2010) Water Stress

4.2.2 Aqueduct 2020

Figure 36 through Figure 38 show the projected change in water stress from baseline to 2020 for three future scenarios: Optimistic, Business as Usual, and Pessimistic, respectively (as detailed in Table 3). A summary of projected change in water stress is incorporated at the beginning of each section below for the respective watershed in the study area.

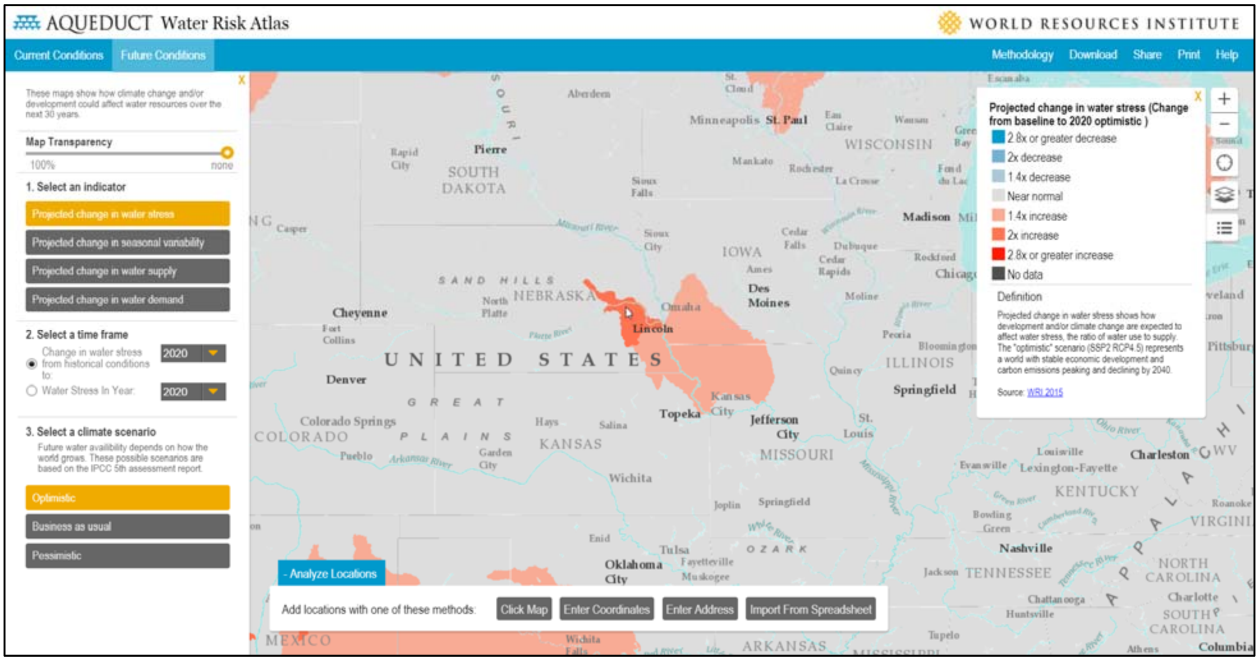


Figure 36: Aqueduct 2020 (2010-2030) Water Stress Change - Optimistic Scenario (SSP2 RCP4.5)

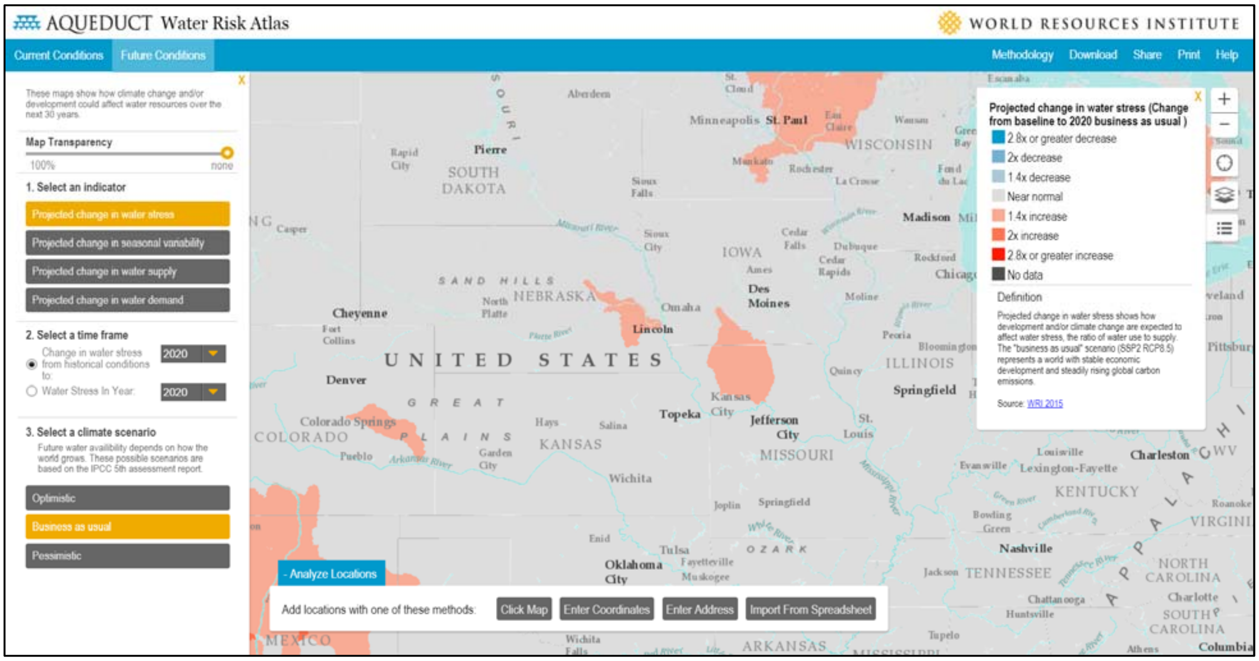


Figure 37: Aqueduct 2020 (2010-2030) Water Stress Change - Business as Usual Scenario (SSP2 RCP8.5)

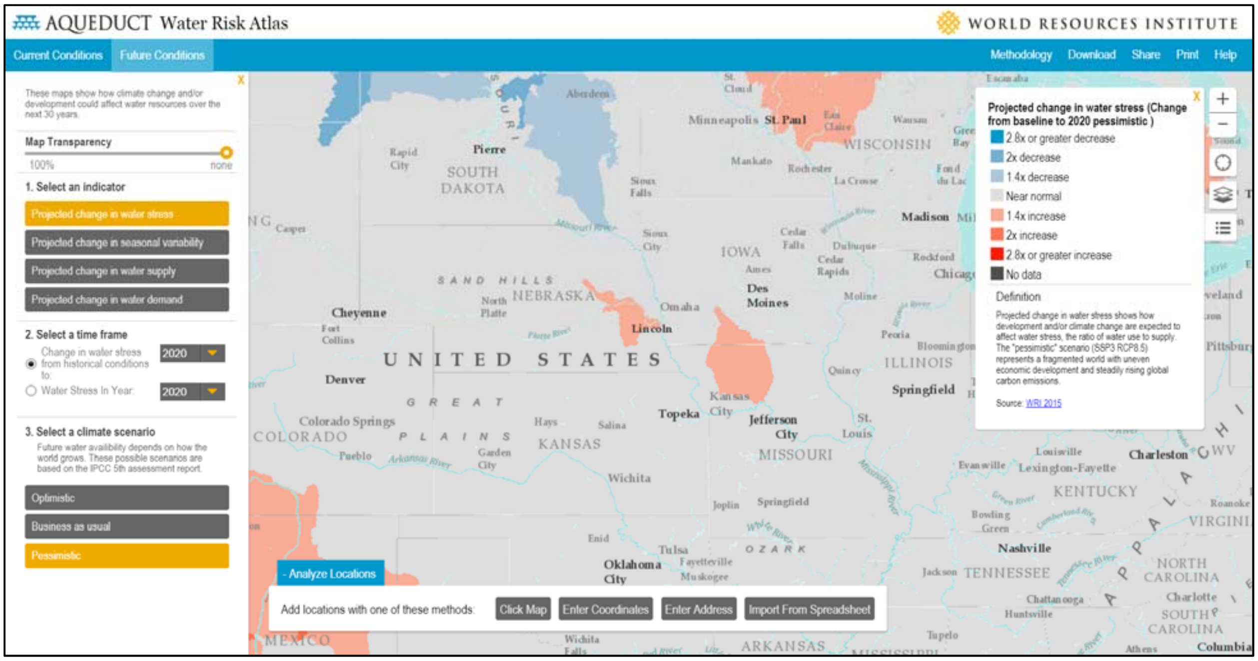


Figure 38: Aqueduct 2020 (2010-2030) Water Stress Change - Pessimistic Scenario (SSP3 RCP8.5)

4.2.3 Aqueduct 2030

Figure 39 to Figure 41 show the projected change in water stress from baseline to 2030 for three future scenarios: Optimistic, Business as Usual, and Pessimistic, respectively. A summary of projected change in water stress from Aqueduct is incorporated at the beginning of each section below for the respective watershed in the study area.

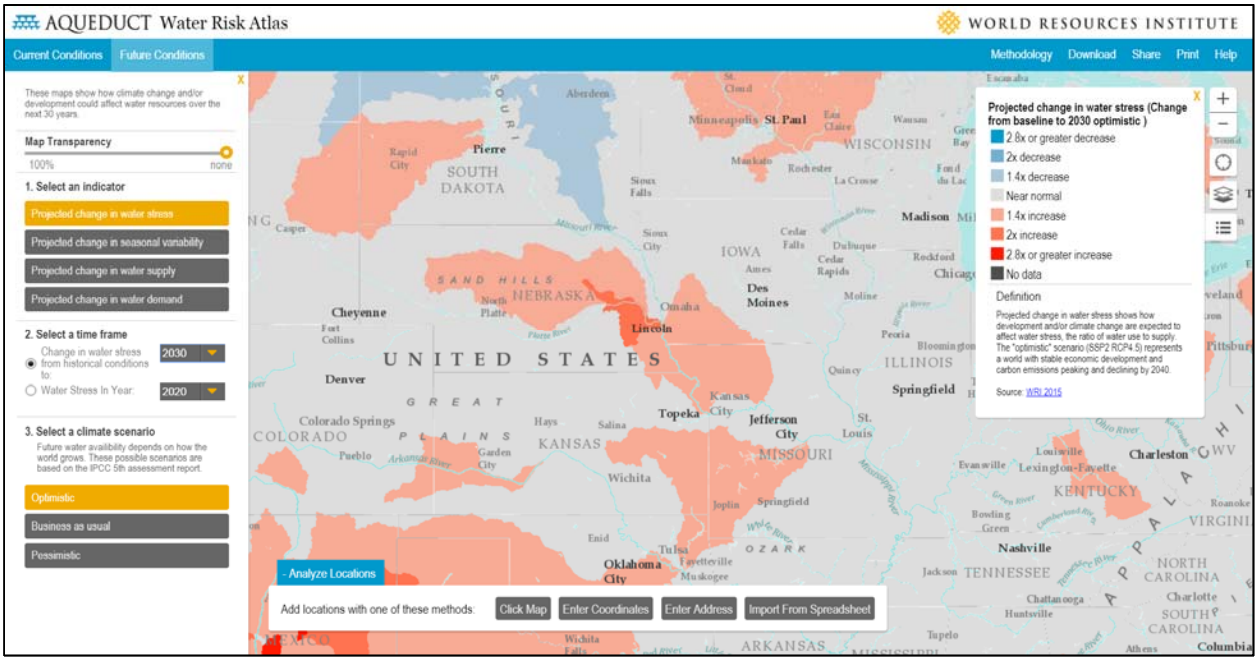


Figure 39: Aqueduct 2030 (2020-2040) Water Stress Change Optimistic Scenario (SSP2 RCP4.5)

