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EXECUTIVE SUMMARY

MISSOURI DROUGHT MITIGATION AND RESPONSE PLAN 2022




MISSOURI
DEPARTMENT OF
NATURAL RESOURCES

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FOREWORD

The 2020 *Missouri Water Resources Plan* assessed the availability of water in the State and highlighted the importance of water to Missouri in all the many ways we use it. One of the recommendations of the plan was to update the State's drought plan, last published in 2002. With significant droughts occurring in 2012, 2018, and 2022, this update benefits from the multiple lessons learned since 2002.

However, this *Drought Mitigation and Response Plan* is much more than an update to the 2002 *Missouri Drought Plan*. While that document has been an effective tool for guiding our reactions to droughts for the last two decades, this plan additionally includes strategies to plan for, mitigate, define, and understand droughts in Missouri. Maintaining a strong drought reaction component while greatly expanding our capability to take action proactively has been the major goal of this current effort.

The *Drought Mitigation and Response Plan* explores the various types of drought, describes and quantifies their impacts, and considers likelihood, susceptibility, impacts, and resilience in assessing overall vulnerability for different regions of the state. The plan describes Missouri's Drought Response System and provides a comprehensive list of actions and initiatives that can be taken at all levels before and during drought.

We would like to thank the U.S. Army Corps of Engineers - a technical and funding partner in the plan; additionally, we thank the many other agencies and stakeholders who contributed to this plan. As always, we thank the Governor's Office and Missouri General Assembly for continuing to make the water resources of our state a priority.

We hope that the *Missouri Drought Mitigation and Response Plan* will be a useful tool for state agencies, communities, water suppliers, individual citizens, among others working to make Missouri more drought resilient.

Dru Buntin
Director
Missouri Department of Natural Resources

ACKNOWLEDGMENTS

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MoDNR appreciates the support from other private, state, and federal partners in the development of the Missouri Drought Mitigation and Response Plan update.

MoDNR would also like to thank those agency employees primarily responsible for the development and organization of the Missouri Drought Mitigation and Response Plan, particularly Charles DuCharme, Scott Kaden, Matthew Kirsch, Aaron Goddard, Elizabeth Kerby, Zackary Becker, and Matthew Hajek.

Missouri Drought Mitigation and Response Plan

EXECUTIVE SUMMARY

The Missouri Drought Mitigation and Response Plan provides a wide-ranging overview of drought types, drought monitoring tools, drought history, drought impacts, current water use and resiliency, drought vulnerability, and drought mitigation capabilities. The information found in this plan is intended to aid government officials, water users, and water suppliers in planning and responding to drought events in Missouri.

While Missouri is generally viewed as a state with an abundant supply of water, experience has shown that shortages can occur during periods of extended or severe drought. Nearly every year, portions of the state have short periods of drought, and severe droughts have been experienced multiple times in the history of Missouri, most recently in 2012 and 2018. A key finding in the *Missouri Water Resources Plan 2020 Update* (Missouri Department of Natural Resources [MoDNR] 2020) is that an extended and/or severe drought would result in a high potential for water supply stress during multiple months of the year regardless of potential future variation in demand, climate conditions, and water supply constraints. Supply and demand analysis completed during the development of the Water Resource Plan demonstrated a need for better long-term drought planning and management. Therefore, it was recommended that the state prepare for droughts by updating the *2002 Missouri Drought Plan* (MoDNR, 2002). This report serves as the update to the *2002 Missouri Drought Plan*, expanding and updating the data and information within that report and providing an assessment of regional drought resiliency and vulnerability, recommendations for drought planning and response, and a matrix of drought preparedness and response actions.

The MoDNR Water Resources Center initiated this update to the *2022 Missouri Drought Plan* in partnership with USACE in 2020. The USACE partnership is achieved through their Planning Assistance to States (PAS) authority (Section 22 WRDA 1974 P.L. 93-251). This provides authority for USACE to assist states financially and technically in preparing comprehensive plans for the development and conservation of water and related land resources.

INTRODUCTION

Missouri has experienced two major droughts in the 20 years since the *2002 Missouri Drought Plan* was written **(Figure ES-1)**. The 2012 drought was one of the worst droughts since the drought of record in the 1950s, and was the worst drought in Missouri since the Great Drought of 1988 to 1989. Agriculture, which is vitally important in Missouri, bears much of the burden of drought, which can devastate crops, greatly reduce food and water available for livestock, and reduce farm incomes. While the exact economic impact on Missouri from the 2012 drought is difficult to ascertain because of the broad nature of drought impacts, estimated losses to livestock and poultry operations exceeded $547 million when accounting for increased feed costs, changes to livestock sales and inventory, and livestock mortality in 2012 and 2013 (MoDNR 2013). In 2018, the state had the second worse drought since the Great Drought, with 98 percent of the state experiencing dry to exceptional drought conditions. In response, the Soil and Water Conservation Program committed over $8 million in assistance to landowners and over $3 million in assistance was committed to public drinking water projects (MoDNR 2019). A key component of this plan update is an assessment of Missouri's drought history and drought impacts to estimate potential future impacts. After the droughts of 2012 and 2018, reports were released that summarized each drought and the state and federal government response. This plan update is intended to build on lessons learned from these past droughts and establish a framework to better prepare, mitigate, and respond to future droughts.

"Dust Bowl" with multiple years of well below average precipitation.

During Missouri's drought of record (1952-1956), some regions recorded a 5-year precipitation deficit of more than 60 inches.

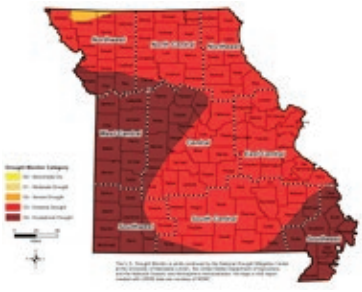
Severe and extreme droughts affected portions of the state in 1980, 1983, 1984 and 1988-1989.

1988-1989 is often referred to as the "Great Drought".

The 1990s were the wettest decade on record; however, notable extensive summer droughts still affected portions of the state in 1991 and 1999.

Severe to extreme summer drought impacted portions of west central, northwestern and north central Missouri in 2002 and 2003 and major growing season droughts occurred in 2005 and 2006.

1930s 1940s 1950s 1960s 1970s 1980s 1990s 2000s 2010s 2012 2018

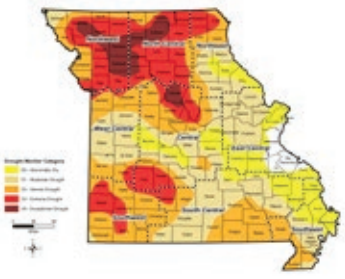


The drought of 2012 was the worst drought in Missouri in the last 30 years, due to its widespread occurrence and severity.

It was considered a "flash" drought as conditions rapidly deteriorated due to heat and lack of precipitation.

