# MISSOURI WATER RESOURCES PLAN

UPDATE 2020

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## Glossary

| | |
|---|---|
| < | less than |
| > | greater than |
| °C | degrees Celsius |
| °F | degrees Fahrenheit |
| AFY | acre-feet per year |
| AgEBB | Agricultural Electronic Bulletin Board |
| APH | American Patriot Holdings LLC |
| ASCE | American Society of Civil Engineers |
| ASR | aquifer storage and recovery |
| AWWA | American Water Works Association |
| BMP | best management practice |
| CAFO | concentrated animal feeding operation |
| CCID | Climate Change and Infectious Diseases |
| CCWWC | Clarence Cannon Wholesale Water Commission |
| CDM Smith | CDM Federal Programs Corporation |
| cfs | cubic feet per second |
| CPI | Consumer Price Index |
| CSF | Congressional Sportsmen's Foundation |
| CSO | combined sewer overflow |
| CWA | Clean Water Act |
| CWNS | Clean Watersheds Needs Survey |
| CWSRF | Clean Water State Revolving Fund |
| DRA | Delta Regional Authority |
| DWINSA | Drinking Water Infrastructure Needs Survey and Assessment |
| DWSRF | Drinking Water State Revolving Fund |
| EDA | U.S. Economic Development Administration |
| EIA | U.S. Energy Information Administration |
| EIERA | Environmental Improvement and Energy Resources Authority |
| EPA | U.S. Environmental Protection Agency |
| EPAct | Energy Policy Act |
| EQIP | Environmental Quality Incentives Program |
| EUM | effective utility management |
| FAC | Financial Assistance Center |
| FAPRI | Food and Agricultural Policy Research Institute |
| FSA | Farm Service Agency |
| FWS | U.S. Fish and Wildlife Service |
| GAC | granular activated carbon |
| GIS | geographic information system |
| GNWWWC | Great Northwest Wholesale Water Commission |
| GPCD | gallons per capita per day |
| GPD | gallon per day |
| gpf | gallons per flush |
| gpm | gallons per minute |
| HDe | hybrid delta ensemble |
| HUC | hydrologic unit code |
| HUC 4 | 4-digit hydrologic unit code |
| HUC 8 | 8-digit hydrologic unit code |
| IATF | Interagency Task Force |
| in/yr | inches per year |

| | |
|---|---|
| IWRM | Integrated Water Resources Management |
| IWRP | Integrated Water Resource Plan |
| KC Water | Kansas City Water Services |
| LEPA | low energy precision application |
| LESA | low elevation sprinkler application |
| M&I | municipal and industrial |
| MAR | managed aquifer recharge |
| MDC | Missouri Department of Conservation |
| mgal | million gallons |
| MGD | million gallons per day |
| Missouri WRP | Missouri Water Resources Plan |
| MoDNR | Missouri Department of Natural Resources |
| MoDOT | Missouri Department of Transportation |
| MSA | metropolitan statistical area |
| MW | megawatts |
| MWh | megawatt-hours |
| NACWA | National Association of Clean Water Agencies |
| NAICS | North American Industry Classification System |
| NCM Commission | North Central Missouri Regional Water Commission |
| NOAA | National Oceanic and Atmospheric Administration |
| NRCS | U.S. Department of Agriculture Natural Resources Conservation Service |
| NWIS | National Water Information System |
| PAS | Planning Assistance to States |
| PFAS | per- and polyfluoroalkyl substances |
| POTW | publicly owned treatment work |
| RO | reverse osmosis |
| RSMo | Missouri Revisor of Statutes |
| SDWIS | Safe Drinking Water Information System |
| SERC-G | Southeastern Electric Reliability Council-Gateway |
| SPP-N | Southwest Power Pool-North |
| SRF | State Revolving Fund |
| TOC | total organic carbon |
| USACE | U.S. Army Corps of Engineers |
| USDA | U.S. Department of Agriculture |
| USGS | U.S. Geological Survey |
| UV | ultraviolet |
| WIFIA | Water Infrastructure Finance and Innovation Act |
| Woods & Poole | Woods & Poole Economics, Inc. |
| WREP | Wetland Reserve Enhancement Partnership |

# Section 1 Introduction

## 1.1 Background

More than any other natural resource, water is crucially important for Missouri. It supplies municipal and rural residents alike, and drives the state's vital agricultural industry. It is relied on to generate power, sustain navigation, and support many environmental and recreational uses. Without access to an adequate supply of water, quality of life in Missouri would be threatened and the state's economy would cease to grow.

The State of Missouri has two large metropolitan areas and a thriving agricultural and recreational economy, all of which depend on the water resources in the state. Many people live near the Missouri or Mississippi rivers or one of the many lakes within the state. The state's rivers, reservoirs, and groundwater aquifers supply water to maintain municipal and rural users and Missouri's agricultural industry. The Missouri River flows from west to east across the state from Kansas City to St. Louis, providing a water supply for many communities along its banks via direct surface water intakes or groundwater wells. The Mississippi River flows from north to south, forming the state's eastern border, and provides a water supply for St. Louis and other providers along its banks. The major rivers and lakes in the state provide additional water supply and cooling water for power generation, and they support numerous environmental and recreational uses. The flow in rivers originating in upstream states and in Missouri provides water to sustain navigation on the Missouri and Mississippi rivers.

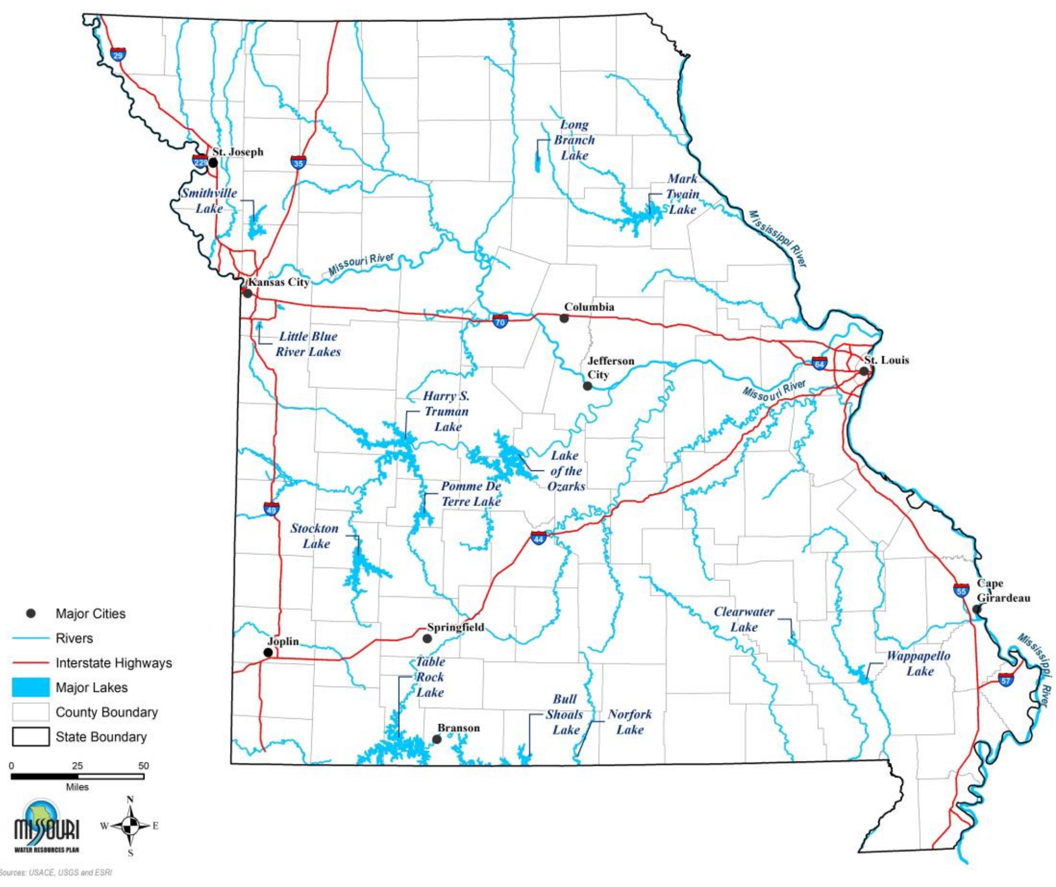


**Figure 1-1. Missouri Major Cities, Waterways, and Roads**

Missouri's economy is linked to the water resources both originating in and flowing through the state; thus, it is critical to understand the availability of water and quantify water needs. Agriculture in Missouri relies heavily on natural precipitation, livestock ponds, and groundwater supplies to provide water for crop growth and livestock production. The agricultural economy alone adds $2.25 billion a year to the state's economy (Missouri Department of Agriculture 2019).

Although Missouri typically has adequate water resources, persistent drought conditions have, at times, resulted in supply shortages. In addition to a shortage of supply, there are other reasons that water may not be available when and where it is needed because of the distance of the need from the source, insufficient conveyance or treatment infrastructure, lack of ample storage, or water quality constraints. In many areas, surface water supplies are subject to seasonal fluctuations and supplies are frequently at their lowest when demand is the highest. Sufficiently developed and maintained infrastructure can help mitigate the impacts of drought episodes and other water emergencies. Groundwater supplies, particularly bedrock aquifers, are less susceptible to drought and seasonal fluctuations than surface waters. In shallow alluvial aquifers, the aquifer and overlying stream can be linked hydrologically, each resource affecting the other.