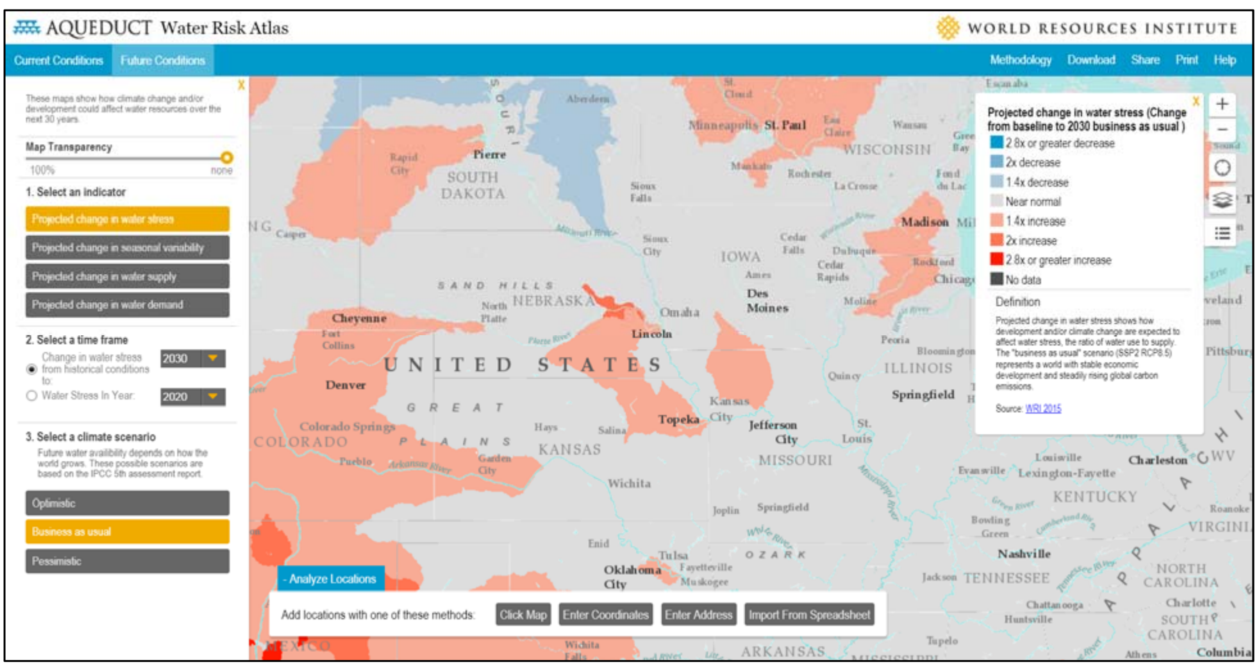


Figure 40: Aqueduct 2030 (2020-2040) Water Stress Change Business as Usual Scenario (SSP2 RCP8.5)

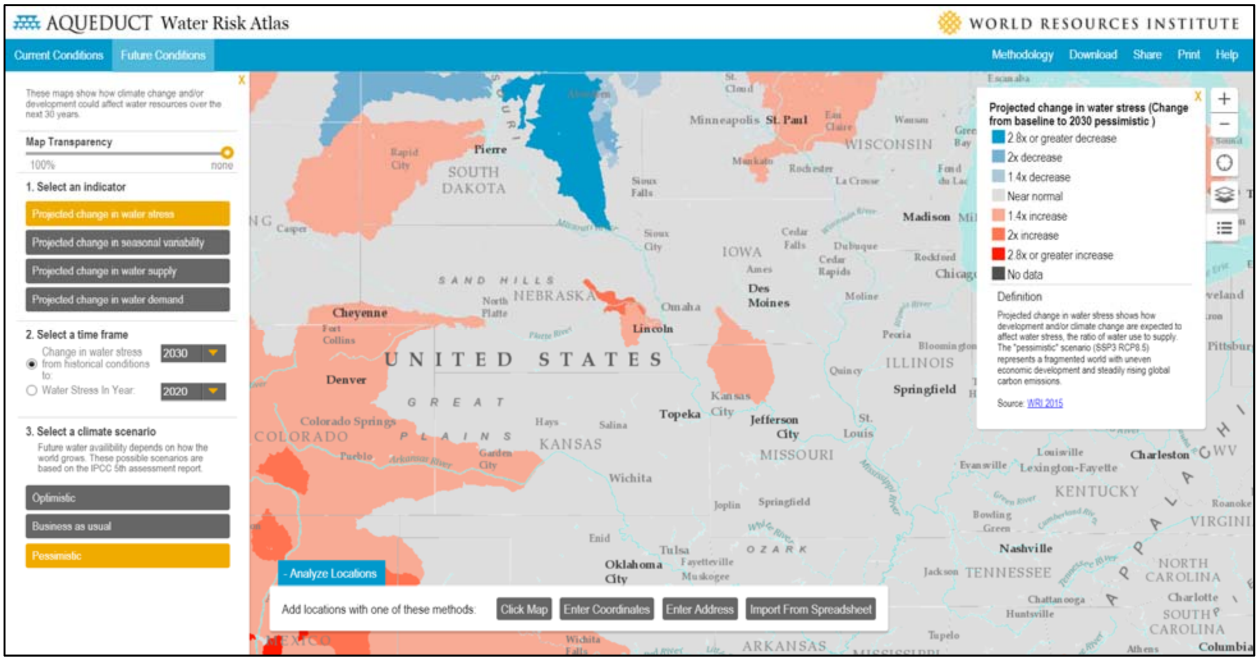


Figure 41: Aqueduct 2030 (2020-2040) Water Stress Change Pessimistic Scenario (SSP3 RCP8.5)

4.3 Impacts on Watersheds and Hydrology

The projected changes for each of the three water resources region in the study area are summarized in this section. Each watershed summary is organized based on 1) projected changes in water stress, 2) projected changes in temperature and precipitation, 3) projected changes in flows and drought trends, and 4) summary.

4.3.1 Upper Mississippi Water Resources Region

4.3.1.1 Projected Changes in Water Stress

In the Upper Mississippi Region, the Aqueduct Water Risk Atlas predicted that water stress in the area is all near normal in 2020. In 2030, water stress is near normal for the optimistic and pessimistic scenarios; however, water stress may increase by 40 percent for certain areas for the business as usual scenario due to decreases in water supply. Table 8 summarizes the predicted change in water stress. Aqueduct uses the following categories in their tool to represent the change in the index values for water stress:

- 2.8x or greater decrease
- 2x decrease
- 1.4x decrease
- Near normal
- 1.4x increase,
- 2x increase
- 2.8x or greater increase

Table 8: Summary of Change in Water Stress - Upper Mississippi River Watershed in Illinois

Aqueduct Climate Scenario	2020 (2010-2030)	2030 (2020-2040)	Comments
Optimistic	All Near Normal	All Near Normal	Minor changes in main indicator variables for both 2020 and 2030
Business as usual	All Near Normal	Mostly Near Normal	2030 small area of 1.4x increase due to anticipated increase in water demand
Pessimistic	All Near Normal	All Near Normal	Minor changes in main indicator variables for both 2020 and 2030

4.3.1.2 Projected Changes in Temperature and Precipitation

Projected future climate trends were obtained from the NOAA Climate Explorer. Hancock County, IL (shown in Figure 1), was selected as a central location within the watershed. The county is located along the western border of Illinois with Missouri and Iowa and is the Illinois side of the Ameren Keokuk facility.

Figure 42 shows the observed and projected mean daily maximum temperature in Hancock County, IL. Hancock County is anticipated to see an increase in daily maximum temperatures in the future compared to the observed time horizon (1980 to 2000).

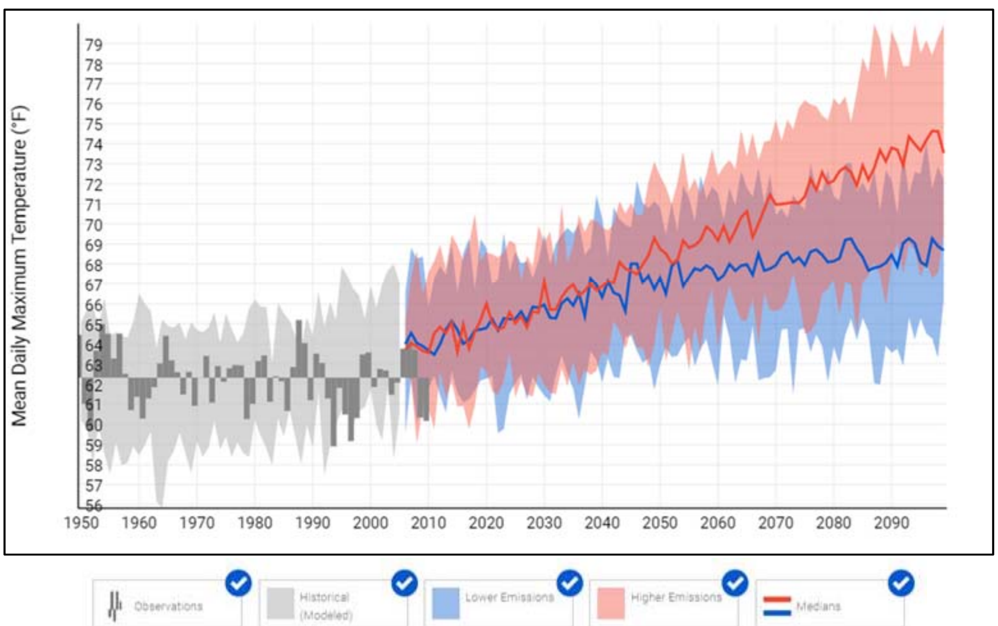


Figure 42: NOAA Climate Explorer - Observed and Projected Mean Daily Maximum Temperature for Hancock County, IL (Low Emissions Scenario in Blue, Higher Emissions Scenario in Red)

For mean daily average precipitation, both emissions scenarios are predicted to see a slight increase into the future; for most years precipitation is greater in the high emissions scenario (red) than the low emissions scenario (blue). Figure 43 shows the observed and projected mean daily average precipitation for Hancock County, IL.

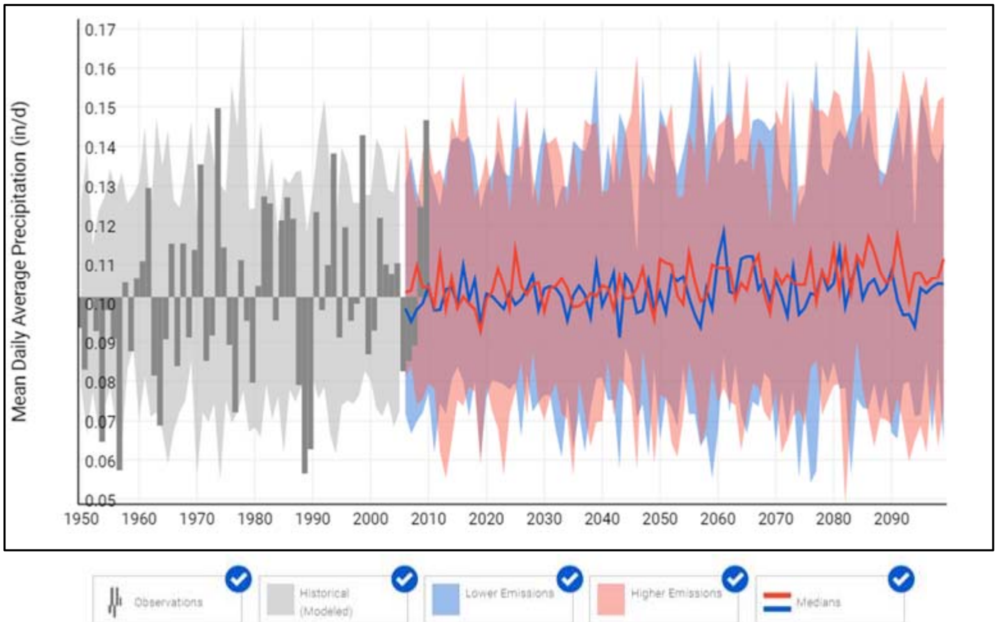


Figure 43: NOAA Climate Explorer - Observed and Projected Mean Daily Average Precipitation for Hancock County, IL (Low Emissions Scenario in Blue, Higher Emissions Scenario in Red)

Figure 44 shows the seasonal variation in mean daily average precipitation for Hancock County for both high and low emissions scenarios for the 2025 time period (2010 to 2040). The figure shows that for both emission scenarios, the mean daily average precipitation is likely to be higher in spring and fall by roughly 0.01 inch per day (in/day), or roughly 1 inch more precipitation for the 3-month season. The predicted increase is much smaller in winter, while in summer there is likely to be slightly lower precipitation than historically observed.

Given the possible ranges of predicted values, in any given year, the seasonal precipitation may be counter to the overall trends. Because droughts tend to occur during the summer months at this location, the lower summer precipitation may indicate a higher likelihood of droughts in the near future.