At peak drought intensity, 100% of the state was in some form of drought and 36% was in D4 (Exceptional) drought conditions.

The drought caused major economic damage to crops and livestock.



At peak drought intensity, 83% of the state was in some form of drought and 6% was in D4 (Exceptional) drought conditions.

In 2018, there were more localized impacts from drought than in 2012.

Figure ES-1. Timeline of droughts in Missouri from 1920 to 2020.

The quick onset of recent droughts has emphasized the need for effective forecasting, monitoring, and pre-drought mitigation actions and strategies. The science of drought monitoring has improved over the last 20 years with a better understanding of the types of drought events and drought metrics that track various aspects of drought conditions. This plan update provides an assessment of drought metrics and uses a more robust set of drought indicators to define drought phases.

Effective drought planning makes communities less susceptible to drought, reduces the potential for damages from drought, and improves resilience. To better assist local communities with drought planning, this drought plan update:

- **Describes the types of droughts that may occur and their impacts in Missouri**
- **Assesses resiliency to drought, that is, how prepared are water users in mitigating impacts from and responding to drought?**
- **Quantifies potential economic impacts from drought**
- **Examines the likelihood of drought and identifies those regions most susceptible to drought**
- **Characterizes regional vulnerability to drought**
- **Develops a portfolio of mitigation actions that may be effective in preventing or minimizing economic and social impacts from drought**
- **Offers region-specific drought mitigation and response actions**
- **Incorporates lessons learned from past droughts and includes a process to capture what actions work and what actions do not work**

A **meteorological** drought may be defined by deficiencies in monthly or seasonal precipitation.

A **hydrological** drought is measured by declines in streamflow, lake levels, and/or groundwater levels.

An **agricultural** drought may be determined by a combination of precipitation shortages; soil moisture deficits; reduced stream, lake, and groundwater levels; and other factors that impact crops and livestock.

A **socioeconomic** drought considers the impacts of meteorological, agricultural, or hydrologic droughts on the supply and demand of economic goods.

An **ecological** drought is a deficit in water availability that drives ecosystems beyond thresholds of vulnerability, impacts ecosystem services, and triggers feedback in natural and/or human systems.

Table ES-1 presents Missouri's drought mitigation and response goals. The goals align with and support the state's hazard mitigation goals and objectives, as identified in the State Hazard Mitigation Plan (Missouri Department of Public Safety Emergency Management 2018).

Table ES-1. Drought Mitigation and Response Plan Goals.

Topic	Plan Goal
Reducing Impacts	Reduce the impacts from drought to Missouri's economy, people, state and local assets, and environment
Increasing Public Awareness	Increase public awareness and provide education about drought planning, mitigation, and response
Enhancing Resiliency	Promote and help develop opportunities to enhance resiliency to drought through interconnections, identification of back-up supplies, water reuse, and other means that increase sources of supply
Promoting Water Conservation	Encourage water conservation and promote efficient water use
Adapting to Climate Change	Evaluate and prepare for impacts from changing climate conditions, including the potential for increased frequency, duration, and severity of drought events
Improving Monitoring	Improve water availability monitoring, stay informed of evolving drought monitoring programs, and continue to refine triggers for the initiation and termination of drought mitigation and response programs
Planning the Response	Develop, review, and update drought response plans and procedures
Clarifying Roles and Responsibilities	Clarify the roles, responsibilities, and capabilities of state and other agencies in preparing for and responding to drought conditions

REGIONAL VULNERABILITY TO DROUGHT

Regional vulnerability to drought was assessed using a combination of four elements: **likelihood** of drought, **susceptibility** to damages from drought, economic value of potential **impacts** from drought, and **resilience** – how quickly a region can respond to drought conditions. By identifying and understanding regional differences in each of these elements, mitigation and response strategies can be appropriately considered and selected to address the elements that most contribute to drought vulnerability. Likelihood, susceptibility, impact, resilience and the overall vulnerability to drought were characterized by region using the U.S. Department of Agriculture's (USDA) nine crop reporting districts shown in **Figure ES-2**.

DROUGHT VULNERABILITY IS THE COMBINATION OF:

LIKELIHOOD
What is the probability of a drought of a certain intensity and severity occurring in a region?

IMPACT
What are the potential impacts to a region if a drought were to occur?

What is the economic value of those impacts?

RESILIENCE
What technical and financial resources are available and how quickly and effectively can each region respond to drought?

SUSCEPTIBILITY
What are the primary sources of water, how much water is available, and what are the current and projected water demands in a region?