The Missouri Water Resources Plan (Missouri WRP) outlines a comprehensive strategy to increase the understanding of Missouri's water resource needs. By identifying future shortfalls in water supplies and exploring options to address those water needs, the plan will help ensure that Missouri's water resources will meet future demands. Maintaining a current plan helps water suppliers and officials to accurately plan for current and future water needs. By applying a variety of scenarios related to climate, increased demand, and supply disruption, the plan fulfills a critical role in predicting water demand in the short and long term. Thorough examination of water supply and demand into the year 2060 plays a vital role in ensuring Missouri's ability to grow and prosper. These factors provided the impetus for developing the plan. It is the most detailed and comprehensive water planning effort in the state's history.

The Missouri Department of Natural Resources (MoDNR) is not only authorized to execute this project, they are required by statute to develop, maintain, and periodically update a state water plan (See **Section 1.2.2** for additional detail).

Prior water resource efforts include the following:

**1938 | First State Water Plan**
Described water-related issues and recommended water resources studies, projects, policies, and legislation.

**1982 | Missouri Water Atlas**
Provided basic water information.

**1986 | Revised Missouri Water Atlas**
Provided basic water information.

**1989 | Missouri Water Resources Law**
Enacted to develop a comprehensive state water plan.

**1990 | Priority Issues List**
Identified 52 water resource issues facing the state.

**1995-1997 | State Water Plan Phase I Update**
A seven-volume plan providing information about the water resources of the state.

**1998-2004 | State Water Plan Phase II Update**
A six-volume report identifying water use concerns in various regions of the state.

**2005, 2011, 2013 | Series of Drought Assessment Reports**
Evaluation of water supplies that are expected to experience water shortages during an extended drought.

**2016-2019 | Current Water Resources Plan Update**

In 2016, the MoDNR Water Resources Center initiated the Missouri WRP in partnership with the U.S. Army Corps of Engineers (USACE). The USACE partnership is achieved through their Planning Assistance to States (PAS) authority (Section 22 WRDA 1974 P.L. 93-251). This gives USACE authority to assist states financially in preparing comprehensive plans for the development and conservation of water and related land resources.

## 1.2 Missouri Department of Natural Resources

### 1.2.1 Mission

MoDNR (2019) identifies its mission as:

> "The Missouri Department of Natural Resources protects our air, land, water, and mineral resources; preserves our unique natural and historic places; and provides recreational and learning opportunities, while promoting the environmentally sound operations of businesses, communities, agriculture, and industry for the benefit of all Missourians."

### 1.2.2 Statutory Authority

MoDNR has the statutory authority to develop, maintain, and periodically update a state water plan for a long-range comprehensive statewide program for surface water and groundwater uses in the state (Missouri Revisor of Statutes [RSMo] 2019a). This statute is provided below.

> **640.415**. State water resource plan to be established for use of surface and ground water — annual report, contents — powers of department. —
>
> 1. The department shall develop, maintain and periodically update a state water plan for a long-range, comprehensive statewide program for the use of surface water and groundwater resources of the state, including existing and future need for drinking water supplies, agriculture, industry, recreation, environmental protection and related needs. This plan shall be known as the "State Water Resources Plan". The department shall collect data, make surveys, investigations and recommendations concerning the water resources of the state as related to its social, economic and environmental needs.
>
> 2. The department shall establish procedures to ensure public participation in the development and revision of the state water plan.
>
> 3. The department shall submit a report to the general assembly at least one year prior to the submission of the state water resources plan. The report shall specify the major components of the plan, and may recommend any statutory revision which may be necessary to implement the requirements of this section. The plan shall be submitted to the general assembly for approval or disapproval by concurrent resolution.
>
> 4.The department may:
>
> (a) Require such reports from groundwater and surface water users and other state agencies as may be necessary.
> (b) Conduct investigations and cooperate or contract with agencies of the United States, agencies or political subdivisions of this state, public or private corporations, associations, or individuals on any matter relevant to the administration of Section 192.300, Sections 640.100, 640.120, and 640.400 to 640.435.

To attain this goal, the Missouri WRP summarizes the existing water supplies and demands projected to 2060 by river basin at a reconnaissance level. In addition, a range of future scenarios was developed, and the adequacy of water supplies was evaluated under each scenario. Existing projects have been documented, and future water supply strategies have been identified. In a few areas of the state, local planning entities have identified projects and can implement those projects. When entities need implementation assistance, the Missouri WRP addresses planning and implementation needs, identifies future water strategies for implementation, and identifies an adaptive management framework for moving forward.

## 1.3 Participating Water Institutions

Water resources in Missouri are overseen by several local, state, regional, and federal water institutions. Each water institution has its own mission and responsibilities related to water resources in the state. The role each of these institutions plays in water resources planning varies by entity. Some key state and federal institutions participating in the Missouri WRP are noted below in Sections 1.3.1 and 1.3.2.

### 1.3.1 State Water Institutions

#### Missouri Department of Natural Resources

Among other responsibilities, MoDNR implements state-level policies related to water. The following subsections describe the functions of some groups within MoDNR that contribute to this task. This is not meant to be an exhaustive list but more an introduction on how programs and sections support one another.

#### Water Resources Center

The Water Resources Center is tasked with overseeing science, planning, and policy on how Missouri utilizes water as a resource to meet its water supply needs. There are two sections carrying out this function, Groundwater and Surface Water.

The Missouri WRP is being led by the Water Resources Center, which is under the Missouri Geological Survey Division of MoDNR. The center has the following responsibilities:

- Perform water supply analysis, drought assessments, flood and hydrology studies, and analysis of water use data
- Monitor surface and groundwater quantity
- Engage in state water planning efforts
- Maintain a database of information from registered major water users
- Engage in interstate water negotiations, compacts, and agreements
- Assist in the construction of public water supply wells
- Determine hydrologic properties of aquifers for sustainable use of these water sources

#### Water Protection Financial Assistance Center

MoDNR's Financial Assistance Center (FAC) provides funding to communities for water, wastewater and stormwater infrastructure. Most of the funding available is provided through the two State Revolving Funds - Drinking Water and Clean Water, though there are additional state grants and loans that FAC administers for a variety of other projects. Through outreach and workshops, FAC works to provide information and guidance on the funding opportunities available to communities.

#### Water Pollution Control Branch

The Water Pollution Control Branch has the responsibility of overseeing water quality, not related to drinking water, in Missouri. To complete this task there are several sections that serve different functions. When constructing a facility that will have wastewater discharge, a construction permit must be obtained. The Engineering section is responsible for evaluating construction permits as well as the design specifications of the proposed infrastructure.

#### Public Drinking Water Branch

The Public Drinking Water Branch addresses water quality in Missouri specific to drinking water. They have the same functions as the Water Pollution Control Branch with a modified structure. The sections that make up Public Drinking Water Branch are Monitoring, Permits & Engineering, and Compliance & Enforcement.

#### Soil and Water Conservation Program

The Soil and Water Conservation Program supports best management practices designed to reduce soil loss, improve water quality and promote sustainable agricultural in the state. Mirroring the 114 counties in Missouri, there are 114 soil and water conservation districts that Soil and Water Conservation Program supports.

#### University of Missouri

The University of Missouri has been an integral team member in developing the agricultural portions of the plan. The College of Agriculture, Food and Natural Resources at the University of Missouri leveraged their extensive knowledge base and data on agricultural practices and operations in Missouri to quantify Missouri's agricultural demands. University staff developed the agricultural water demands for crop irrigation, livestock, agricultural food processing, and biofuel production. In addition, the staff participated in and provided direction to the agricultural discussions in the technical workgroups.

#### Missouri Department of Conservation

In addition, the Missouri Department of Conservation (MDC), Missouri Department of Economic Development, and Missouri Department of Agriculture participated in the water planning process and provided technical support. The MDC has a mission to "protect and manage the fish, forest, and wildlife resources of the state; to facilitate and provide opportunity for all citizens to use, enjoy, and learn about these resources." This mission includes the protection and management of water bodies in the state. The Missouri Department of Economic Development works to create and promote economic growth by supporting Missouri's businesses and industries. The Missouri Department of Economic Development supports and leads community redevelopment efforts post disasters such as the recent droughts and flooding in Missouri. The Missouri Department of Agriculture sets agriculture policy and provides assistance to farmers throughout the state. Although many of its duties are regulatory, its expanded duties include consumer protection, public health roles, environmental advocacy, agricultural marketing, and promoting new uses for Missouri's agricultural goods.

### 1.3.2 Federal Water Institutions

USACE partnered with MoDNR to provide financial and technical assistance to this project. The partnership with the USACE is achieved under their PAS authority (Section 22 of the Water Resources Development Act of 1974, as amended), which provides authority for USACE to assist local governments, states, Native American tribes, and other nonfederal entities in preparing comprehensive plans for the development and conservation of water and related land resources.