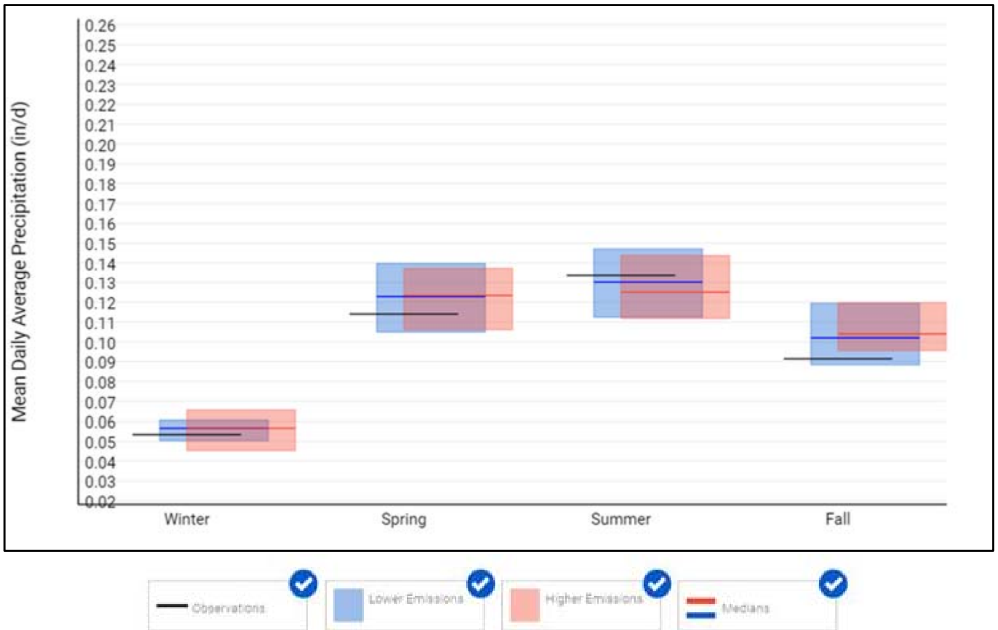


Figure 44: NOAA Climate Explorer Projected Seasonal Mean Daily Average Precipitation for Hancock County, IL, for Time Period 2025 (2010-2040) (Low Emissions Scenario in Blue, Higher Emissions Scenario in Red)

4.3.1.3 Projected Changes in Flows and Drought Trends

The following sections discuss the historical and predicted trends of flows based on the USACE Climate Hydrology Assessment Tool. Figure 45 shows the historical annual peak instantaneous streamflow and the trend line for the Mississippi River at St. Louis, MO.

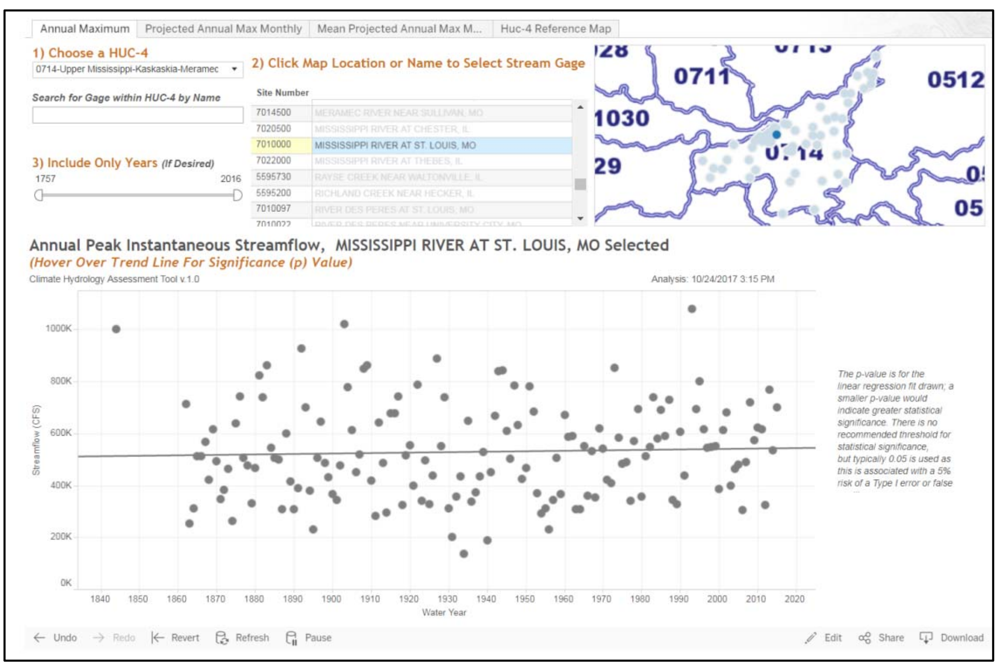


Figure 45: USACE Climate Hydrology Assessment Tool - Past Annual Flood Maximum Data for the Mississippi River at St. Louis, Missouri

There is a small positive slope to the best fit trend line through the annual peak flows, indicating a very slight increase in average annual flooding based on the observed data. Observed stream and river gage annual peak flow data are the basis for conducting flood frequency analysis, which determines the peak flow values associated with flood events. The trend line in Figure 45 represents the mean, or 50-percent-annual-chance (2-year recurrence interval), flood event. For the larger, less frequent events typically associated with catastrophic flooding, such as the 1-percent-annual-chance (100-year recurrence interval) flood, a different type of statistical analysis (using the highest peak flow values) would be needed to show if those events are also showing an increasing trend.

Figure 46 shows the range of projected annual maximum monthly flows and the mean of the 93 projections for the HUC 0714–Upper Mississippi-Kaskaskia-Meramec Watershed. The projected future flows (after 2015) have a wider range with higher peaks than projected past flows (prior to 2015).

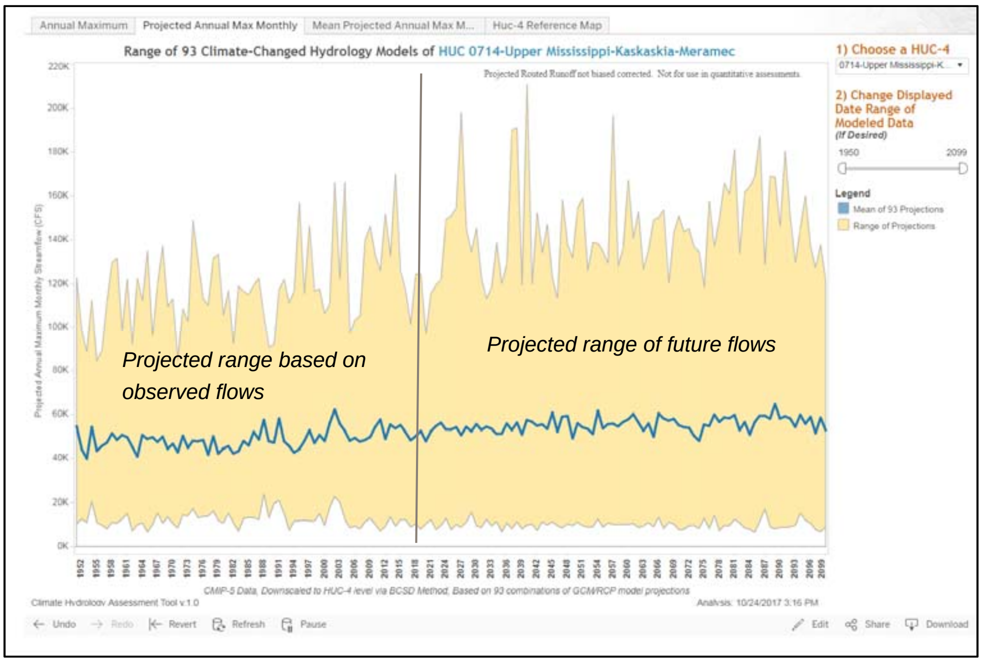


Figure 46: USACE Climate Hydrology Assessment Tool – Projected Annual Maximum Monthly Flow for HUC 0714–Upper Mississippi-Kaskaskia-Meramec Watershed

Figure 47 shows that the projected future annual maximum monthly flow for the HUC 0714–Upper Mississippi-Kaskaskia-Meramec Watershed is trending upward through the year 2100. The slope (rate of increase) of the trend line for existing flows starting in 2000 and for projected flows is much higher than the slope of the trend line using historical flows up to 2000. The underlying hydrology modeling (based on climate change data) used to produce Figure 46 and Figure 47 was only conducted at this specific HUC resolution. Therefore, the trends shown in these two figures only provide a qualitative indication for the entire land area within this 4-digit HUC watershed of possible trends for average annual flooding. While Figure 47 shows higher maximum monthly streamflows, this may only indicate an increase in flows associated with more frequent flood events, such as the 2-year recurrence interval associated with average annual peak flows. Flooding trends for either smaller watersheds (6-digit HUC watersheds) or larger flood events (100-year recurrence interval) would require additional analysis to determine if the same increasing flooding trends hold for those scenarios.

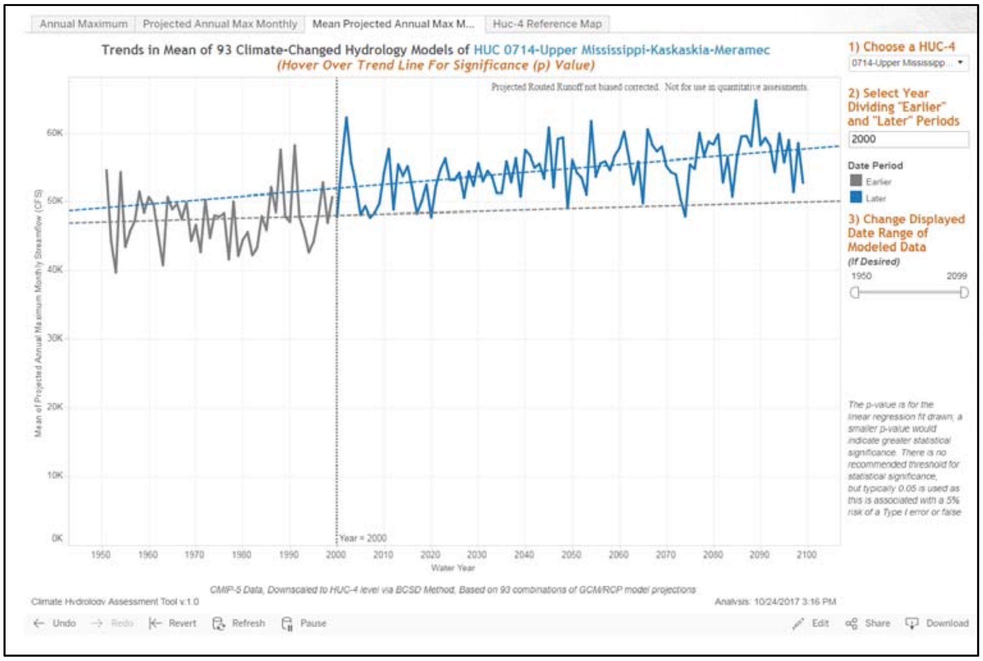
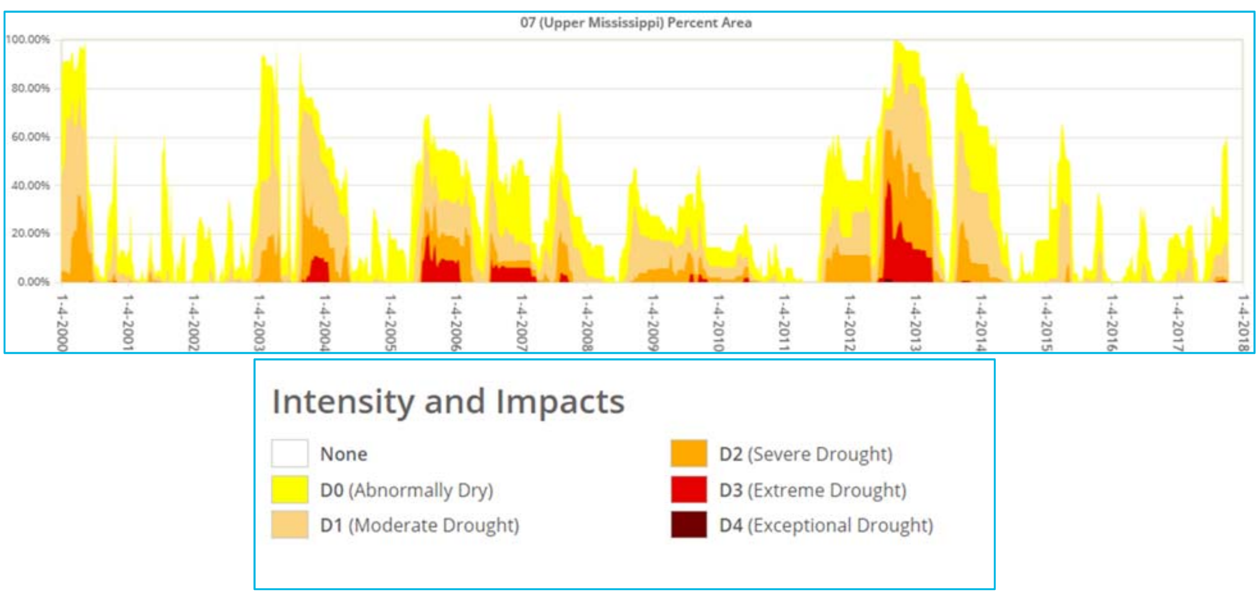


Figure 47: USACE Climate Hydrology Assessment Tool - Trends from Mean Projected Annual Maximum Monthly Flow for HUC 0714–Upper Mississippi-Kaskaskia-Meramec Watershed

Drought Trends

Figure 48 shows the percent area of drought within the Upper Mississippi Region from January 2000 to October 19, 2017. In this time frame, the period from 2012 to 2013 experienced the worst drought. However, data prior to 2000 are not available for download automatically.