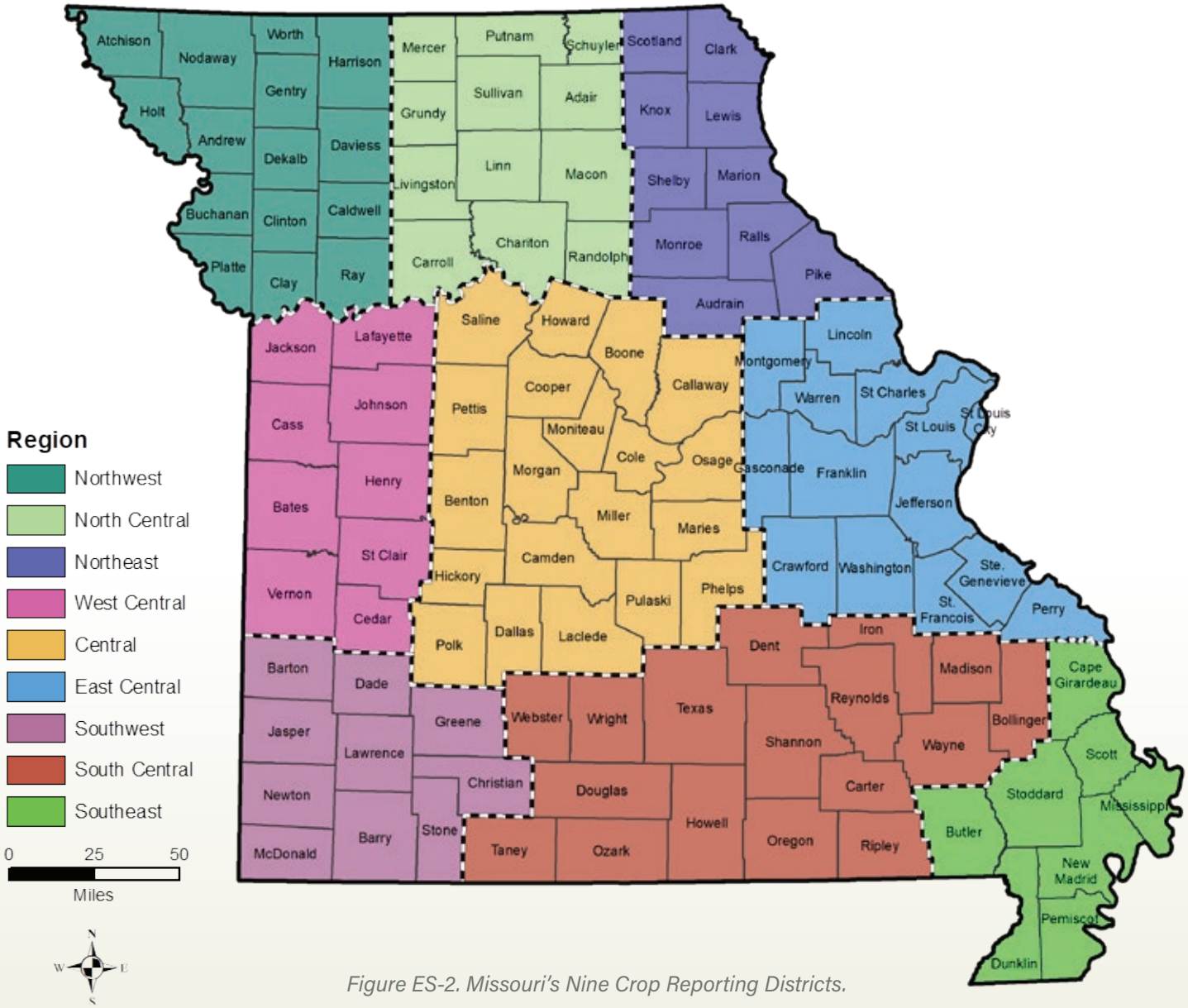


Figure ES-2. Missouri's Nine Crop Reporting Districts.

LIKELIHOOD OF DROUGHT

The Palmer Drought Severity Index (PDSI) is a commonly used drought indicator which categorizes levels of wetness and dryness using monthly temperature and precipitation data along with information on the water-holding capacity of soils. Projections of annual average PDSI to the year 2070 were developed using data from global climate models. The projections suggest a likely future decrease in average soil moisture levels throughout the state owing to warming temperatures and an increasing likelihood for more severe droughts in all areas of Missouri. Higher temperatures and lower soil moisture levels may lead to an increasing demand for irrigation water. Results may also imply a gradual shift to alternative crop types or agricultural practices, as necessitated by water availability. The projections of future PDSI vary by region and correlate to the precipitation gradient historically seen across Missouri, as shown in **Figure ES-3**, with the Northwest region receiving the lowest annual average precipitation while the South Central and Southeast regions receive the highest annual average precipitation. The existing spatial distribution of precipitation is expected to continue in the future.

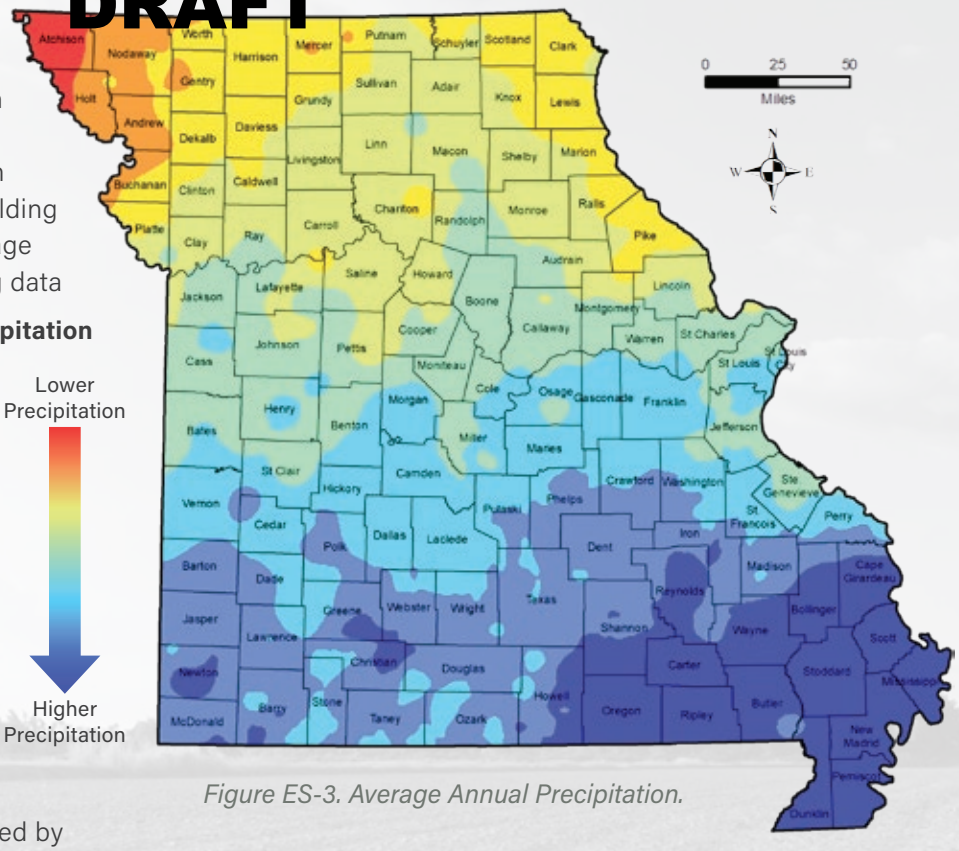


Figure ES-3. Average Annual Precipitation.

The historical and projected drought probabilities were converted to drought probabilities for the nine crop reporting districts. Based on analysis of historical and projected future PDSI trends, combined with the existing and projected precipitation gradient across the state, the Northwest, North Central, and West Central crop reporting districts are more likely to experience drought relative to the other districts, as shown in **Figure ES-4**.