The USACE PAS program can support many types of studies dealing with water resource issues. In this case, the PAS program is assisting MoDNR in updating the Missouri WRP. USACE is interested in supporting studies like the Missouri WRP because of the benefits of planning ahead to address water resources issues before they become more difficult to address. Through programs like the PAS, USACE can partner with a local or state government agency to avoid damages associated with flooding, or shortages owing to demands greater than available supplies.

There are seven USACE districts operating in Missouri. They are the Kansas City, Little Rock, Memphis, Omaha, Rock Island, St. Louis, and Tulsa districts (see **Figure 1-2**). The Missouri WRP has engaged the Kansas City and Little Rock districts.

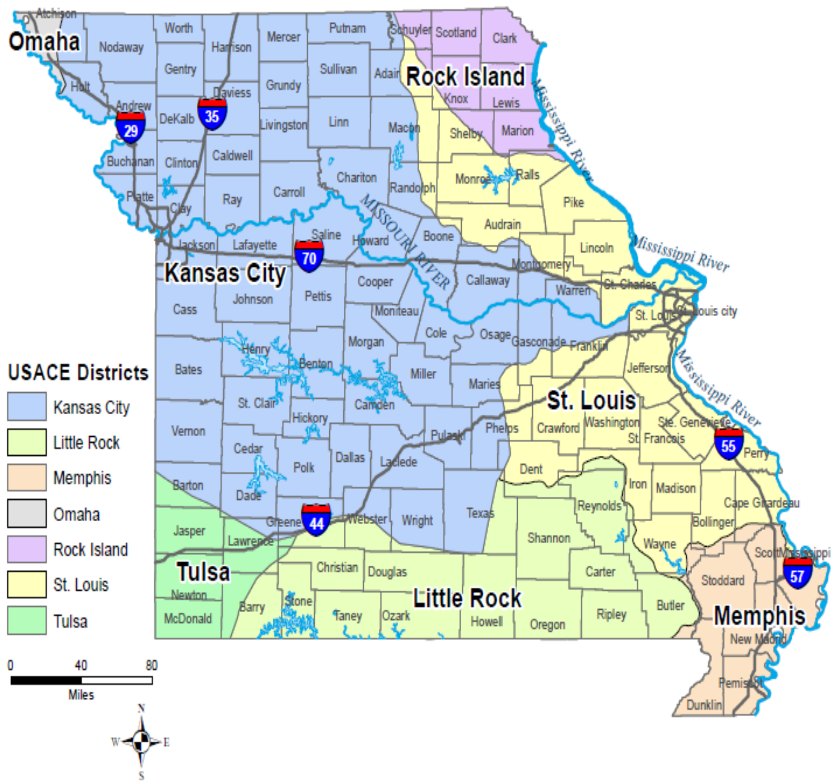


**Figure 1-2. USACE District Boundaries in Missouri**
*Source: USACE*

In addition to USACE, the U.S. Geological Survey (USGS) has been a valuable participant in the Missouri WRP. In addition to monitoring stream flow and developing water use reports, USGS has developed a numerical groundwater model in MODFLOW of the Ozark Plateaus Aquifer located in the southern half of Missouri and portions of surrounding states. This MODFLOW model was used to assess potential impacts to groundwater levels in Missouri under future projected demands for the Missouri WRP. The USGS groundwater model provided a valuable tool to identify areas of potential concern where water levels are dropping as a result of groundwater pumping in Missouri.

## 1.4 Stakeholder Process

The Missouri WRP included several key stakeholder engagement activities to promote and seek input on the plan as it was being created. These activities included regularly scheduled meetings of water resources stakeholders and agency representatives. In addition, MoDNR staff helped build awareness of the update to the plan through public presentations throughout the state on the Missouri. Information on these stakeholder meetings, presentations, notes, and brochures is available on the Missouri WRP website (https://dnr.mo.gov/mowaterplan/).

### 1.4.1 Interagency Task Force

Water Resources Law, Section 640.430 (RSMo 2019b), RSMo, directs MoDNR to establish an Interagency Task Force (IATF) to promote coordination among state departments and water resource stakeholders, ensure surface water and groundwater resources are maintained at the highest level practicable, and support present and future uses. The IATF serves as an advisory group to the Missouri WRP, providing guidance and direction.

**Interagency Task Force Meetings:**

- February 24, 2016
- November 28, 2017
- May 31, 2018
- November 29, 2018
- May 30, 2019
- November 6, 2019

The IATF members at the commencement of the Missouri WRP were:

- Paul Wieland, Missouri State Senator
- Don Rone, Missouri State Representative
- Ajay K. Arora, Ameren Missouri
- Heather Brouillet Navarro, Missouri Coalition for the Environment
- Baolin Deng, Ph.D., University of Missouri, Water Resources Research Center
- Denise Derks, Missouri Department of Economic Development
- Dan Engemann, Coalition to Protect the Missouri River
- Danny Flynn, Well Installation Board
- Elizabeth Grove, Safe Drinking Water Commission
- Michele Helton, Tyson Foods, Inc.
- Leslie Holloway, Missouri Farm Bureau
- Ramona Huckstep, Missouri Municipal League
- Robert Kallenbach, Ph.D., University of Missouri, College of Agriculture, Food and Natural Resources
- Chris Klenklen, Missouri Department of Agriculture
- Derek Linam, Missouri American Water
- Ashley McCarty, Clean Water Commission
- Patrick McKenna, Missouri Department of Transportation
- Adam McLane, The Nature Conservancy
- Roddy Rogers, City Utilities of Springfield
- Todd Sampsell, Missouri Department of Conservation
- Darrick Steen, Missouri Soybean and Corn Growers Association
- Kerri Tesreau, Missouri Department of Health and Senior Services
- Gary Vandiver, Soil and Water Districts Commission
- Ron Walker, Missouri Department of Public Safety

### 1.4.2 Technical Workgroups

Five technical workgroups were organized by water plan topic area: Consumptive Needs, Nonconsumptive Needs, Infrastructure Needs, Agricultural Needs, and Water Quality. The objectives of the technical workgroups were to provide guidance on technical analyses, give feedback to the development of technical products, identify and prioritize water resource issues, and provide recommendations on how to address those issues. This information was incorporated into the Missouri WRP. A list of the members for each of the five technical workgroups is contained on the Missouri Water Plan website (https://dnr.mo.gov/mowaterplan/technical-groups.htm).

#### Consumptive Needs

The Consumptive Needs workgroup reviewed technical data and analyses regarding consumptive water uses such as public drinking water, industrial self-supply, and other domestic and municipal use. The workgroup identified items not already contained in the data or reflected in the analysis. In addition, the workgroup worked with the project team to identify water supply challenges associated with consumptive needs and provide recommendations about how to address those challenges.

### Nonconsumptive Needs

The Nonconsumptive Needs workgroup provided input and guidance related to nonconsumptive water uses such as recreation, navigation, and portion of thermoelectric and hydropower use. The workgroup assessed nonconsumptive needs data and analyses, worked with the project team to identify water supply challenges associated with nonconsumptive needs, and provided recommendations about how to address those challenges.

### Infrastructure Needs

The Infrastructure Needs workgroup reviewed technical data and analyses regarding water and wastewater infrastructure needs while considering water quality-related infrastructure challenges. The workgroup worked with the project team to identify water supply challenges related to infrastructure, identify funding and financing opportunities to meet infrastructure needs, and provided recommendations about how to address those challenges.

### Agricultural Needs

The Agricultural Needs workgroup reviewed technical data and analyses regarding agricultural water use such as crop irrigation and livestock use. In addition, the workgroup worked with the project team to identify water supply challenges facing agriculture and provided recommendations about how to address those challenges. The University of Missouri's College of Agriculture, Food and Natural Resources performed the agricultural water needs analysis portion of the Missouri WRP.

### Water Quality

The Water Quality workgroup reviewed technical data and analyses regarding water quality to assess how it affects water supply needs. For the purposes of the Missouri WRP, analysis regarding water quality focused on its impacts on drinking water supplies. The workgroup identified water supply challenges related to water quality, and provided recommendations about how to address those concerns.

Technical workgroups began meeting in November 2017 and met quarterly throughout the development of the Missouri WRP. At first, each of the technical workgroups met separately, focusing on their topic area. As each of the topic areas were developed, it became apparent several of the topic areas were not mutually exclusive but shared related concerns.

At the May 2018 technical workgroup meetings, the Consumptive Needs and Infrastructure Needs workgroups consolidated because of the closely related interests of the two areas. After the May meetings, the Missouri WRP tasks focused on quantifying supply and demand. Therefore, rather than talk about consumptive, nonconsumptive, and agricultural demand in isolation, it was determined it would be beneficial to combine the technical workgroups into one. This allowed all of the technical workgroup members to hear, discuss, and provide input on the supply and demand analysis. In August 2018, the technical workgroups began to focus on developing four planning scenarios. In this and subsequent technical workgroup meetings, two breakout groups, Municipal and Industrial (M&I) and Agriculture, were used to focus on the specific interests of each topic area.