Source: http://droughtmonitor.unl.edu/Data/Timeseries.aspx

Figure 48: Upper Mississippi Region (HUC2) Percent Area by Drought Category

There have been several drought periods of varying intensity since the 2000s. Figure 49 shows the percentage of months between 1900 and 2017 that fell into each severity category of the

PDSI. Extreme (drought or moist) events account for approximately 8 percent of Illinois time since 1900.

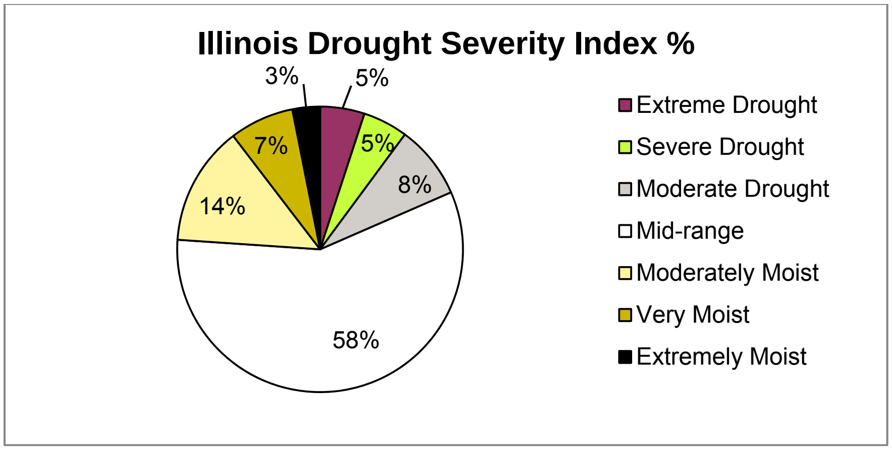


Figure 49: Percent of Time for Drought Severity Index – Illinois (1900-2017)

Figure 50 shows the number of months per decade between January 1900 and September 2017 that fell into the drought severity category. Illinois had its worst historical droughts in the periods from 1930 to 1939 and 1950 to 1959; these periods had a significantly higher number of extreme drought months.

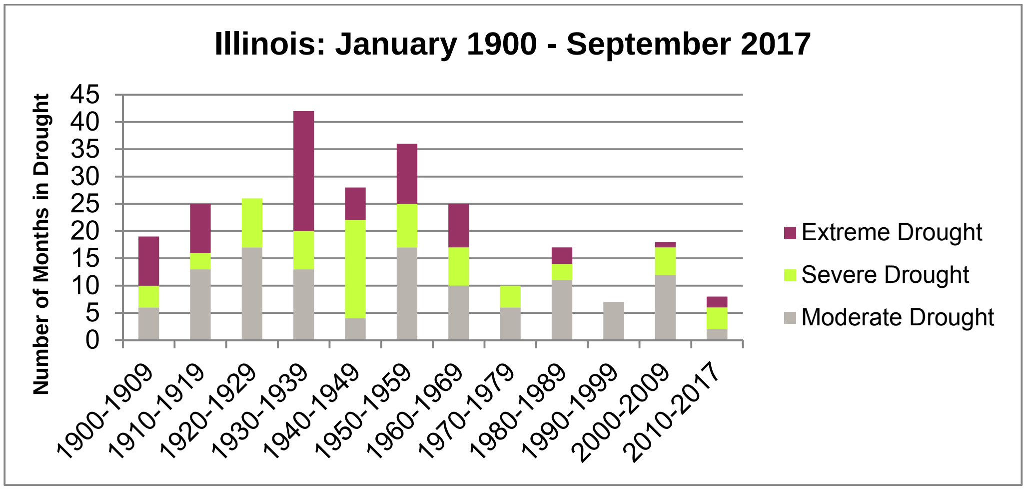


Figure 50: Number of Months in Drought from 1900-2017 - Illinois

4.3.1.4 Impacts of Changing Climate Variables on Droughts and Floods – Upper Mississippi Region

Table 9 summarizes the impacts of anticipated changes in climate variables by mid-century for the Upper Mississippi Region. Ameren's service area in the Upper Mississippi Region is anticipated to see an increase in average annual temperature, in annual average and seasonal precipitation, and in the frequency of extreme events (droughts and floods) by mid-century, regardless of emission scenarios.

Table 9: Climate Impacts on Droughts and Floods – Upper Mississippi Region

Primary Variable	Observed Trend	Observed Source	Projected Trend	Projected Source
Average Annual Temp	↑	• USACE, 2015 • State Summaries, 2017 • NOAA Climate Explorer, 2017	↑↑	• USACE, 2015 • State Summaries, 2017 • NCA, 2014 • NOAA Climate Explorer, 2017
Average Annual Precipitation	↑	• USACE, 2015 • NCA, 2014 • State Summaries, 2017 • NOAA Climate Explorer, 2017	↑	• USACE, 2015 • State Summaries, 2017 • NOAA Climate Explorer, 2017
Seasonal Precipitation Variability	↑	• USACE, 2015 • State Summaries, 2017 • NOAA Climate Explorer, 2017	↑	• USACE, 2015 • State Summaries, 2017 • NOAA Climate Explorer, 2017
Extreme Event (Flood)	↑	• USACE, 2015 • State Summaries, 2017 • NCA, 2017 • USACE Climate Hydrology Assessment , 2017	↑	• USACE, 2015 • NCA, 2017 • USACE Climate Hydrology Assessment , 2017
Extreme Event (Drought)	↑↓	• USACE, 2015 • NCA, 2014 • U.S. Drought Monitor, 2017	↑	• USACE, 2015 • State Summaries, 2017 • U.S. Drought Monitor, 2017

Trend Scale	
↑ = Small Increase	↑↑ = Large Increase
↓ = Small Decrease	↓↓ = Large Increase
↑↓ = Literature varies	

4.3.2 Missouri Water Resources Region

4.3.2.1 Projected Changes in Water Stress

For the lower Missouri Region in Ameren's service area, the Aqueduct Water Risk Atlas predicted that water stress in the area is mostly near normal in 2020 except for a small area in northwest Missouri. This area is anticipated to see an increase in water stress by 2020. In 2030, the northwest corner of Missouri is anticipated to experience an increase in water stress to 1.4 times current conditions. Table 10 summarizes the predicted change in water stress. Depending on the scenarios, the water supply may experience no change or decrease by 20 percent, and there will be an increase in future water demand in all scenarios in 2030.

Table 10: Summary of Change in Water Stress – Lower Missouri Water Resources Region

Aqueduct Climate Scenario	2020 (2010-2030)	2030 (2020-2040)	Comments
Optimistic	Mostly Near Normal	Mostly Near Normal	Small areas (northwest and southwest corners of Missouri) of 1.4X increase due to a slight increase in water demand in 2030
Business as usual	Mostly Near Normal	Mostly Near Normal	Small area (northwest corner of Missouri) of 1.4X increase due to a slight increase in water demand for both 2020 and 2030
Pessimistic	Mostly Near Normal	Mostly Near Normal	Small area (northwest corner of Missouri) of 1.4X increase due to an anticipated increase in water demand in 2020 and 2030

4.3.2.2 Projected Changes in Temperature and Precipitation

Projected climate data trends were obtained from the NOAA Climate Explorer. Boone County, MO, was selected as a central location within the watershed; the county is located in the middle of Missouri and the county seat is the city of Columbia (see Figure 1).

Figure 51 shows the observed and projected mean daily maximum temperature in Boone County, which is anticipated to see an increase in daily maximum temperatures in the future compared to the observed time horizon (1980 to 2000). The trends for both low and high emissions scenarios indicate higher temperatures into the future. This same trend was also observed for mean daily minimum temperatures.

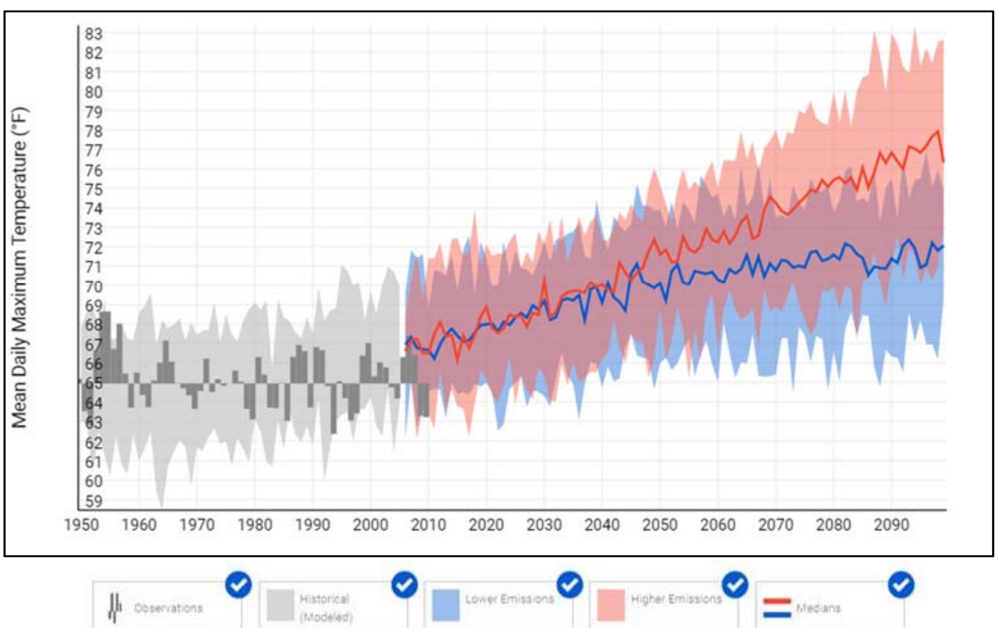


Figure 51: NOAA Climate Explorer - Observed and Projected Mean Daily Maximum Temperature for Boone County, MO (Low Emissions Scenario in Blue, Higher Emissions Scenario in Red)

Figure 52 shows the observed and projected mean daily average precipitation for Boone County, MO. For mean daily average precipitation, both emission scenarios are predicted to see a slight increase in the future. However, there is no clear trend as to which emissions scenario is greater for most years. The range of the predicted extremes appears only slightly larger in the future; however, the majority of the extremes are within the range of historical highs and lows.

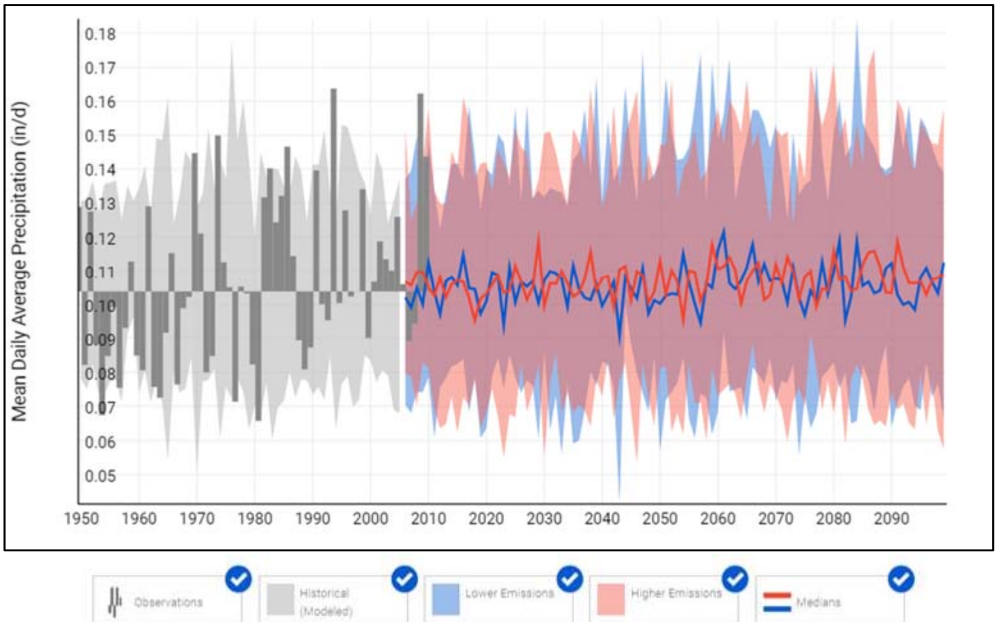


Figure 52: NOAA Climate Explorer - Observed and Projected Mean Daily Average Precipitation for Boone County, MO (Low Emissions Scenario in Blue, Higher Emissions Scenario in Red)

Figure 53 shows the projected seasonal mean daily average precipitation for Boone County. For seasonal variation in precipitation, both emissions scenarios are showing similar trends about the medians (shown as solid lines), with precipitation increases in spring and fall around 0.01 in/day, a slight precipitation increase in winter, and a slight decrease in precipitation in summer. However, given the possible range of values, in any given year seasonal precipitation counter to the overall trends might be seen. Since droughts historically tend to occur in Boone County during the summer months, the lower summer precipitation may indicate a higher likelihood for droughts in the near future.