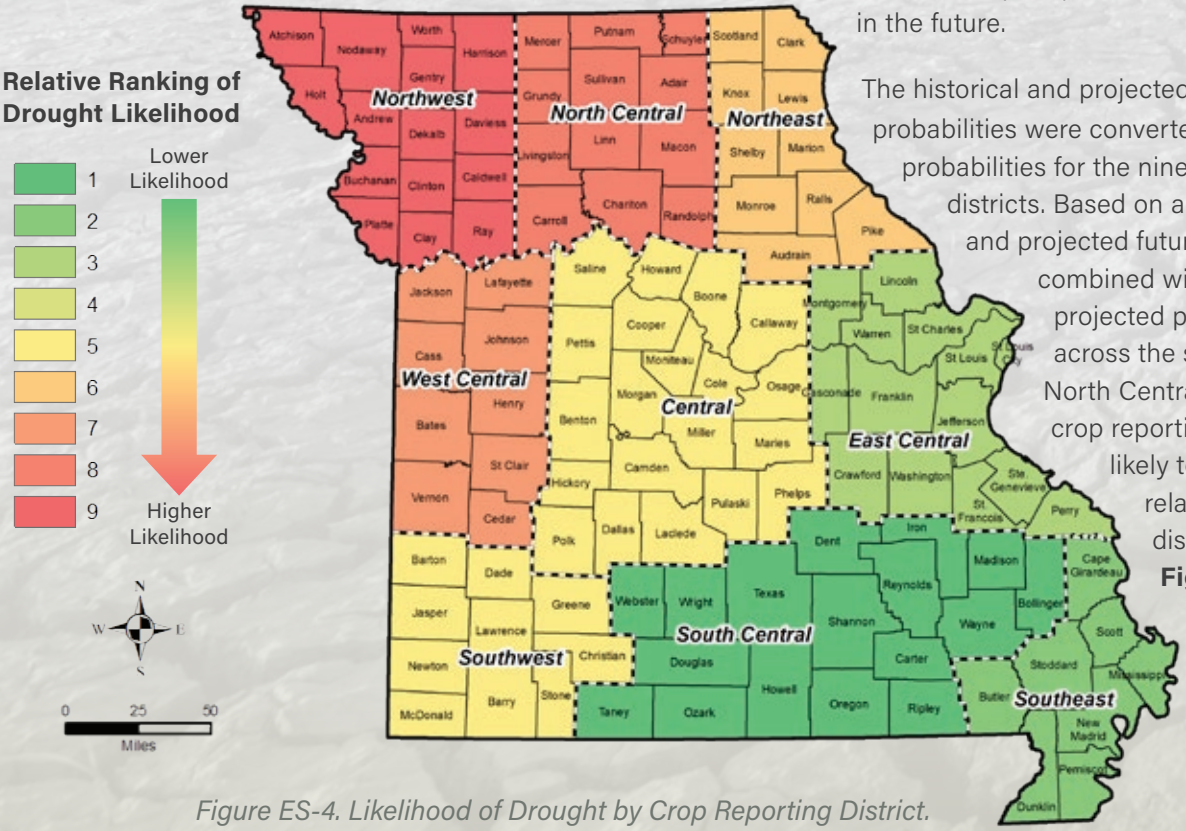


Figure ES-4. Likelihood of Drought by Crop Reporting District.

DROUGHT SUSCEPTIBILITY

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The assessment of regional drought susceptibility was based on the source of water (i.e., groundwater or surface water), how much water is available, and current and projected water demands. Most of the aquifers used as groundwater supplies across much of southern Missouri contain vast amounts of water. For example, over 129,000 billion gallons of potable groundwater is estimated to be stored in the Ozark Aquifer of the Gasconade-Osage subregion (MoDNR 2020). The Gasconade-Osage subregion covers most of the West Central and Central crop reporting districts. Projected groundwater withdrawals in 2060 are estimated to be less than 0.1 billion gallons per day in this area – a small fraction of what is stored in the aquifer. Groundwater modeling suggests that even during extreme, long-term drought conditions, these sources are not susceptible to significant impacts due to the vast amount of available storage. Conversely, a surface water source on a river, stream or small lake or reservoir is more susceptible to drought due to the relative lack of available storage.

Results of county-level analysis of water availability and demands from the 2020 Missouri Water Resources Plan (MoDNR 2020) were aggregated by crop reporting district. Based on the sources of water available, current and future demands, and the potential for future water stress, the North Central, Northwest, and Northeast crop reporting districts are more susceptible to drought relative to the other districts, as shown in **Figure ES-5**.

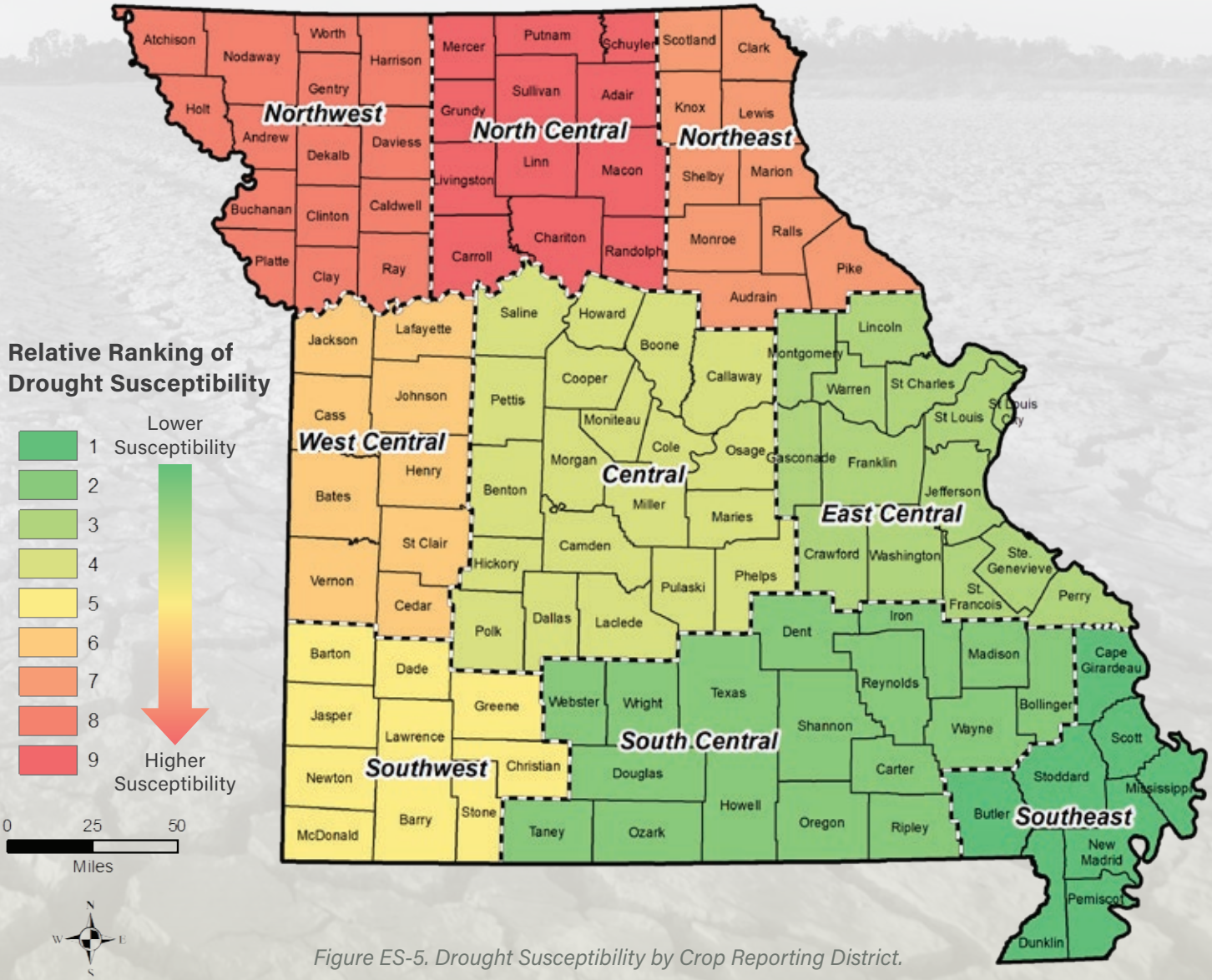

Figure ES-5. Drought Susceptibility by Crop Reporting District.