**Technical Workgroup Meetings:**

- November 14–16, 2017
- February 6–8, 2018
- May 15–17, 2018
- August 28, 2018
- November 11, 2018
- February 21, 2019
- May 29, 2019
- November 6, 2019

Members of the technical workgroups were identified and invited based upon their representation of various water use sectors in Missouri. The organizations/entities represented in the technical workgroups are:

- AgriServices and Inland Rivers, Ports & Terminals
- Alliance Water Resources
- Allstate Consultants
- Ameren
- American Waterways Operators
- APAC-Kansas City
- Association of Missouri Clean Water Agencies
- Black & Veatch
- Boone County Resource Management
- Burns & McDonnell
- City of Springfield
- City of St. Joseph
- City of St. Louis Water
- Clarence Cannon Wholesale Water Commission (CCWWC)
- Coalition to Protect the Missouri River
- Ducks Unlimited
- Environmental Improvement and Energy Resources Authority
- Fort Leonard Wood
- Geosyntec Consultants
- Greenway Network
- HDR
- Heartland Conservation Alliance
- JBS USA
- Kansas City Water Services (KC Water)
- Lathrop & Gage
- Lincoln University-Busby Research Farm
- Metropolitan St. Louis Sewer District
- MFA Incorporated
- Missouri American Water
- Missouri Canoe & Floaters Association
- Missouri Corn Growers Association
- Missouri Dairy Association
- Missouri Department of Agriculture
- Missouri Department of Conservation
- Missouri Department of Transportation
- Missouri Egg Council
- Missouri Farm Bureau
- Missouri Pork Association
- Missouri Prairie Foundation
- Missouri Public Utility Alliance
- Missouri Rural Water Association
- Missouri Soybean Association
- National Oceanic and Atmospheric Administration
- Natural Resources Conservation Service
- Newman, Comley & Ruth P.C.
- Olsson Associates
- Ozarks Water Watch
- Southwest Missouri Regional Water Commission
- Southwest Power Administration
- The Nature Conservancy
- The Poultry Federation
- Tyson Foods
- U.S. Coast Guard
- U.S. Fish and Wildlife Service
- USGS
- University of Missouri
- Watershed Committee of the Ozarks
- Waterways Council, Inc.

## 1.5 Fundamental Goals

At the beginning of this update to the Missouri WRP, MoDNR and stakeholders developed goals and objectives for the plan. These goals and objectives have been posted on the Missouri WRP website, have been presented in several presentations across the state, and are as follows:

- Evaluate current and future groundwater and surface water availability
- Evaluate the needs of all water users, such as drinking water suppliers, agriculture, industry, navigation, and recreation
- Develop projected water supply needs through the year 2060, taking into account projected population changes, new or increasing industry demands, and hydrologic conditions
- Identify gaps in water availability based on water use projections
- Identify water and wastewater infrastructure needs, funding, and financing opportunities
- Identify impacts affecting water availability
- Outline a series of strategies to meet Missouri's water needs
- Identify gaps in water-related datasets

## 1.6 Water Resources Plan Approach

Missouri WRP efforts began in 2015 with the development of a report compiling available background data and developing a methodology to serve as the foundation for the plan update. This gathering of baseline data and resources and development of an approach provided the basis on which the plan would be built, with minor modification when additional data, information, or resources became available.

The second and third steps were to develop population and economic forecasts used to define water demands and develop forecasts of those demands through 2060, the planning period for the Missouri WRP. These water demand forecasts rely on population and economic forecasts for the M&I sector throughout the state. Agricultural demands were computed by the University of Missouri using land use information, which includes typical crop type and historical weather patterns.

The fourth step in the process was to determine available water supplies. Missouri has significant surface water and groundwater supplies, and each was evaluated separately. Surface water supplies were evaluated by basin throughout the state using a water budget approach that quantifies the water flowing into the basin, water that is consumed, and water that flows out of the basin. A similar approach was used to quantify the amount of groundwater supplies available by basin—the approach is based upon a water balance of the aquifers underlying each basin and includes factors such as aquifer recharge, storage, and withdrawals.

Once demands and available supplies were quantified, they were compared to identify potential shortages both spatially within the state and temporally within the year. Potential shortages were identified for normal water years and drought of record years, providing critical indicators of the severity of a potential shortage. This was evaluated for four scenarios.

Based upon the identified potential shortages, a list of water supply options was developed. These options were focused on the location and timing of the identified shortages. In the last step of the plan, an adaptive management framework was defined to guide the implementation of water supply options in a structured way to avoid the pitfalls of either underperformance or overinvestment as the future unfolds.

## 1.7 Report Organization

**Section 2** discusses the physical setting in which the water resources of Missouri are being assessed in the Missouri WRP. **Section 3** explores the demographics and associated water use within Missouri to quantify demands, followed by a review and assessment of available surface water and groundwater supplies in **Section 4**. **Section 5** characterizes water and wastewater infrastructure throughout Missouri and identifies the major water resources projects currently in various stages of planning. **Section 6** summarizes the drinking and wastewater funding options available in Missouri. Options for meeting future water needs are identified in **Section 7**, and the framework for evaluating water resources strategies is described in **Section 8**. In **Section 9**, four hypothetical water resource scenarios representing a range of future conditions are evaluated to identify potential shortages and the results are used to develop an adaptive management strategy to assess planning decisions at future milestones. Finally, in **Section 10**, the plan uses the information and analyses performed in **Sections 3** through **9** to develop a list of key findings and recommendations to maintain a long-term, comprehensive strategy to meet Missouri's water resources needs into the future.

### Overview of Water Resources Plan Sections

The Missouri WRP sections are organized as follows:

- Section 2 Physical Setting – provides a summary of Missouri's climate, physiography, drainage basins, and groundwater provinces.
- Section 3 Statewide Demographic and Water Use Forecast – defines the population projections under varying economic assumptions to quantify water demands for the 2060 planning horizon.
- Section 4 Missouri's Water Supply – quantifies Missouri's available supply of surface water and groundwater.
- Section 5 Missouri's Drinking Water and Wastewater Infrastructure – characterizes water and wastewater infrastructure throughout Missouri.
- Section 6 Drinking Water and Wastewater Funding Options – characterizes water and wastewater infrastructure funding opportunities throughout Missouri.
- Section 7 Developing Options for Future Water Needs – evaluates the options for meeting future water supply needs and their advantages and disadvantages.
- Section 8 Planning Methods – evaluates future water resource needs under four defined scenarios.
- Section 9 Future Scenarios Assessed – defines adaptive management strategies that can be implemented to minimize or alleviate potential shortages.
- Section 10 Findings and Recommendations – provides a list of the key findings and recommendations identified during the development of the plan.

## 1.8 References Cited

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# Section 2 Physical Setting

## 2.1 Introduction

This section provides the physical description of the three physiographic provinces, nine subregions, and seven groundwater provinces in Missouri. Subregion characterizations include spatial and climate analysis and detailed land use descriptions. The geology and hydrogeology of the groundwater provinces are presented and their importance as a water supply source is discussed.

### Overview of Section 2 Physical Setting

Subsections are organized as follows:

- Section 2.2 Location and Climate – summarizes Missouri's geographic location and the typical climate patterns.
- Section 2.3 Physiography – describes the physiographic provinces in the state.
- Section 2.4 Subregion Drainage Basin Descriptions – summarizes the nine subregions that, based on surface hydrology, correspond to the USGS 4-digit hydrologic unit code (HUC 4) units.
- Section 2.5 Groundwater Province Descriptions – summarizes the seven distinct groundwater provinces and their unique hydrogeologic and geologic characteristics.

The primary data sources used include the following:

- **Section 2.3**, which describes the physiography of the state, used *Missouri State Water Plan Series Volume I: Surface Water Resources of Missouri* as a reference (Vandike 1995).
- Subsections within **Section 2.5** describing the geology and hydrogeology of each of the nine groundwater provinces used *Missouri State Water Plan Series Volume II: Groundwater Resources of Missouri* as a reference (Miller and Vandike 1997).

In addition, discussions of topographic relief are based on elevation data from the Missouri Spatial Data Information Service State-Extent digital elevation model (Missouri Spatial Data Information Service 1999).

## 2.2 Location and Climate

Missouri is in the Midwestern United States, south of Iowa and north of Arkansas. The state is bordered to the west by Nebraska, Kansas, and Oklahoma and to the east by Illinois, Kentucky, and Tennessee and encompasses approximately 69,707 square miles (USGS 2018). Missouri is divided among 114 counties and the City of St. Louis, which is a separate entity outside of any county, as shown in **Figure 2-1**.

The climate of Missouri is marked by strong seasonality driven by its inland location and lack of mountain barriers to airflow from both the north and south (National Oceanic and Atmospheric Administration [NOAA] 2017). Winters bring dry, cold air masses that periodically come south from the northern plains and Canada and may mix with warmer regional air masses to result in humid air, snow, and rain. Summers bring moist, warm air masses, which come north from the Gulf of Mexico, producing heavy rain. Spring and autumn, both transitional seasons, bring abrupt changes in temperature and precipitation due to successive, fast-moving fronts that separate contrasting air masses (Decker 2018).