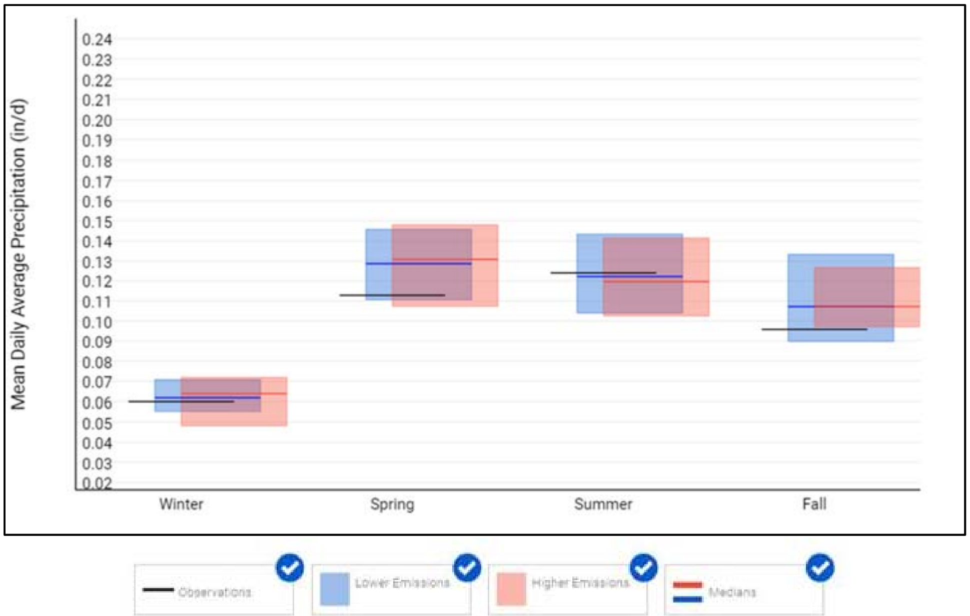


Figure 53: NOAA Climate Explorer - Projected Seasonal Mean Daily Average Precipitation for Boone County, MO for Time Period 2025 (2010-2040) (Low Emissions Scenario in Blue, Higher Emissions Scenario in Red)

4.3.2.3 Projected Changes in Flows and Drought Trends

This subsection discusses the historical and predicted trends of flow based on the USACE Climate Hydrology Assessment Tool. Figure 54 shows the historical annual peak instantaneous flow and the trend line for the Missouri River at Waverly, MO.

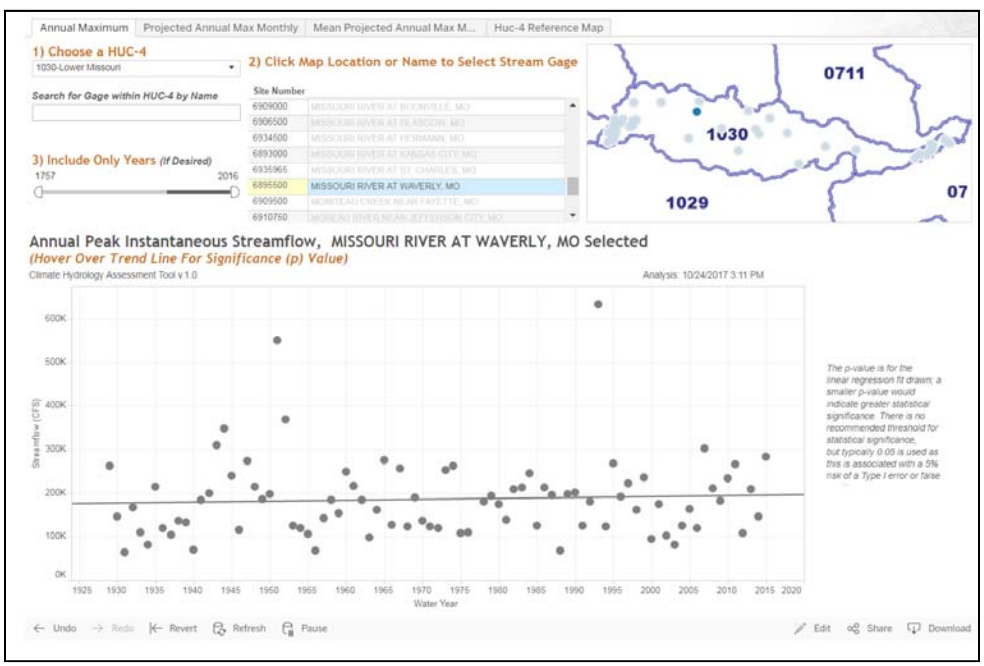


Figure 54: USACE Climate Hydrology Assessment Tool - Past Annual Flood Maximum Data for the Missouri River at Waverly, MO

Over the period of record available, the best fit line is trending upward slightly based on the observed data. This indicates a slight increase in average annual peak flows, which can lead to a slight increase in annual flood severity.

Figure 55 shows the future projected flows (after 2015) for the HUC 1030–Lower Missouri watershed. The projected flows appear to have a wider range, especially with higher values, than the flows prior to the period from 2010 to 2015.

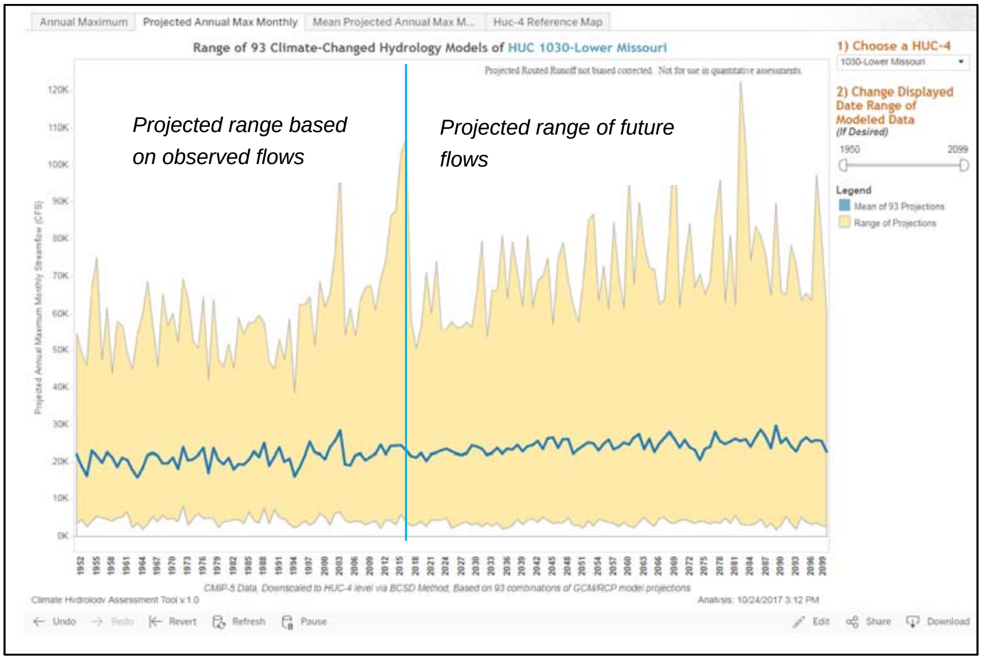


Figure 55: USACE Climate Hydrology Assessment Tool - Projected Annual Flood Monthly Data for HUC 1030–Lower Missouri Watershed

Figure 56 shows that the projected future annual maximum monthly flows for the HUC 1030–Lower Missouri watershed are trending higher through the year 2100. The slope (rate of increase) of the trend line for the projected flows is higher than the slope of the trend line using historical flows up to 2000. This indicates a likelihood of increased average annual flood severity in the future. As was noted for the Upper Mississippi Water Resource Region, this upward trend for projected flows primarily applies to average annual flood trends. Additional analysis would be needed to determine whether this same trend applies to smaller watershed areas within the lower Missouri Water Resource Region and may also for more severe flood events.

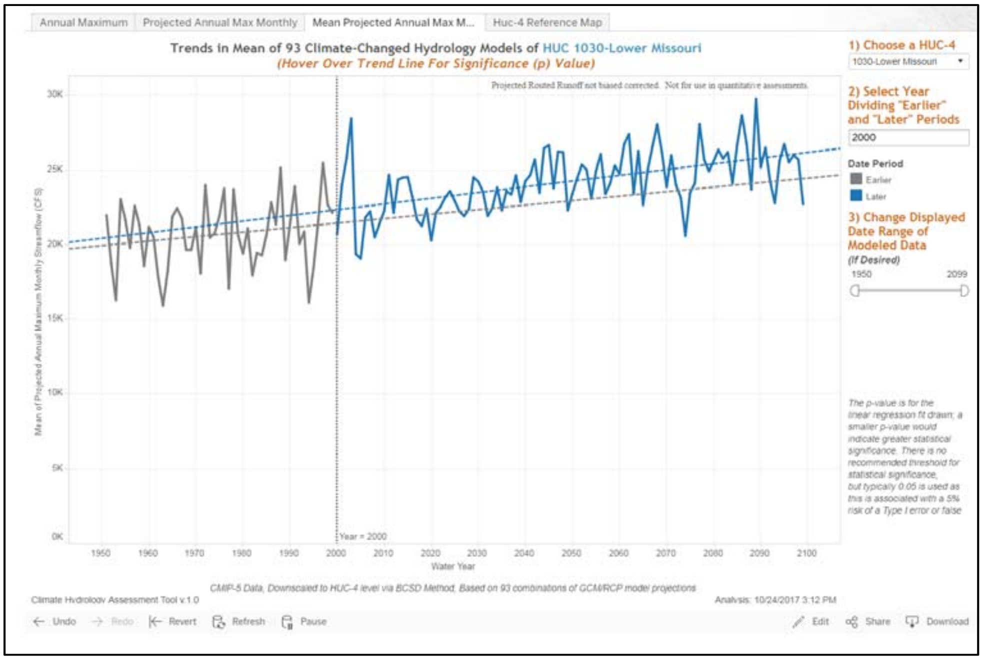


Figure 56: USACE Climate Hydrology Assessment Tool - Trends from Mean Projected Annual Flood Monthly Data for HUC 1030–Lower Missouri Watershed

Drought Trends

Figure 57 shows the percent area of drought from January 2000 to October 19, 2017, within the lower Missouri Region using the U.S. Drought Monitor. The period from 2012 to 2013 has the worst drought, followed by the drought in 2003. Data prior to 2000 are not available for download automatically.