DROUGHT IMPACTS

Drought-related damages are estimated by region and county based on the severity of drought impacts to the following sectors:

Agriculture – Crops and Livestock

Municipal Water Supply Systems

Thermoelectric Power Generation

Tourism/Recreation

Agriculture

The agricultural sector is typically the first to be impacted by drought. Drought can have a significant impact on crop production and pasture conditions, and result in substantial economic impacts, especially when it occurs during the development stage of crops.

Annual payments from 2000 to 2020 to farmers from the USDA Livestock Forage Program for drought-related damages shows that the average payment per county ranges from $0.7 million in both the Northeast and Southeast districts, to $2.4 million in the South Central district. The statewide average payment from 2000 to 2020 was $1.7 million per county. Counties with more crop acres and livestock inventory have the potential to see more impacts from drought than those with fewer acres and less livestock inventory.

Drought-related reductions in crop yield can cost the Missouri economy billions of dollars a year. Expected potential value of annual crop loss for soybeans ranges from approximately $250 million at a 10 percent reduction in yield, to $1.2 billion at a 50 percent yield reduction. Expected potential value of crop loss for corn ranges from approximately $190 million at a 10 percent reduction in yield, to $1 billion at a 50 percent yield reduction.

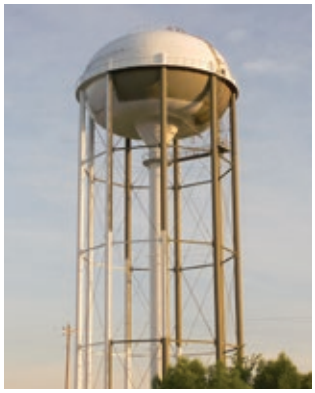

Photo by Jennie Wilson, U.S. Army Corps of Engineers

Municipal Water Supply Systems

In the early stages of drought, public water system customers and self-supplied users experience browning lawns and landscapes. Some communities may tolerate browning lawns while others may increase irrigation practices to offset the drought impacts. The increase in summer irrigation puts an additional strain on water resources. As a drought worsens, municipalities may ask for voluntary reductions in landscape irrigation or impose mandated restrictions with fines. A public water system with an abundant water supply, large storage infrastructure, and alternative water sources will avoid drought damages for a longer period than a water system with a single water source and minimal storage capacity. The economic impact of drought on municipalities and public water providers may vary with the severity of drought, length of drought, adequacy of water supply, and customer attitudes.

Recent studies of industrial water use show that many industrial facilities are willing to invest in water conservation at a unit cost (e.g., cost per 1,000 gallons) that is higher than the unit cost of their current water supply, which reflects a willingness to pay a premium for increased water reliability (i.e., management is willing to invest in efforts that minimize the risk of production interruptions). In the short term, a water shortage may limit production, postpone capital investments, and cause temporary unemployment. In the long term, water shortages may result in industry relocation and loss of local employment. Manufacturing in Missouri represents 12 percent (or $39.8 billion) of the 2019 total gross state product, and accounts for 13.6 percent of the state's private sector employment, with over 277,000 jobs and an annual payroll of $16.5 billion.

Thermoelectric Power Generation

Electric energy (power) is generated in Missouri from hydroelectric power, thermoelectric power (coal, natural gas, petroleum, and nuclear), and renewable energy. The availability of water plays an important role in power generation. Drought conditions and high temperatures not only increase the demand for power but can reduce the capacity to generate power. One study of data from 2012 suggests a 20 percent reduction in power generation under exceptional drought conditions (Pulwarty 2013).

Tourism/Recreation

During drought, recreational activities such as fishing, tubing, canoeing, and boating can be impacted by low-flow water conditions. In extremely dry conditions, access to recreational areas can be restricted or limited. This in turn impacts the local economies that service the tourism and recreational activities, such as hotels, restaurants, rental and guide companies, and golf courses. Crop reporting districts were ranked by tourism-related expenditures to identify those districts likely to be more impacted by decreases in tourism.

Potential drought impacts to agriculture, municipal water supply, industries, power generation, and tourism by region were merged to provide an overall assessment of drought impacts. Based on the assessment of economic impacts, the Southwest, West Central, and Southeast crop reporting districts may be more impacted by drought relative to the other districts, as shown in **Figure ES-6**.