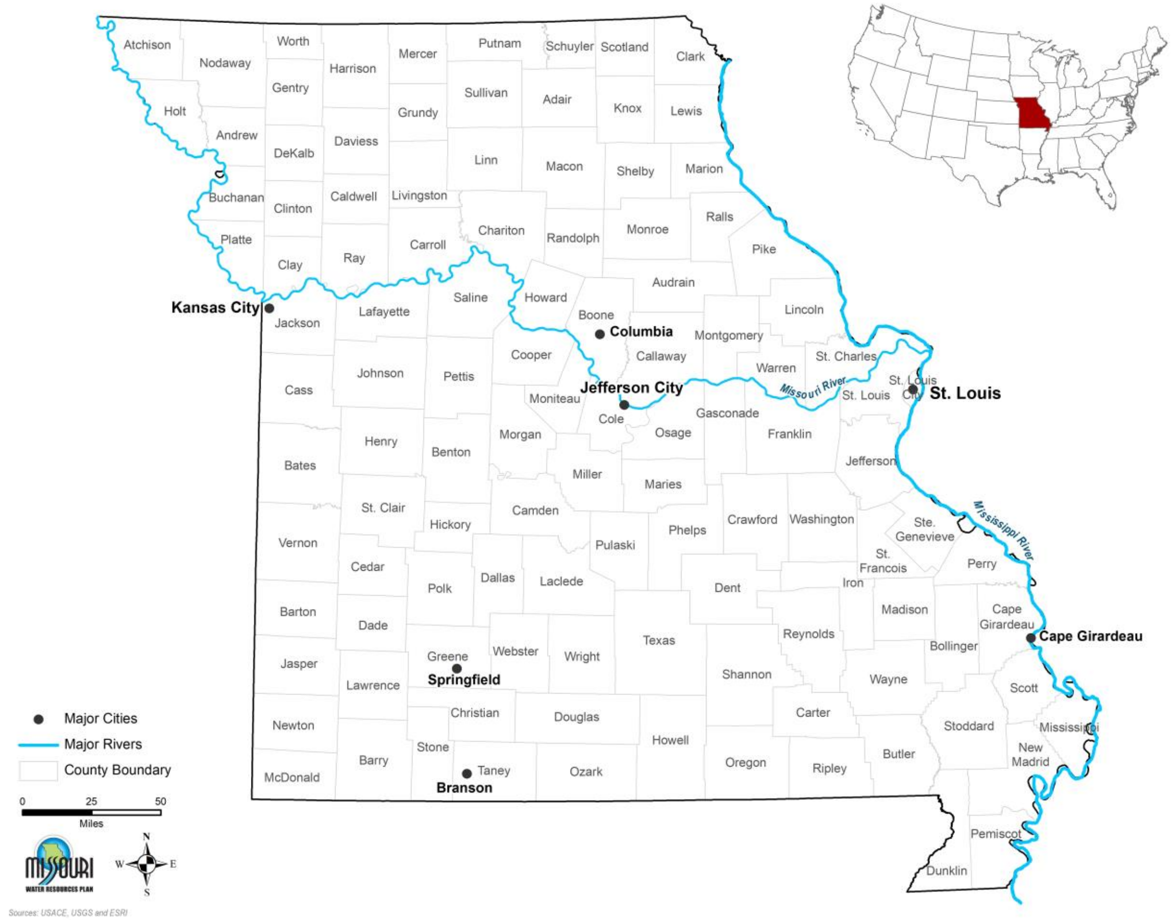


**Figure 2-1. County Map of Missouri**

Winter temperatures in Missouri are cool, with lows typically below freezing. Mean January minimum temperatures, which follow a northwest-to-southeast gradient, range from 12 degrees Fahrenheit (°F) in the northwest to 24°F in the southeast. Summers, conversely, include stretches of hot, humid weather that are broken up by occasional periods of dry-cool weather. Mean July maximum temperatures show little geographic variation throughout the state and range from 87 to 90°F (Decker 2018).

As shown in **Figure 2-2**, mean annual precipitation varies along the same northwest-to-southeast gradient as winter temperatures, ranging from 34 inches in the northwest to 50 inches in the southeast. Seasonal precipitation varies widely throughout the state. In northwestern Missouri, summer precipitation is five times greater than winter precipitation, whereas in southeastern Missouri, precipitation has minimal seasonality due to the influence of subtropical air masses throughout the year. Spring, summer, and early autumn precipitation generally come in the form of showers or thunderstorms. Hail also occurs in all regions and is most likely to fall in May (Decker 2018).

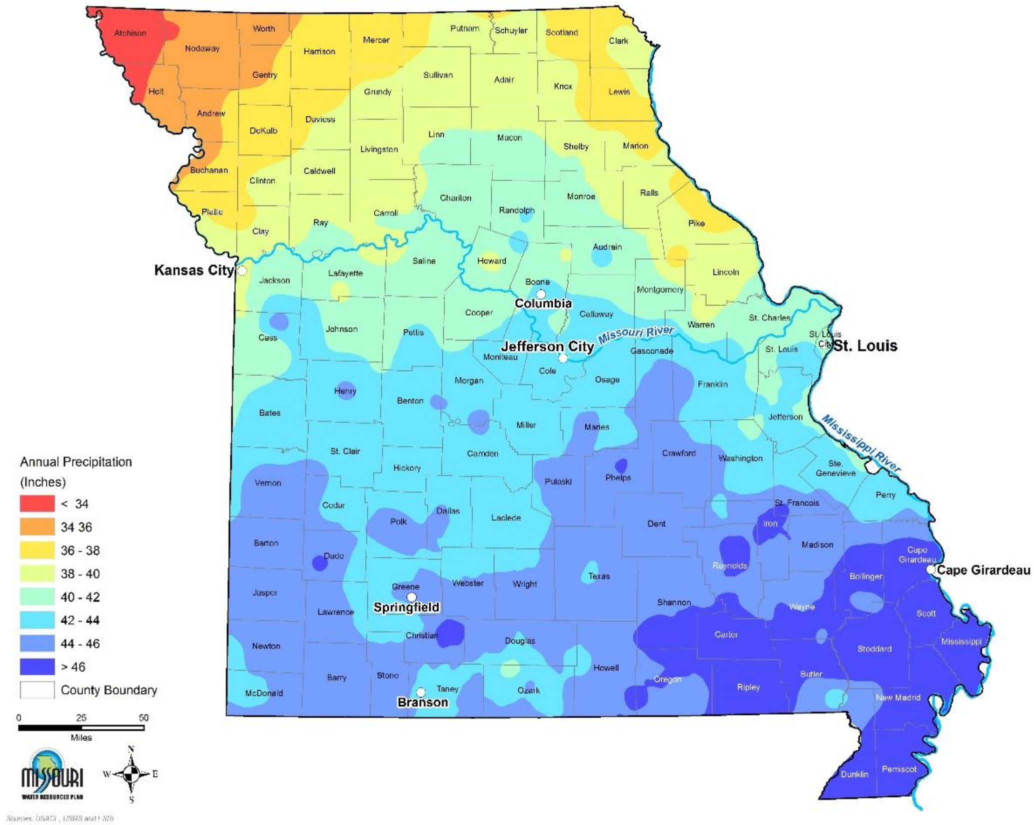


Figure 2-2. Mean Annual Precipitation for Missouri

Most snow in Missouri falls in December, January, and February, although snow may fall as early as October and as late as May. North of the Missouri River, annual snowfall averages 18 to 24 inches, whereas annual snowfall averages 8 to 12 inches in the southernmost counties (NOAA 2017).

## 2.3 Physiography

Missouri's physiography, which is characterized by factors such as geologic structure, landforms, climate, vegetation, soil and water, varies across the state. Three major physiographic provinces have been delineated: the Central Lowlands in the north and west; the Ozark Plateaus in central and southern Missouri; and the Coastal Plain in the southeast. Distinctive structural or geologic differences further divide the provinces into several subprovinces as shown in **Figure 2-3**. The unique features of the physiographic provinces are discussed below.

### 2.3.1 Central Lowlands Province

The Central Lowlands province is in northern Missouri and lies within the larger Interior Plains division of the United States (Fenneman and Johnson 1946). This province includes the Dissected Till Plains to the north and the Osage Plains to the west.

The Dissected Till Plains was formed by advances and retreats of two major ice sheets that left behind thick deposits of unconsolidated, glacially derived sediments. It is characterized by moderately dissected, glaciated, flat to rolling plains that slope gently toward the Missouri and Mississippi river valleys, with dendritic drainage (McNab and Avers 1994). Ground surface relief (i.e., the change in elevation) of the Missouri portion of this subregion is approximately 900 feet. The primary lithology of the subprovince includes Pleistocene loess underlain by Pleistocene till (McNab and Avers 1994).