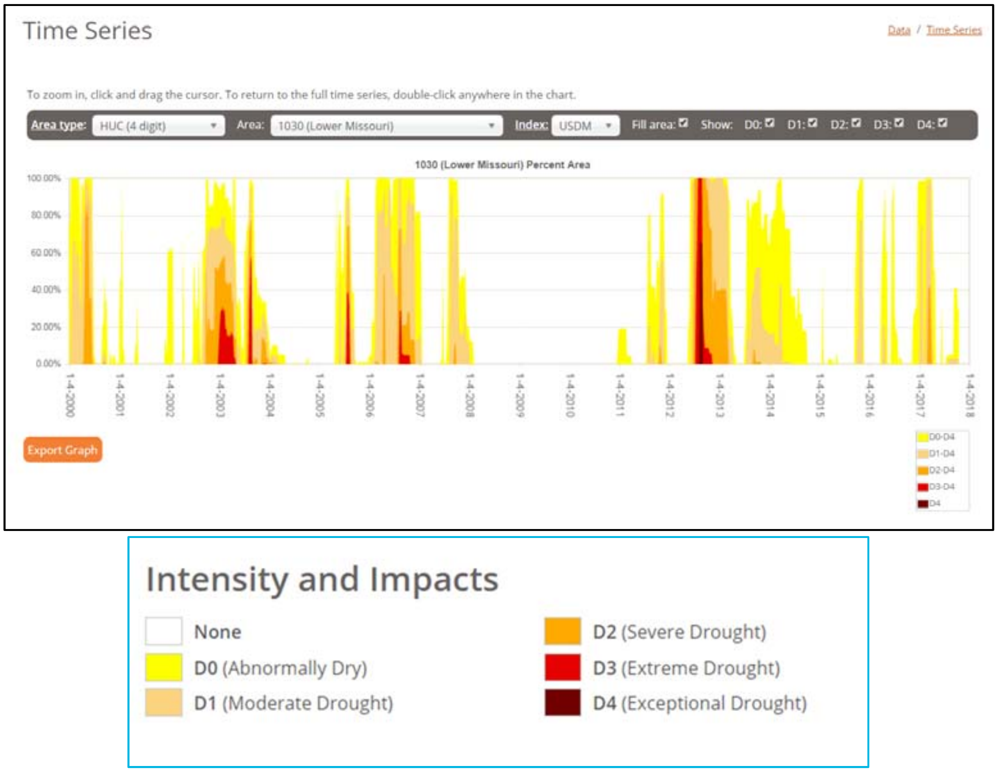


Figure 57: U.S. Drought Monitor Observed Drought Conditions from 2000-2017 for HUC 1030–Lower Missouri Watershed

Figure 58 shows the percentage of time between January 1900 and September 2017 that fell into the drought severity category. Based on the PDSI, the extreme drought accounts for 4 percent of the time between 1900 and 2017 in Missouri, while extremely moist events account for 5 percent of the time in the same period.

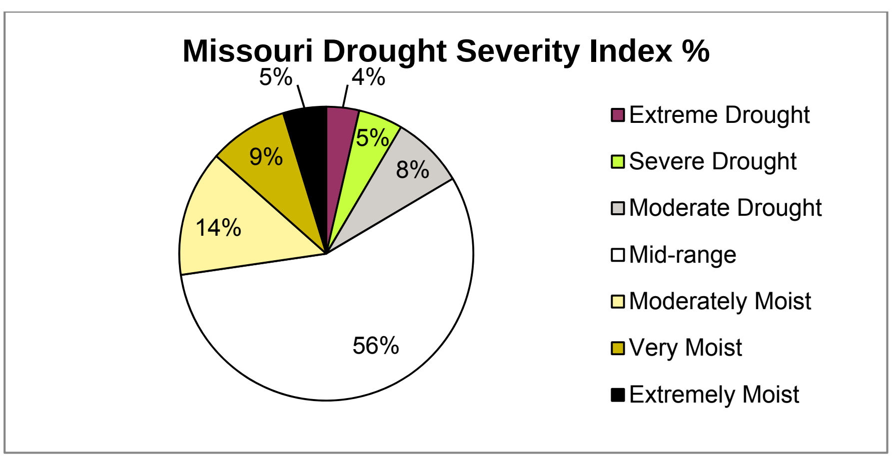


Figure 58: Percent of Time for Drought Severity Index – Missouri (1900-2017)

Figure 59 shows the number of months between January 1900 and September 2017 in Missouri that fell into the drought severity category. Missouri had its worst drought, with a higher number of months in severe and extreme drought, in the 1950s. Since the historic drought of 1950 to 1959, the occurrence of drought, and drought intensity and severity have reduced significantly.

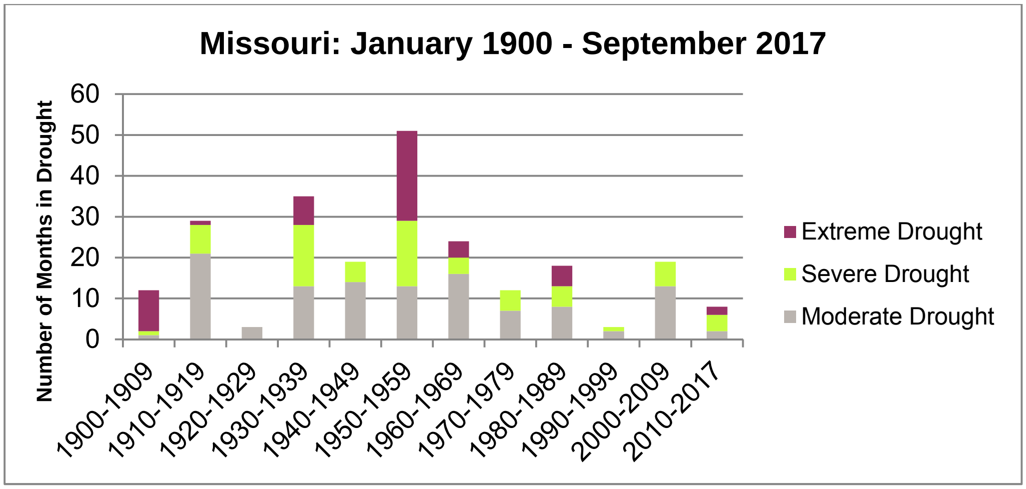


Figure 59: Number of Months in Drought from 2000-2017 – Missouri

Droughts are projected to increase in this region, as increased temperature and evapotranspiration rates are anticipated to outweigh the projected increase in precipitation (USACE 2015a).

4.3.2.4 Impacts of Changing Climate Variables on Droughts and Floods – Missouri Region

Table 11 provides a summary of the observed climate variables for the Missouri Region and the anticipated changes in them by mid-century. Based on this analysis, regardless of emissions scenarios, this region is anticipated to see an increase in average annual temperature, in annual average and seasonal precipitation, and in the frequency of extreme events (drought and flood) by mid-century.

Table 11: Climate Impacts on Droughts and Floods – Missouri Region

Primary Variable	Observed		Projected	
	Trend	*Source*	*Trend*	*Source*
Average Annual Temp	↑	• USACE, 2015 • NOAA Climate Explorer, 2017	↑↑	• USACE, 2015 • NOAA Climate Explorer, 2017
Average Annual Precipitation	↑↓	• USACE, 2015 • State Summaries, 2017 • NCA, 2014 • NOAA Climate Explorer, 2017	↑	• USACE, 2015 • State Summaries, 2017 • NCA, 2014 • NOAA Climate Explorer, 2017
Seasonal Precipitation Variability	↑	• USACE, 2015 • State Summaries, 2017 • NOAA Climate Explorer, 2017	↑	• USACE, 2015 • State Summaries, 2017 • NCA, 2014 • NOAA Climate Explorer, 2017
Extreme Event (Flood)	↑	• USACE, 2015 • NCA, 2017 • State Summaries, 2017 • USACE Climate Hydrology Assessment , 2017	↑	• USACE, 2015 • NCA, 2017 • USACE Climate Hydrology Assessment , 2017
Extreme Event (Drought)	↑↓	• USACE, 2015 • NCA, 2014 • U.S. Drought Monitor, 2017	↑	• USACE, 2015 • State Summaries, 2017 • U.S. Drought Monitor, 2017

Trend Scale	
↑ = Small Increase	↑↑ = Large Increase
↓ = Small Decrease	↓↓ = Large Increase
↑↓ = Literature varies	

4.3.3 Powder River Basin

4.3.3.1 Projected Changes in Water Stress

Based on the Aqueduct Water Stress predictions (see Section 4.2 for maps; the predictions are summarized in Table 12), the PRB is anticipated to have little change in water stress (near normal) in 2020 under all scenarios. For 2030, water stress is expected to increase by 40 percent; the water supply (primarily based on precipitation) may experience no change or decrease by 20 percent, while the future water demand may go up 20 percent.

Table 12: Summary for Water Stress - Campbell and Converse Counties in Power River Basin in Wyoming

Aqueduct Climate Scenario	2020 (2010-2030)	2030 (2020-2040)	Comments
Optimistic	All Near Normal	All 1.4x Increase	Underlying water stress indicator in “Arid and low water use” category for majority of both counties in 2020 and 2030. Other indicators show near normal for 2020 and 2030.
Business as usual	All Near Normal	All 1.4x Increase	2030 increases due to 1.2x increase in water demand; underlying water stress indicator in “Arid and low water use” category for majority of both counties in 2020 and for Campbell County in 2030.
Pessimistic	All Near Normal	All 1.4x Increase	2030 increases due to 1.2x increase in water demand; underlying water stress indicator in “Arid and low water use” category for majority of both counties in 2020 and for Campbell County in 2030.

4.3.3.2 Projected Changes in Temperature and Precipitation

Future climate trends for temperature and precipitation were obtained from the NOAA Climate Explorer for Campbell County, WY, one of the two counties (along with Converse County) in this study region. The trends for the two counties are similar due to the resolution of the model.

Figure 60 shows the observed and projected mean daily maximum temperature in Campbell County, WY. The county is anticipated to see an increase in daily maximum temperatures in the future compared to the observed time horizon (1980 to 2000) . The trends for both emissions scenarios indicate higher temperatures into the future. The same warming trend was also observed for mean daily minimum temperature.

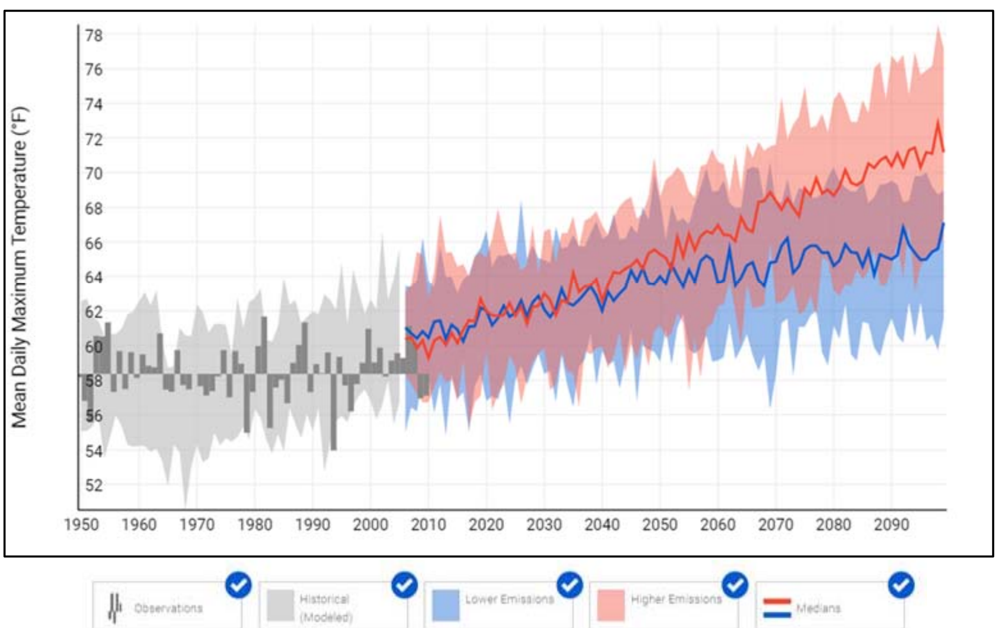


Figure 60: NOAA Climate Explorer Observed and Projected Mean Daily Maximum Temperature for Campbell County, WY (Low Emissions Scenario in Blue, Higher Emissions Scenario in Red)

Figure 61 shows that for mean daily average precipitation in Campbell County, WY, both emissions scenarios are predicted to see a slight increase into the future. The high emissions scenario (red) is anticipated to be higher beyond the year 2070.