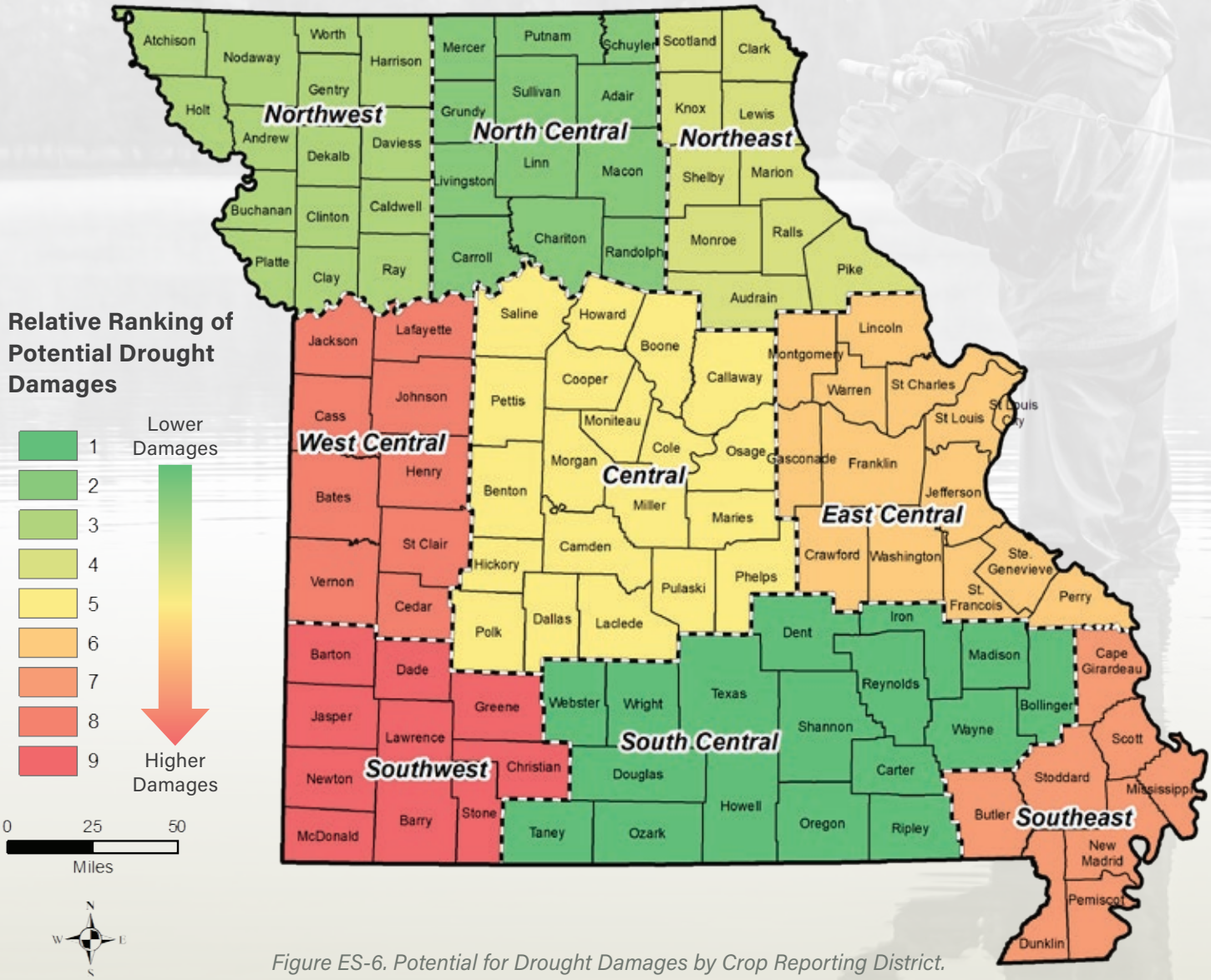

Figure ES-6. Potential for Drought Damages by Crop Reporting District.

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DROUGHT RESILIENCE

Drought resiliency is evaluated by the ease and ability to access alternative sources of water (such as interconnections with other water systems) and based on the presence of vulnerable populations. Drought resilience can be improved particularly for public water suppliers by securing a combination of water sources including both surface water and groundwater and/or establishing interconnections with nearby water suppliers. These alternate sources of supply have been shown to increase resiliency during drought conditions. Additionally, drought response planning has been shown to improve drought resilience through identification of potential drought impacts and system weaknesses.

In addition to evaluating supply sources, interconnections, and drought response planning efforts, regional drought resilience was also measured based on the Centers for Disease Control and Prevention Social Vulnerability Index (SVI). This index measures the vulnerability of counties to environmental hazards, based on a number of demographic and socioeconomic factors. The SVI is used by the Missouri Department of Public Safety to help determine where mitigation resources are needed. While the SVI represents vulnerability and the ability to respond to a wide variety of hazards, it can also help policy makers in determining a region's ability to respond to a drought situation quickly and appropriately.

Based on assessment of alternative/emergency sources of water, regional water supply projects, and social vulnerability, the Southeast, South Central, and Central crop reporting districts are less resilient to drought relative to the other districts, as shown in **Figure ES-7**.

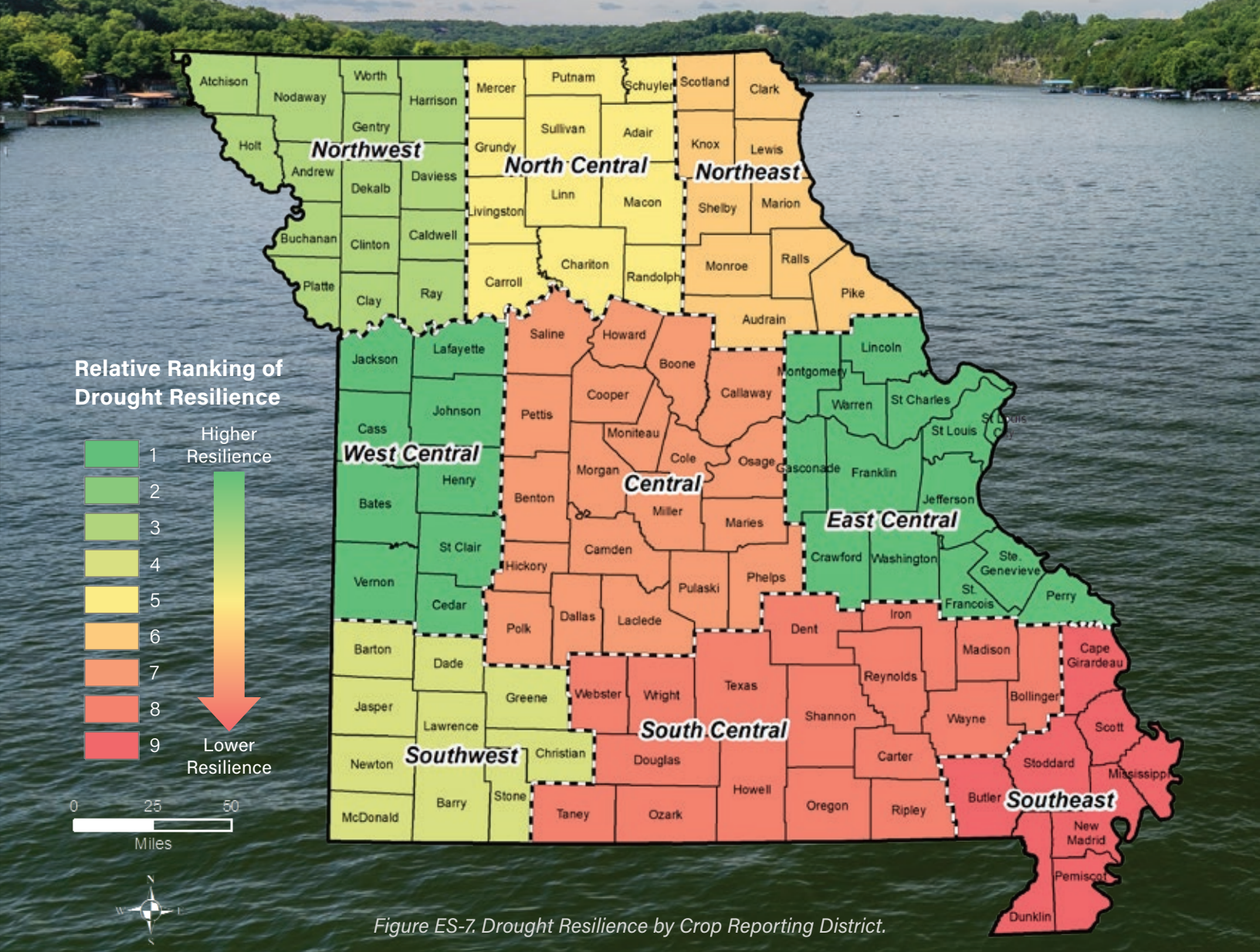

Figure ES-7. Drought Resilience by Crop Reporting District.