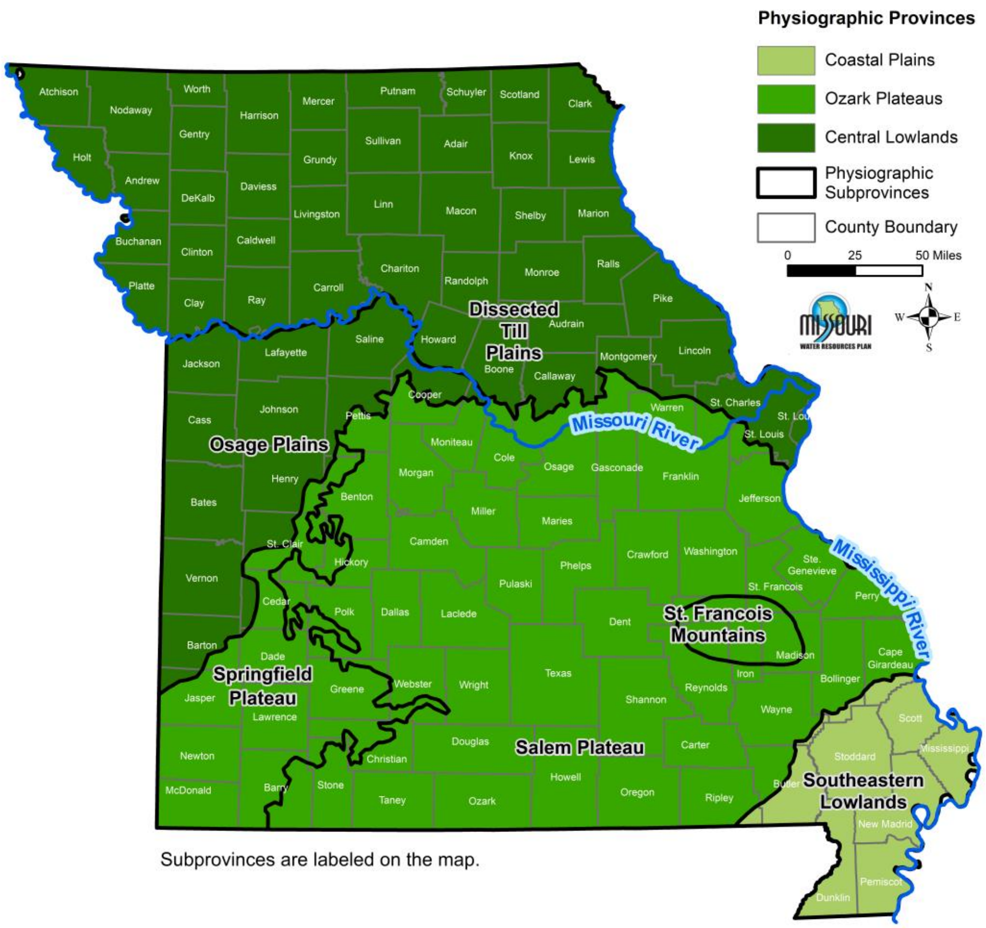


**Figure 2-3. Physiographic Provinces and Subprovinces of Missouri**

The Osage Plains presents a gentler topography than the Dissected Till Plains. These plains are not a result of glaciation and are underlain by Pennsylvanian-age sedimentary rocks that consist of thin limestone, sandstone, and shale. The relief of this subprovince is approximately 520 feet. A moderate density of small to medium size, highly meandering, perennial and intermittent streams with dendritic drainage patterns exist within the Osage Plains (McNab and Avers 1994). Water generally drains east and north into the Missouri River, with the exception of the southern tip of the subprovince, which drains south and west to the Arkansas River.

## 2.3.2 Coastal Plain Province

The Coastal Plain province of Missouri is located within the larger U.S. Atlantic Plains division and includes the southeastern corner of the state (Fenneman and Johnson 1946), commonly referred to as the Bootheel, or as shown on **Figure 2-3**, the Southeastern Lowlands. The portion within Missouri is covered by alluvium comprised of sand, gravel, silt, and clay that was deposited by the St. Francis, Black, Mississippi, and Ohio rivers. The province also includes erosional remnants of previous plains in the form of Crowley's Ridge, Hickory Ridge, and Benton Hills (Brookshire 1997). These ridges and hills are composed of Tertiary, Cretaceous, and Paleozoic rocks that form islands in the alluvial materials that surround them. Ground surface relief within the province is approximately 370 feet.

In the 19th century, the Southeastern Lowlands was noted for its swamps and poor drainage. Since the late 1800s, however, drainage patterns have been altered for agricultural and development purposes, and water is now generally channeled south toward Arkansas and eventually to the Mississippi River.

### 2.3.3 Ozark Plateaus Province

Between the Central Lowlands and the Coastal Plains provinces lies the Ozark Plateaus province (Fenneman and Johnson 1946). The Ozark Plateau is an uplifted area in southern Missouri and adjacent parts of Arkansas, Illinois, and Oklahoma. In the Missouri portion, there is approximately 1,490 feet of relief. The province is further divided into the St. Francois Mountains, the Salem Plateau, and the Springfield Plateau subprovinces. The St. Francois Mountains subprovince is in southeastern Missouri and includes the highest point in the state, Taum Sauk Mountain. The St. Francois Mountains are the center of uplift, where an eroded Precambrian mountain range is surrounded by younger sedimentary rock.

The Salem Plateau subprovince is in central and south-central Missouri. The subprovince is primarily comprised of Ordovician- and Cambrian-age sedimentary rocks and surrounds the St. Francois Mountains. The area consists of steep-sided, deep valleys and is dissected. In upland areas, the bedrock is covered by thick deposits of unconsolidated residual material.

The Springfield Plateau subprovince is in southwestern Missouri, with Mississippian-age limestone forming the uppermost bedrock, and is separated from the Salem Plateau by the Eureka Springs escarpment.

## 2.4 Subregion Drainage Basin Descriptions

Missouri can be divided in to nine subregions based on surface hydrology. Each subregion represents a major drainage basin that corresponds to the USGS HUC 4 units shown in **Figure 2-4**. Each subregion is described below. Subregions are comprised of numerous subbasins and watersheds that correspond to other hydrologic unit classifications. The USGS 8-digit hydrologic unit code (HUC 8) is referred to as a subbasin.

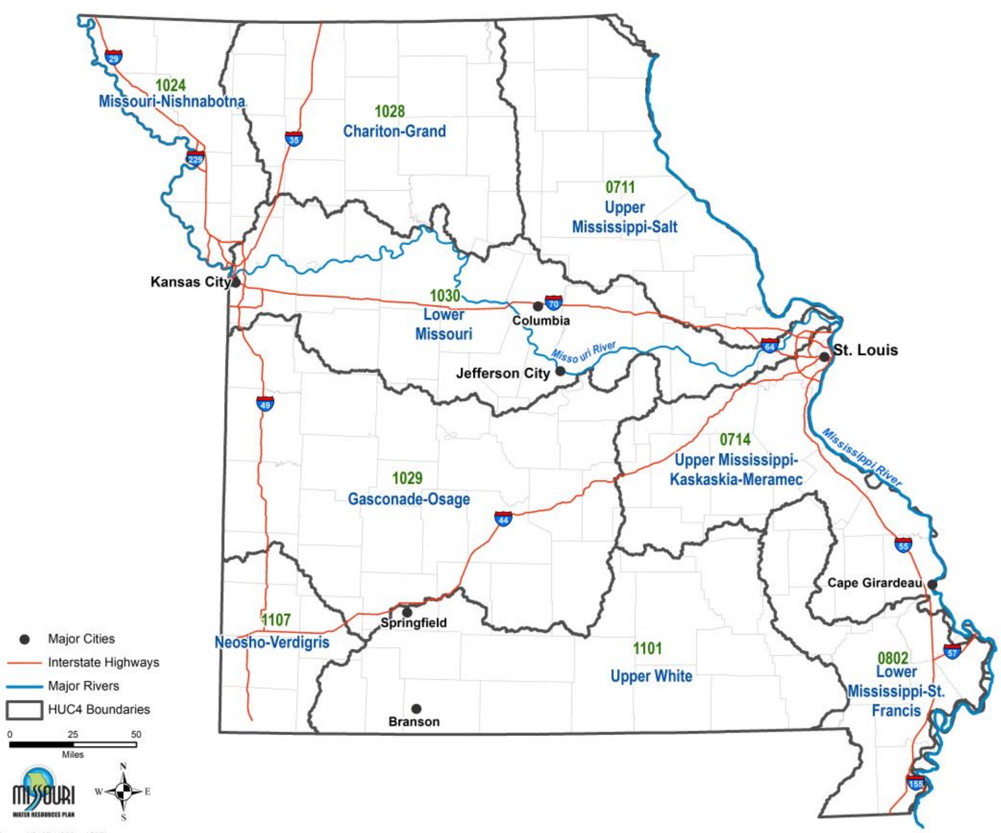


**Figure 2-4. Missouri HUC 4 Subregion Map**

### 2.4.1 Upper Mississippi-Salt Subregion

The Upper Mississippi-Salt subregion (hydrologic unit code [HUC] 0711) is in the northeastern corner of Missouri. The subregion is 10,077 square miles, 7,764 square miles of which are in Missouri, or 77 percent of the subregion (USGS and the U.S. Department of Agriculture Natural Resources Conservation Service [NRCS] 2018). The remainder is in southern Iowa and western Illinois. Major tributaries to the Mississippi River in the Upper Mississippi-Salt include the Salt River, the Fabius River, the Cuivre River, and the Des Moines River, all of which generally flow to the southeast. The portion of the Mississippi River within this subregion is approximately 165 miles long, extends from the confluence with the Des Moines River to the confluence with the Missouri River, and forms the border between Missouri and Illinois.