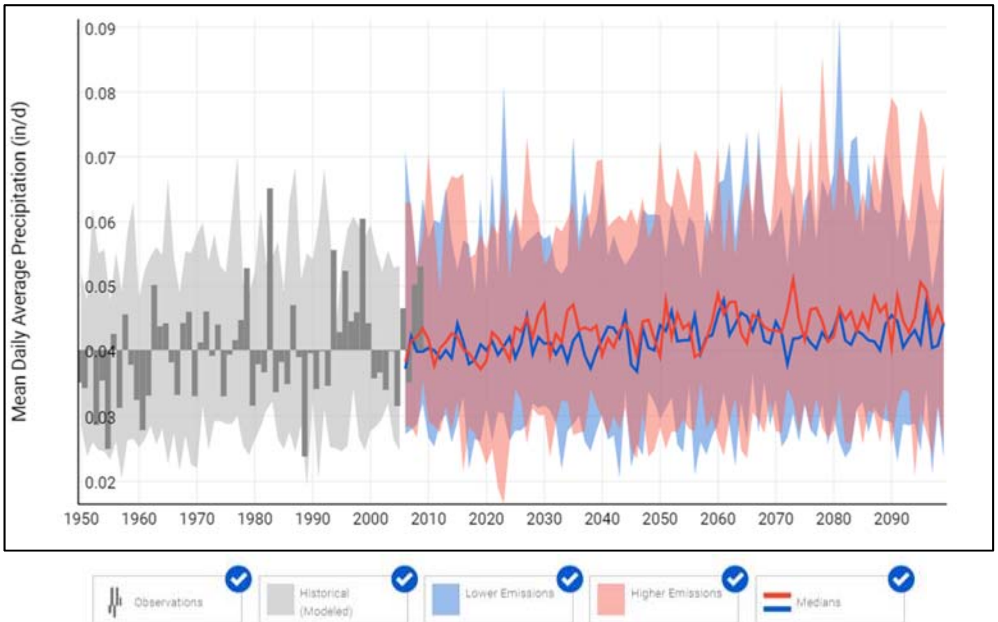


Figure 61: NOAA Climate Explorer Observed and Projected Mean Daily Average Precipitation for Campbell County, WY (Low Emissions Scenario in Blue, Higher Emissions Scenario in Red)

Figure 62 shows the seasonal variation in mean daily average precipitation in Campbell County, WY, in the 2025 time period. Both emissions scenarios are showing similar trends about the medians (shown as solid lines), with greater precipitation in spring and fall and little to no change in winter and summer. However, given the possible range of values, in any given year seasonal precipitation counter to the overall trends might be seen.

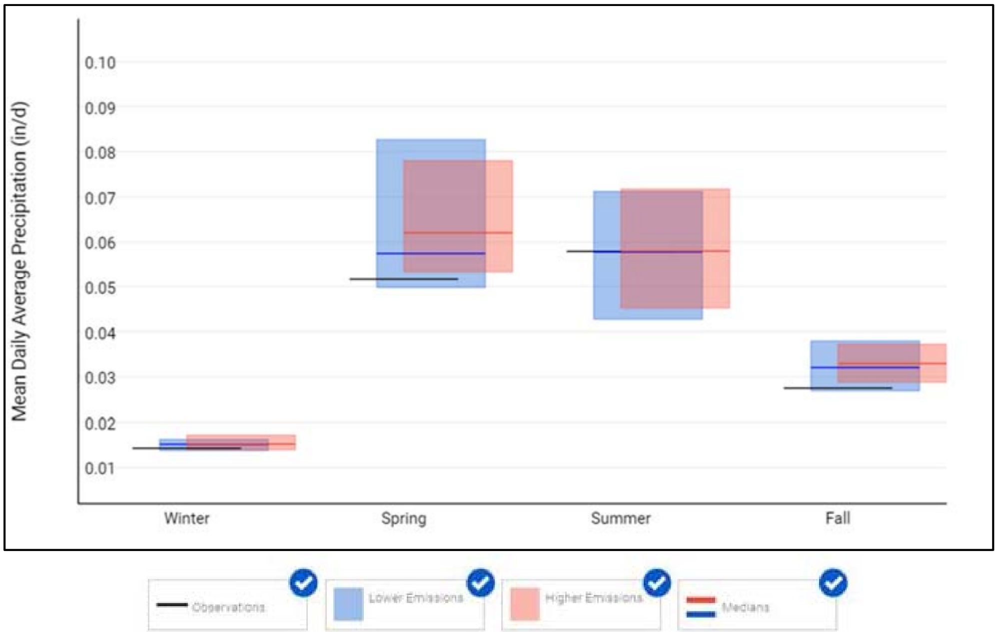


Figure 62: NOAA Climate Explorer Projected Seasonal Mean Daily Average Precipitation for Campbell County, WY, for Time Period 2025 (2010-2040) (Low Emissions Scenario in Blue, Higher Emissions Scenario in Red)

4.3.3.3 Projected Changes in Flows and Drought Trends

This subsection discusses the historical and predicted trends of flow based on the USACE Climate Hydrology Assessment Tool. Figure 63 shows the historical annual peak instantaneous streamflow and the trend line for the Powder River at Morehead, MT.

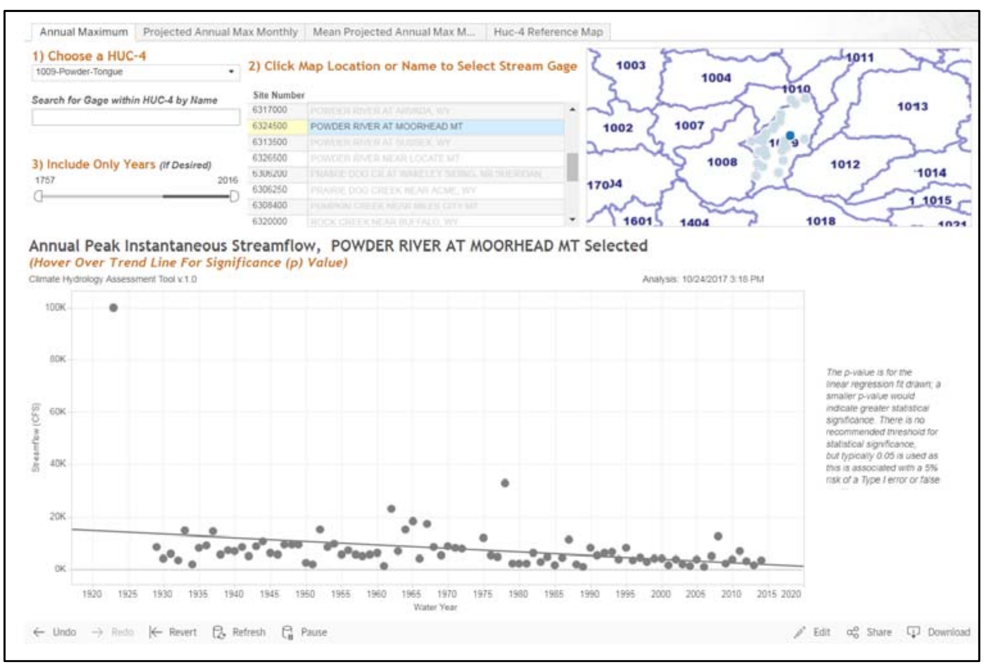


Figure 63: USACE Climate Hydrology Assessment Tool Past Annual Flood Maximum Data for the Powder River at Moorhead, MT

Based on the observed data and trend analysis of historical flows, the annual peak instantaneous flows have been decreasing. As the PRB is considered arid, the range of flow is significantly lower than the flows available in the larger rivers in the Upper Mississippi and lower Missouri Water Resources Regions.

Figure 64 shows the projected future flows for the HUC 1009–Powder-Tongue watershed. The projected mean for the annual maximum monthly streamflow is trending slightly upward into the future, and the range of projected flows (after the period from 2010 to 2015) is significantly wider with higher peak values.

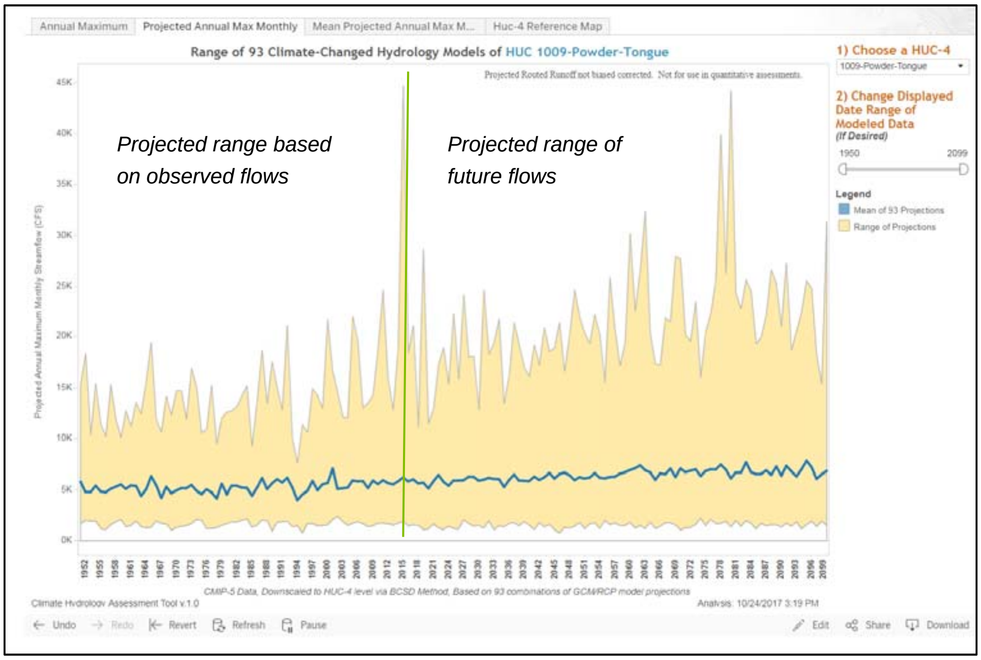


Figure 64: USACE Climate Hydrology Assessment Tool Projected Annual Flood Monthly Data for HUC 1009–Powder-Tongue Watershed

Figure 65 shows the projected future maximum monthly flows being consistently higher than the historical flows, indicating that the trend of increased flooding over time may continue. This is the opposite of the decreasing trend shown on Figure 64 for observations of peak instantaneous flow for the Powder River only. This may be a result of the underlying hydrologic models not correctly accounting for the snowmelt contribution to maximum monthly peak flows.

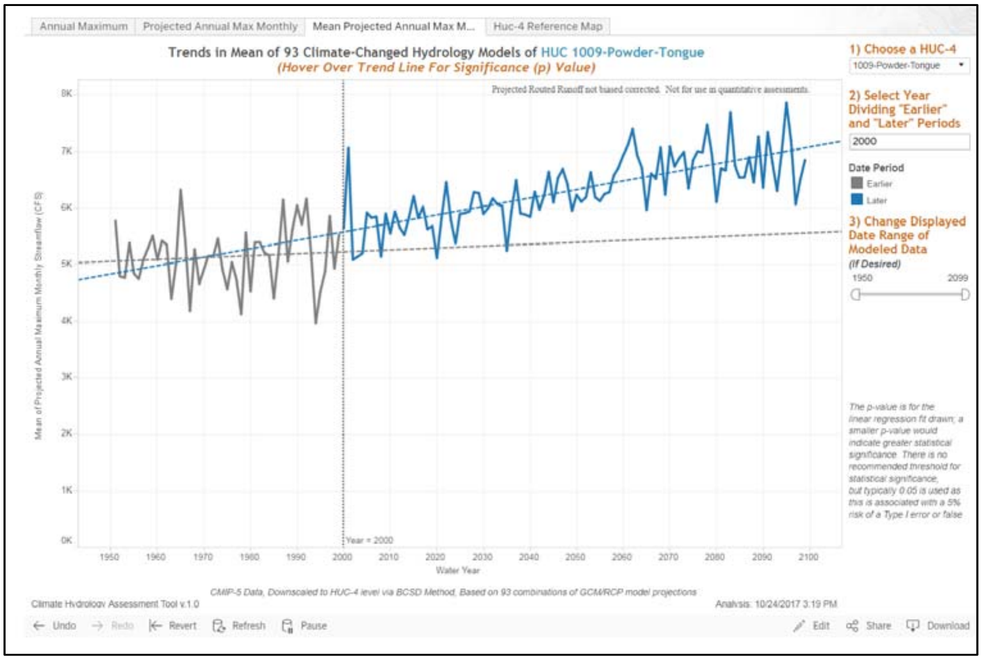


Figure 65: USACE Climate Hydrology Assessment Tool - Trends from Mean Projected Annual Maximum Monthly Streamflow for HUC 1009–Powder-Tongue Watershed

Drought Trends

Figure 66 shows the percentage of time the HUC2 region is in various drought categories, as observed by the U.S. Drought Monitor. For the time period shown (2000 to 2017), the most severe drought continued for almost a decade; it began in 2000 and did not fully end until 2009. Since then, there have been shorter-duration droughts in the period from 2012 to 2014. The current drought started in 2015 and is continuing to the present day.