CHARACTERIZING REGIONAL VULNERABILITY TO DROUGHT

Combining the relative rankings of likelihood, susceptibility, impact, and resilience, the overall vulnerability to drought generally increases from the Southeast crop reporting district, where vulnerability is the lowest, to the North Central, Northeast, and Northwest districts, where vulnerability is the highest, as shown in **Figure ES-8**. While drought can impact any part of the state, effective planning, preparedness, and response actions are most important in the three northern districts which are more likely to experience drought, are more susceptible to drought, and have the highest overall vulnerability.

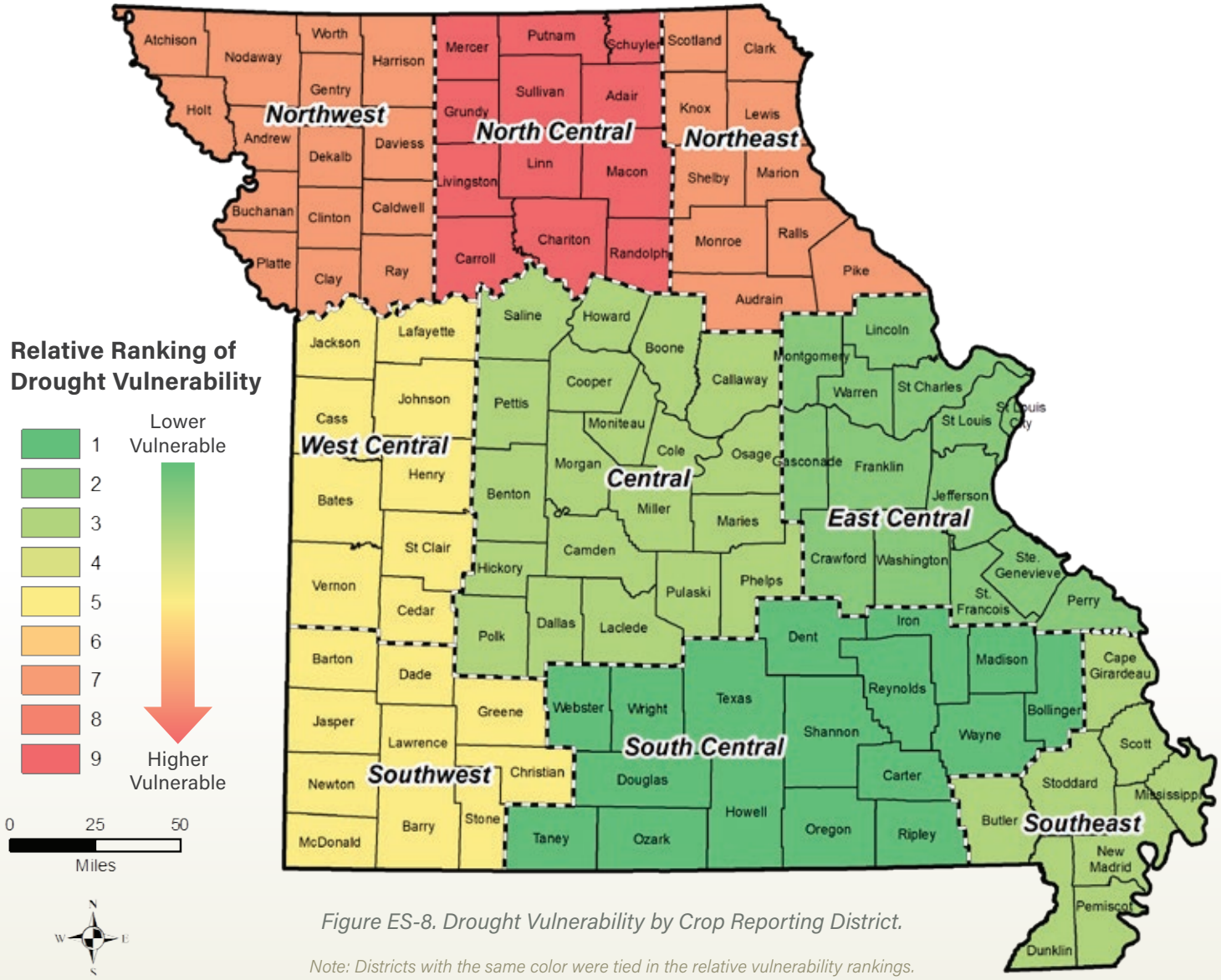

Figure ES-8. Drought Vulnerability by Crop Reporting District.

Note: Districts with the same color were tied in the relative vulnerability rankings.

DROUGHT MITIGATION AND RESPONSE ACTIONS

Drought plans, especially those developed at the state level, have historically focused on drought monitoring and response. In recent years, drought plans have also begun to identify, evaluate, and recommend actions and strategies that can be implemented prior to drought occurring to enhance resiliency and reduce or eliminate potential impacts. There has also been an increasing emphasis on actions that assess impacts from drought to aid in the selection of appropriate response options. The Missouri Drought Mitigation and Response Plan considers actions and strategies, with a focus on those initiated at the state level, that can be made (1) prior to drought, to avoid or reduce potential impacts; (2) as drought is occurring, to identify impacts and assess their severity; and (3) in response to drought.

This drought plan update includes a matrix of over 100 mitigation and response actions and strategies. Actions are identified for different water use sectors and categorized based on whether the action addresses water supply, water demand, data and monitoring, or education and outreach. The actions are identified based on their ability to reduce impacts, lower susceptibility, and/or improve resilience. Some actions are intended to be implemented at the local level, while others are implemented at the state level. Many actions are intended to address specific vulnerabilities of certain regions. The matrix includes notation for why an action is needed, where to find more information about the action, and the primary implementing agencies for the action. The drought phase at which the action should be implemented is also identified. The matrix is intended to be regularly updated to capture new strategies and eliminate ineffective actions. Some examples of pre-drought preparedness actions from the matrix are listed in **Table ES-2** and examples of response actions are listed in **Table ES-3**.

DROUGHT ACTIONS

Mitigation programs include actions and strategies performed before a drought occurs to reduce impacts, increase resilience, and lessen vulnerability.

Impact assessment actions are performed to identify and quantify impacts during a drought to identify and prioritize response options and allocate resources.

Response programs are initiated during or after a drought to reduce or eliminate impacts as they occur and/or respond to emergency situations caused by lack of water.

Table ES-2. Examples of Preparedness Actions.

SUPPLY

INCREASE STORAGE
- Explore technologies for water supply banking, floodwater diversion storage, and managed aquifer recharge.
- Reduce sedimentation and loss of storage capacity in ponds and reservoirs through creation of wetlands, use of cover crops, and other means of minimizing erosion.

ALTERNATE SOURCES
- Build a water system interconnection to one or more nearby water systems or a pipeline to a new raw water supply.
- Where existing water supplies are limited, add additional treatment and blend highly mineralized or lower-quality groundwater with existing, higher-quality water.