#### Climate

The northern portion of the Upper Mississippi-Salt subregion is classified as a continental, fully humid, hot summer (Dfa) climate (Climate Change and Infectious Diseases [CCID] 2018), according to the Köppen-Geiger climate classification, a widely used vegetation-based climate classification system (NOAA 2018a). Dfa climates are characterized by large seasonal temperature differences, with warm to hot summers and cold winters. Summers are often humid and winters are sometimes severely cold in northern areas. Precipitation is usually distributed throughout the year. The southern portion of the subregion, in contrast, is classified as a warm temperate, fully humid, hot summer climate (Cfa) (CCID 2018). The primary difference between the two climate types of the subregion are the slightly higher temperatures of the Cfa climate type. The Dfa and Cfa climate types are the only two that appear in Missouri, as shown in **Table 2-1**. The Dfa type roughly extends across the northern quarter of the state (e.g., north of St. Joseph in the west and La Grange in the east).

**Table 2-1. Köppen-Geiger Climate Classifications within Missouri[1]**

| Area of Missouri | Main Climates | Precipitation | Temperature |
|---|---|---|---|
| Southern Missouri | Temperate (C) | Without Dry Season (f) | Hot Summer (a) |
| Northern Missouri | Continental (D) | Without Dry Season (f) | Hot Summer (a) |

[1]CCID 2018

The subregion receives an average of 42 inches of rainfall each year and an average of 15 inches of annual snowfall. Temperatures reach an average maximum of 86°F in the summer, with an average low of 65°F, and an average maximum of 40°F in the winter, with an average low of 24°F (**Table 2-2**) as calculated using climate data from the Missouri portion of the subregion.

**Table 2-2. Upper Mississippi-Salt Subregion Climate Data[1]**

| Mean Annual Rainfall (inches) | Mean Annual Snowfall (inches)[2] | Mean Maximum Summer (June–August) Temp (°F) | Mean Minimum Summer (June–August) Temp (°F) | Mean Maximum Winter (December–February) Temp (°F) | Mean Minimum Winter (December–February) Temp (°F) |
|---|---|---|---|---|---|
| 42 | 15 | 86 | 65 | 40 | 24 |

[1]NOAA 2018b
[2]U.S. Climate Data 2018

#### Land Use

The Upper Mississippi-Salt subregion has extensive plains and gently rolling hills, which are conducive to livestock farming and the growing of crops such as corn, soybeans, hay, wheat, and sorghum (Brookshire 1997). In Missouri, the subregion is primarily agricultural, with 28.8 percent used for pasture and hay and 37.4 percent used for cultivated crops. Land uses are listed in **Table 2-3**.

The Missouri portion of the Upper Mississippi-Salt subregion contains several urban clusters, which are defined as areas containing at least 2,500 and fewer than 50,000 people. These urban clusters include Bowling Green, Centralia, Hannibal, Kirksville, Louisiana, Macon, Mexico, Moberly, Montgomery City, Palmyra, Troy, Vandalia, Warrenton, and Wright City. St. Louis, whose city limits also extend into the Upper Mississippi-Kaskaskia-Meramec and Lower Missouri-Blackwater subregions, is considered an urbanized area based on its population of over 50,000 (NRCS 2015).

**Table 2-3. Upper Mississippi-Salt Subregion Land Use Data[1]**

| Land Cover | Land Use Area within Missouri (Acres) | Percent Cover (%) |
|---|---|---|
| Open Water | 83,064 | 1.7% |
| Developed, Open Space | 186,851 | 3.8% |
| Developed, Low Intensity | 92,272, | 1.9% |
| Developed, Medium Intensity | 29,341 | 0.6% |
| Developed, High Intensity | 8,833 | 0.2% |
| Barren Land (Rock/Sand/Clay) | 4,674 | 0.1% |
| Deciduous Forest | 995,180 | 20.0% |
| Evergreen Forest | 4,108 | 0.1% |
| Mixed Forest | 7,270 | 0.1% |
| Shrub/Scrub | 42,436 | 0.9% |
| Grassland/Herbaceous | 66,838 | 1.3% |
| Pasture/Hay | 1,431,638 | 28.8% |
| Cultivated Crops | 1,859,313 | 37.4% |
| Woody Wetlands | 141,711 | 2.9% |
| Emergent Herbaceous Wetlands | 17,475 | 0.4% |
| **Total** | **4,971,004** | **100.0%** |

[1]USGS 2014

## 2.4.2 Upper Mississippi-Kaskaskia-Meramec Subregion

The Upper Mississippi-Kaskaskia-Meramec subregion (HUC 0714) is in eastern Missouri, south of the Missouri River. The subregion is 17,111 square miles, 6,986 square miles of which are in Missouri, or 41 percent of the subregion (USGS and NRCS 2018). The remainder is in southwestern Illinois. Major tributaries to the Mississippi River within the Upper Mississippi-Kaskaskia-Meramec subregion include the Bourbeuse River, the Meramec River, and the Big River, all of which generally flow to the northeast.

### Climate

The entire Upper Mississippi-Kaskaskia-Meramec subregion is classified as warm temperate, fully humid, hot summer (Cfa), according to the Köppen-Geiger climate classification (CCID 2018).

The subregion receives an average of 44 inches of rainfall each year and an average of 10 inches of annual snowfall. Temperatures in the Missouri portion reach an average maximum of 87°F in the summer, with an average low of 66°F, and an average maximum of 44°F in the winter, with an average low of 25°F as shown in Table 2-4.

**Table 2-4. Upper Mississippi-Kaskaskia-Meramec Subregion Climate Data[1]**

| Mean Annual Rainfall (inches) | Mean Annual Snowfall (inches)[2] | Mean Maximum Summer (June–August) Temp (°F) | Mean Minimum Summer (June–August) Temp (°F) | Mean Maximum Winter (December–February) Temp (°F) | Mean Minimum Winter (December–February) Temp (°F) |
|---|---|---|---|---|---|
| 44 | 10 | 87 | 66 | 44 | 25 |

[1]NOAA 2018b
[2]U.S. Climate Data 2018

### Land Use

In Missouri, the Upper Mississippi-Kaskaskia-Meramec subregion is 54.1 percent deciduous forest, 20.9 percent pasture and hay, and 5.2 percent cultivated crops. All other land uses are individually less than 5 percent as shown in **Table 2-5**.

The Missouri portion of the Upper Mississippi-Kaskaskia-Meramec subregion includes several urban clusters including Cuba, De Soto, Eureka, Farmington, Hillsboro, Owensville, Pacific, Perryville, Potosi, Rolla, Salem, Scott City, St. Clair, St. James, Ste. Genevieve, Sullivan, and Union. The subregion also contains two urbanized areas within Missouri, Cape Girardeau and a portion of St. Louis (NRCS 2015).

**Table 2-5. Upper Mississippi-Kaskaskia-Meramec Subregion Land Use Data[1]**

| Land Cover | Land Use Area within Missouri (Acres) | Percent Cover (%) |
|---|---|---|
| Open Water | 48,672 | 1.1% |
| Developed, Open Space | 206,417 | 4.6% |
| Developed, Low Intensity | 154,499 | 3.5% |
| Developed, Medium Intensity | 55,424 | 1.2% |
| Developed, High Intensity | 25,634 | 0.6% |
| Barren Land (Rock/Sand/Clay) | 12,770 | 0.3% |
| Deciduous Forest | 2,419,499 | 54.1% |
| Evergreen Forest | 122,751 | 2.7% |
| Mixed Forest | 129,555 | 2.9% |
| Shrub/Scrub | 15,570 | 0.3% |
| Grassland/Herbaceous | 78,728 | 1.8% |
| Pasture/Hay | 934,951 | 20.9% |
| Cultivated Crops | 231,855 | 5.2% |
| Woody Wetlands | 31,455 | 0.7% |
| Emergent Herbaceous Wetlands | 1,833 | <0.1% |
| **Total** | **4,469,613** | **100.0%** |

[1]USGS 2014

## 2.4.3 Lower Mississippi-St. Francis Subregion

The Lower Mississippi-St. Francis subregion (HUC 0802) is in the southeast corner of Missouri and includes the Bootheel. The subregion is 16,842 square miles, 4,717 square miles of which are in Missouri, or 28 percent of the subregion (USGS and NRCS 2018). The remainder is in northeastern Arkansas. The river with the highest flow in the subregion is the St. Francis River, which generally flows south into Arkansas and to the Mississippi River. In addition, numerous channelized ditches also provide surface drainage. The Mississippi River forms the eastern boundary of this subregion. The subregion is unique due to its topographic diversity – flat lowlands in the Bootheel, dissected ridges and highly dissected plateaus north of the Bootheel, and scattered high peaks in Madison, Iron and St. Francois counties.

### Climate

The entirety of the Lower Mississippi-St. Francis subregion is classified as warm temperate, fully humid, hot summer (Cfa), according to the Köppen-Geiger climate classification (CCID 2018).

The subregion receives an average of 48 inches of rainfall each year and an average of 6 inches of annual snowfall. Temperatures within the Missouri portion reach an average maximum of 89°F in the summer, with an average low of 67°F, and an average maximum of 46°F in the winter, with an average low of 28°F as shown in **Table 2-6**.