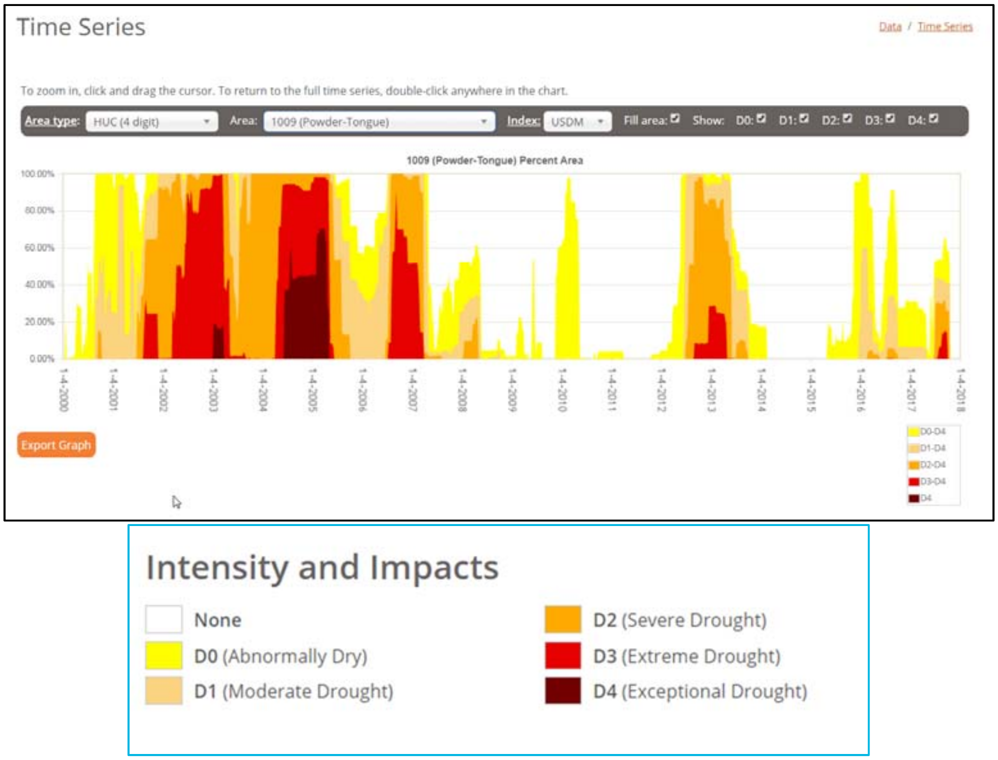


Figure 66: U.S. Drought Monitor Observed Drought Conditions from 2000-2017 for HUC 1009–Powder-Tongue Watershed

Figure 67 shows the percentage of months between 1900 and 2017 that fell into each of the severity categories of the PDSI. Since 1900, extreme drought or moist events account for 25 percent of the time for Wyoming, a percentage that is much higher than that of Illinois or Missouri.

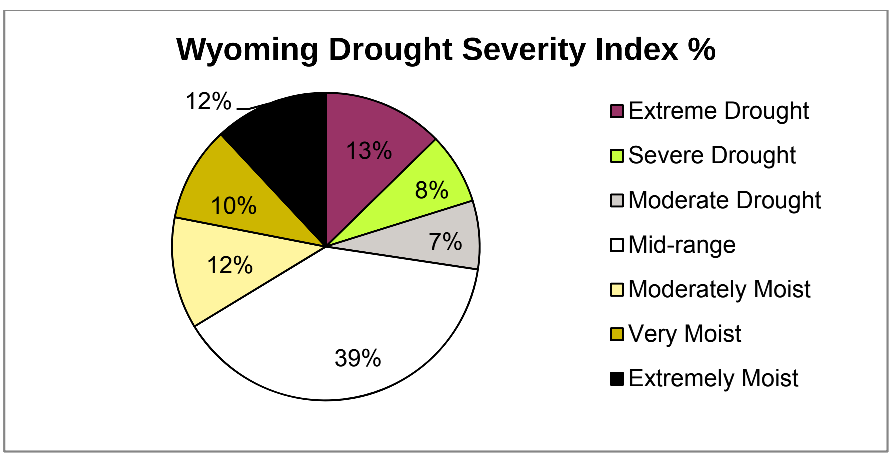


Figure 67: Percent of Time for Palmer Drought Severity Index (1900-2017) – Wyoming

Figure 68 shows the number of months between January 1900 and September 2017 that fell into the drought severity categories. Of the three states, Wyoming has had a total of more drought months than the other two states. Wyoming's most extreme drought occurred between 2000 and 2009.

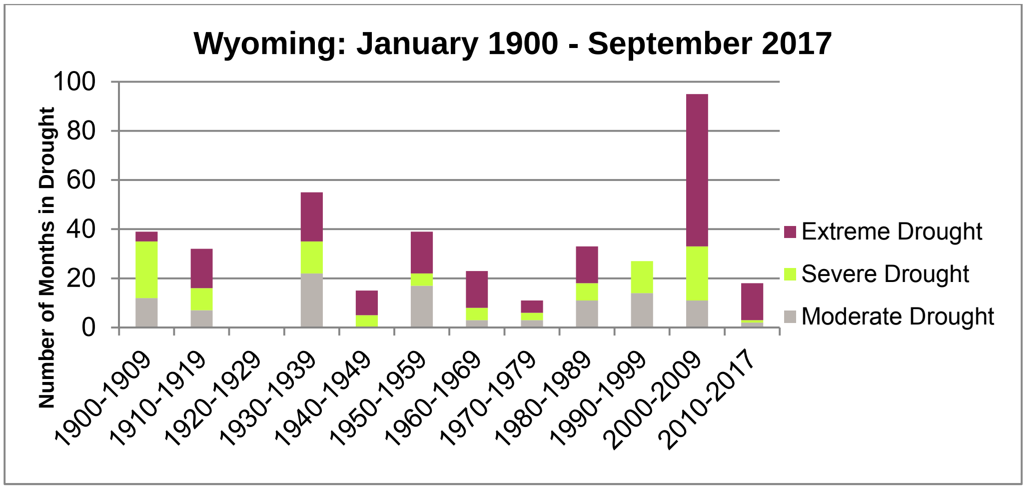


Figure 68: Number of Months in Drought from 1900-2017 - Wyoming

Wyoming experienced a much higher percentage of time in severe to extreme weather (both drought and moist) than Missouri and Illinois, and its percentages of extreme categories nearly doubled those of Missouri and Illinois.

Droughts are projected to increase in this region, as increased temperature and evapotranspiration rates are anticipated to outweigh a projected increase in precipitation (USACE 2015a).

4.3.3.4 Impacts of Changing Climate Variables on Droughts and Floods – Powder River Basin

Table 13 summarizes the anticipated changes in climate variables by mid-century for the PRB in the upper Missouri Region. Based on this summary, regardless of emission scenarios, this region is anticipated to see an increase in average annual temperature, in annual average and seasonal precipitation, and in the frequency of drought events by mid-century. Despite a projected increase in precipitation, droughts are projected to increase as a result of increased temperature and evapotranspiration rates. However, it is uncertain whether this region will see an increase in peak flows or flood events by mid-century.

Table 13: Climate Impacts on Droughts and Floods – Powder River Basin

Primary Variable	Observed Trend	Observed Source	Projected Trend	Projected Source
Average Annual Temp	↑	• State Summaries, 2017 • USACE, 2015 • US Climate Resilience Toolkit • NOAA Climate Explorer, 2017	↑↑	• USACE, 2015 • NCA, 2014 • US Climate Resilience Toolkit • State Summaries, 2017 • NOAA Climate Explorer, 2017
Average Annual Precipitation	⇅	• USACE, 2015 • NOAA Climate Explorer, 2017	↑	• USACE, 2015 • NOAA Climate Explorer, 2017
Seasonal Precipitation Variability	↑	• USACE, 2015 • State Summaries, 2017 • NOAA Climate Explorer, 2017	↑	• USACE, 2015 • State Summaries, 2017 • NOAA Climate Explorer, 2017
Extreme Event (Flood)	⇅	• USACE, 2015 • State Summaries, 2017 • USACE Climate Hydrology Assessment , 2017	⇅	• USACE, 2015 • NCA, 2017 • USACE Climate Hydrology Assessment , 2017
Extreme Event (Drought)	⇅	• State Summaries, 2017 • NCA, 2014 • USACE, 2015 • U.S. Drought Monitor, 2017	↑	• NCA, 2017 • State Summaries, 2017 • NASA, 2015 • U.S. Drought Monitor, 2017

Trend Scale	
↑ = Small Increase	↑↑ = Large Increase
↓ = Small Decrease	↓↓ = Large Increase
⇅ = Literature varies	

5. Conclusions

The Water Resilience Assessment report provides information regarding the potential impacts of climate change and resource availability within three regions through 2030: the Upper Mississippi Water Resources Region, focusing on the states of Illinois and Missouri; the lower Missouri Water Resources Region, focusing on the state of Missouri; and the Powder River Basin, with specific focus on Converse and Campbell Counties in Wyoming. The potential climate change impacts presented in this report are based on data, models, and tools that were readily available as of the date of the report.

The report presents historic and current climate observations and trends in changing temperature, precipitation, and extreme weather events within the three regions in the study area. The principal conclusions from the report are summarized below:

- **Temperatures**: Based on a review of technical reports, the temperatures within the Midwestern Region and the state of Wyoming have been steadily increasing. The reports and tools referenced present a consensus on increasing temperatures across all three focus regions.
- **Precipitation**: No significant trend has been assigned to precipitation due to seasonal variability. While the Upper Mississippi Region has seen increasing trends in annual precipitation, most significantly in the summer and fall, the Missouri Region had less consistent trends and greater historical variation in increased and decreased precipitation depending on location within the region. The Powder River Basin showed historical decreasing trends in total annual precipitation. Projected changes in precipitation patterns are less consistent, although parts of each region studied are likely to see increases in average annual precipitation, with increased variability in seasonal precipitation and potentially increased severity and frequency of extreme events.
- **Water Stress**. Based on the Aqueduct projections, in the 2030 time period the water stress is anticipated to be near normal for most areas in the Upper Mississippi and lower Missouri Regions, except for a small area in the northwest corner of Missouri, which is projected to see a potential increase in water stress. The water stress is anticipated to increase by 2030 for the three scenarios simulated by the Aqueduct Water Risk Atlas for the Powder River Basin. The projections for the future flooding trend are mixed, as the historical instantaneous peak flows in this area have been steadily decreasing, while projected maximum monthly flows are shown to increase in the future.
- **Extreme Weather Events**: Flooding and drought projections may have slight increases in future time periods, possibly brought on by more seasonal variability in precipitation. The Upper Mississippi and the lower portion of the Missouri Region are anticipated to see an increasing trend for maximum monthly flow and flooding events. The projected increase in temperature and evaporation and the potentially lower streamflow in the summer is anticipated to outweigh a projected increase in average annual precipitation and to contribute to an increase in drought events by midcentury.

Included within the report is an assessment of datasets and tools beneficial for use in understanding climate change, and possible future drought, and flood conditions. Although the datasets and tools presented are not an exhaustive list, those provided are expected to be of interest and value for assessing potential climate change implications to water resources and consistent water availability. An overview of the tool or datasets purpose is provided, as well as a description of what specific variables can be obtained and used from each source.

The information provided in this report can be useful context for consideration in planning of Ameren’s future operations. Increased seasonal variability, future drought and potential water stress, all being affected by climate change, are important to consider when developing future plans. With consistently improving climate science and models, and increasing data availability, the approach taken in this report can be replicated to account for updates in related knowledge. In addition, more detailed assessments of specific sections of rivers that consider the potential effects of climate change on annual flows, droughts, and floods by incorporating downscaled climate data into hydrologic and hydraulic modeling can also be considered.

6. Statement of Limitations

This report is based on data, conditions, and other information that is generally applicable as of the date of this report, and the conclusions herein are based on that information. Background information and other data, including climate change information and flood modeling inputs, used and referenced in this report were accessed by AECOM and created/provided by third parties. AECOM did not independently verify the accuracy or veracity of such third-party sources. Opinions presented herein apply to the existing and reasonably foreseeable conditions at the time of AECOM's assessment and do not apply to future conditions unknown to AECOM.

Any evaluation of future climate change scenarios involves inherent uncertainties and assumptions. Nevertheless, this report can provide valuable information in planning for potential changes in climate and potential future flood and drought impacts to water resources.

This report is intended for the sole use of Ameren. The scope of services performed during the development of this report may not be appropriate to satisfy the needs of other users, and any use or re-use of this document or of the findings, conclusions, or recommendations presented herein is at the sole risk of said user.

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