PLANNING
- Promote, support, and fund water supply regionalization and public/private partnerships to augment or replace local, limited water supplies.
- Conduct a statewide survey of water utility interconnections.

ASSISTANCE
- Provide technical assistance to evaluate a reservoir's capacity to meet current and projected water supply needs during drought.
- Fund water system improvements for drought mitigation and resiliency.

INCREASE SUPPLY
- Develop reclaimed (recycled) water systems for nonpotable uses such as landscape irrigation, nonfood crop irrigation, cooling towers, and vehicle washing.
- Change state regulations to allow the discharge of treated wastewater to water supply streams or reservoirs to supplement sources of supply (indirect potable reuse).
- Reallocate water supply storage in federal reservoirs where additional storage could be allocated for municipal and industrial supply.

WATER EFFICIENCY
- Explore beneficial uses for flushed water, such as irrigation, construction, firefighting storage, or other nondrinking water uses.
- Promote rainwater harvesting methods, such as cisterns or rain barrels and cooling condensate capture, for nonpotable uses such as landscape irrigation.

DEMAND

ASSISTANCE
- Provide grants, technical assistance, and/or planning assistance for improving leak control efforts and metering of all customers.
- Conduct water audits or provide water audit training to industrial and commercial users or to water utility/municipal staff so they can provide water audits to their customers.

WATER EFFICIENCY
- Conduct water audits of agricultural irrigation systems and implement measures to increase water use efficiency.
- Implement and maintain a water efficiency and water loss control program.

EDUCATION/DATA

MONITORING
- Increase weather and climate monitoring and expand the manual/automated data network on precipitation, hydrology, and soil moisture/infiltration to support drought assessment.
- Make use of more recent and experimental drought forecasting tools to monitor when conditions favor quickly emerging droughts.

PLANNING
- Perform data collection and analysis of the impacts on private (domestic) water supplies from drought. Determine standardized method of analysis to ensure information is useful, can be analyzed over a period of several years, and assessed over different drought events.

EDUCATION/ OUTREACH

PLANNING
- Encourage local-level drought planning and increase community/local-level drought planning assistance.

ASSISTANCE
- University of Missouri Extension and other state universities should conduct routine outreach with the agriculture sector to build awareness of the drought planning and response information and guides available to them through University of Missouri Extension and other sources.

Table ES-3 Example Drought Response Actions.

SUPPLY

INCREASE STORAGE

- Request temporary authorization from regulatory agencies to reduce water releases from reservoirs to keep more water in storage while still meeting essential flows needed for the environment, hydropower, or other downstream uses.

ALTERNATE SOURCES

- Allow water to be pumped from Missouri Department of Conservation areas and state parks to family-owned farms to meet livestock needs.

DEMAND

POLICY

- To discourage excessive water use, temporarily suspend a reduced water rate given to large water users.

WATER EFFICIENCY

- Establish water rate drought surcharges on water use during drought conditions.

OTHER

POLICY

- Grant waivers that eliminate the fee for oversize loads so that farmers can more easily transport wide loads of hay. Also allow for transportation of oversize loads at night and during holidays.
- Allow haying of cover crops to provide needed forage and waive the requirement that the production crop must be a minimum of two crop rotations.
- Soil and water districts can grant variances that allow grazing in livestock exclusion areas.

Photo by Jennie Wilson, U.S. Army Corps of Engineers

DROUGHT RESPONSE SYSTEM

The Drought Response System outlined in Missouri's 2002 Drought Response Plan used four phases to provide a measured response to worsening effects of drought, typically on a county-by-county basis. The four phases, which guided state-level government actions and responsibilities, were defined by changes in the PDSI and observed streamflow, reservoir, and groundwater levels.

MoDNR has more recently considered other indices to monitor drought conditions across the state, including short-term weather forecasts for signs of possible emerging drought. The new Drought Response System detailed in this plan update uses five phases to better align with the U.S. Drought Monitor; allow for consideration of additional indices applicable to meteorological, hydrologic, and agricultural indicators; and includes indices that help identify rapidly changing conditions and the possible emergence of a flash drought. The primary indices and indicators are shown in **Table ES-4**. The declaration of a drought phase is based on a "convergence of evidence" approach by the Drought Assessment Committee, which includes representatives from MoDNR and other state agencies.

DROUGHT RESPONSE SYSTEM PHASES

- Phase 0 - Advisory
- Phase 1 - Incipient
- Phase 2 - Drought Alert
- Phase 3 - Conservation
- Phase 4 - Drought Emergency

Table ES-4. Recommended Primary Indices and Indicators.

Primary Indices & Indicators	Drought Type	Description
U.S. Drought Monitor (USDM)	Comprehensive	Uses a variety of drought, climatological, hydrological, soil moisture, and other indicators.
Standard Precipitation Index (SPI)	Meteorological	Compares observed precipitation over 1- to 24-month periods with long-term averages for the same period.
Palmer Drought Severity Index (PDSI)	Agricultural	Incorporates monthly temperature and precipitation along with water-holding capacity of soils. Includes memory from past months.
Crop Moisture Index (CMI)	Agricultural	Uses the difference between potential evapotranspiration and moisture to indicate short-term moisture supply for crop producing regions.
Streamflow (28-day)	Hydrologic	Compares observed streamflow over a 28-day period with long-term averages for the same period.
Secondary Indices & Indicators	**Drought Type**	**Description**
Evaporative Drought Demand Index (EDDI)	Flash	Examines how anomalous the atmospheric evaporative demand (the thirst of the atmosphere) is for a given location over 1 week and 4 weeks.
QuickDRI	Flash	Represents a drought alarm indicator of emerging or rapidly changing drought conditions.

ORGANIZATION OF THE DROUGHT PLAN

Section 1 of the drought plan provides and introduction to this update of the Missouri Drought and Response Plan. **Section 2** discusses the different types of drought, highlights potential impacts from drought, summarizes the history of drought in Missouri, and provides an overview of strategies to prepare for and respond to drought. **Section 3** discusses current water use in Missouri, including sources of supply and regional source constraints. It also identifies factors that improve drought resilience and assesses the use of these factors on the regional scale. **Section 4** identifies damages from drought events and provides estimates of economic damages from drought by water use sectors. Secondary, indirect effects are also identified. **Section 5** discusses the likelihood, susceptibility, and overall vulnerability to drought by region within Missouri. **Section 6** introduces Missouri's drought mitigation goals and summarizes federal, state, and local capabilities, roles, and responsibilities. **Section 7** provides major recommendations for drought planning and response. **Section 8** presents the Matrix of Drought Actions supporting federal, state, and local preparedness, with drought response actions organized by water use category and applicable drought response phase.

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Photo by Jennie Wilson, U.S. Army Corps of Engineers

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