**Table 2-6. Lower Mississippi-St. Francis Subregion Climate Data[1]**

| Mean Annual Rainfall (inches) | Mean Annual Snowfall (inches)[2] | Mean Maximum Summer (June–August) Temp (°F) | Mean Minimum Summer (June–August) Temp (°F) | Mean Maximum Winter (December–February) Temp (°F) | Mean Minimum Winter (December–February) Temp (°F) |
|---|---|---|---|---|---|
| 48 | 6 | 89 | 67 | 46 | 28 |

[1]NOAA 2018b
[2]U.S. Climate Data 2018

### Land Use

The Lower Mississippi-St. Francis subregion is primarily agricultural, with 57.7 percent of the land in Missouri used for cultivated crops and 7.6 percent for pasture and hay, as shown in **Table 2-7**. The northern portion, which includes parts of Wayne, Iron, Madison and St. Francois counties is dominated by deciduous forest.

The Lower Mississippi-St. Francis subregion includes several urban clusters within Missouri, including Caruthersville, Chaffee, Charleston, Dexter, East Prairie, Farmington, Fredericktown, Hayti, Ironton, Kennett, Malden, New Madrid, Portageville, Scott City, and Sikeston (NRCS 2015).

**Table 2-7. Lower Mississippi-St. Francis Subregion Land Use Data[1]**

| Land Cover | Land Use Area within Missouri (Acres) | Percent Cover (%) |
|---|---|---|
| Open Water | 26,285 | 0.9% |
| Developed, Open Space | 127,733 | 4.2% |
| Developed, Low Intensity | 33,672 | 1.1% |
| Developed, Medium Intensity | 9,648 | 0.3% |
| Developed, High Intensity | 2,871 | 0.10% |
| Barren Land (Rock/Sand/Clay) | 3,206 | 0.1% |
| Deciduous Forest | 672,857 | 22.3% |
| Evergreen Forest | 20,978 | 0.7% |
| Mixed Forest | 39,987 | 1.3% |
| Shrub/Scrub | 4,444 | 0.1% |
| Grassland/Herbaceous | 14,252 | 0.5% |
| Pasture/Hay | 229,251 | 7.6% |
| Cultivated Crops | 1,740,875 | 57.7% |
| Woody Wetlands | 76,593 | 2.5% |
| Emergent Herbaceous Wetlands | 13,247 | 0.4% |
| **Total** | 3,015,899 | 100% |

[1]USGS 2014

## 2.4.4 Missouri-Nishnabotna Subregion

The Missouri-Nishnabotna subregion (HUC 1024) is in the northwest corner of Missouri. The subregion is 13,607 square miles, 3,682 square miles of which are in Missouri, or 27 percent (USGS and NRCS 2018). The remainder of the subregion is in southwestern Iowa, southeastern Nebraska, and northeastern Kansas. Major tributaries are Missouri's Platte River, the Nishnabotna River, and the Nodaway River, all of which generally flow to the southwest to the Missouri River.

## Climate

The entirety of the Missouri-Nishnabotna subregion is classified as continental, fully humid, hot summer (Dfa), according to the Köppen-Geiger climate classification (CCID 2018).

The subregion receives an average of 38 inches of rainfall each year and an average of 14 inches of annual snowfall. Temperatures in the Missouri portion reach an average maximum of 86°F in the summer, with an average low of 66°F, and an average maximum of 40°F in the winter, with an average low of 21°F as shown in **Table 2-8**.

**Table 2-8. Missouri-Nishnabotna Subregion Climate Data[1]**

| Mean Annual Rainfall (inches) | Mean Annual Snowfall (inches)[2] | Mean Maximum Summer (June–August) Temp (°F) | Mean Minimum Summer (June–August) Temp (°F) | Mean Maximum Winter (December–February) Temp (°F) | Mean Minimum Winter (December–February) Temp (°F) |
|---|---|---|---|---|---|
| 38 | 14 | 86 | 66 | 40 | 21 |

[1]NOAA 2018b
[2]U.S. Climate Data 2018

## Land Use

In Missouri, the Missouri-Nishnabotna subregion is primarily agricultural, with 48.9 percent of the land used for cultivated crops and 23.7 percent used for pasture and hay, as shown in **Table 2-9**.

The Missouri-Nishnabotna subregion includes several urban clusters within Missouri, including Maryville, Platte City, Savannah, and Smithville. The subregion also contains two urbanized areas in Missouri: Kansas City and St. Joseph (NRCS 2015).

**Table 2-9. Missouri-Nishnabotna Subregion Land Use Data[1]**

| Land Cover | Land Use Area within Missouri (Acres) | Percent Cover (%) |
|---|---|---|
| Open Water | 46,894 | 2.0% |
| Developed, Open Space | 130,490 | 5.5% |
| Developed, Low Intensity | 49,125 | 2.1% |
| Developed, Medium Intensity | 14,942 | 0.6% |
| Developed, High Intensity | 5,882 | 0.2% |
| Barren Land (Rock/Sand/Clay) | 1,199 | 0.1% |
| Deciduous Forest | 247,589 | 10.5% |
| Evergreen Forest | 423 | <0.1% |
| Mixed Forest | 844 | <0.1% |
| Shrub/Scrub | 4,949 | 0.2% |
| Grassland/Herbaceous | 57,454 | 2.4% |
| Pasture/Hay | 557,927 | 23.7% |
| Cultivated Crops | 1,151,652 | 48.9% |
| Woody Wetlands | 35,649 | 1.5% |
| Emergent Herbaceous Wetlands | 51,703 | 2.2% |
| **Total** | **2,356,722** | **100.0%** |

[1]USGS 2014

## 2.4.5 Chariton-Grand Subregion

The Chariton-Grand subregion (HUC 1028) is in north-central Missouri. The subregion is 10,951 square miles, 8,306 square miles of which are in Missouri, or 76 percent (USGS and NRCS 2018). The remainder of the subregion is in south-central Iowa. Major tributaries within the subregion include the Grand River, the Thompson River, which generally flow to the southeast, and the Chariton River, which generally flows to the south. All of the major tributaries originate in Iowa and all flow in these rivers is eventually conveyed to the Missouri River.

## Climate

The Chariton-Grand subregion is classified as continental, fully humid, hot summer (Dfa), according to the Köppen-Geiger climate classification, with the exception of the southernmost portion, which is classified as warm temperate, fully humid, hot summer (Cfa) (CCID 2018).

The subregion receives an average of 41 inches of rainfall each year and an average of 16 inches of snowfall. Temperatures in the Missouri portion reach an average maximum of 85°F in the summer, with an average low of 64°F, and an average maximum of 38°F in the winter, with an average low of 19°F as shown in **Table 2-10.**

**Table 2-10. Chariton-Grand Subregion Climate Data[1]**

| Mean Annual Rainfall (inches) | Mean Annual Snowfall (inches)[2] | Mean Maximum Summer (June–August) Temp (°F) | Mean Minimum Summer (June–August) Temp (°F) | Mean Maximum Winter (December–February) Temp (°F) | Mean Minimum Winter (December–February) Temp (°F) |
|---|---|---|---|---|---|
| 41 | 16 | 85 | 64 | 38 | 19 |

[1]NOAA 2018b
[2]U.S. Climate Data 2018

## Land Use

The Chariton-Grand subregion in Missouri is primarily agricultural, with 44.3 percent of the subregion used for pasture and hay and 25.9 percent used for cultivated crops, as shown in **Table 2-11**. Additionally, 17.8 percent is deciduous forest.

The portion of the Chariton-Grand subregion in Missouri includes several urban clusters including Bethany, Brookfield, Cameron, Chillicothe, Kirksville, Macon, Moberly, and Trenton (NRCS 2015).

**Table 2-11. Chariton-Grand Land Use Data[1]**

| Land Cover | Land Use Area within Missouri (Acres) | Percent Cover (%) |
|---|---|---|
| Open Water | 56,840 | 1.1% |
| Developed, Open Space | 188,023 | 3.5% |
| Developed, Low Intensity | 63,975 | 1.2% |
| Developed, Medium Intensity | 6,267 | 0.1% |
| Developed, High Intensity | 1,512 | <0.1% |
| Barren Land (Rock/Sand/Clay) | 3,555 | 0.1% |
| Deciduous Forest | 944,532 | 17.8% |
| Evergreen Forest | 3,077 | 0.1% |
| Mixed Forest | 34,599 | 0.7% |
| Shrub/Scrub | 35,099 | 0.7% |
| Grassland/Herbaceous | 110,482 | 2.1% |
| Pasture/Hay | 2,358,502 | 44.3% |
| Cultivated Crops | 1,376,425 | 25.9% |
| Woody Wetlands | 124,347 | 2.3% |
| Emergent Herbaceous Wetlands | 11,997 | 0.2% |
| **Total** | **5,319,231** | **100.0%** |

[1]USGS 2014

## 2.4.6 Gasconade-Osage Subregion

The Gasconade-Osage subregion (HUC 1029) is in west-central Missouri, south of the Missouri River. The subregion is 18,603 square miles, 14,301 square miles of which are in Missouri, or 77 percent of the subregion (USGS and NRCS 2018). The remainder of the subregion is in eastern Kansas. Major tributaries include the Osage River, South Grand River, Pomme de Terre River, Sac, and Gasconade River. The Osage and South Grand rivers flow generally east to the Missouri River, whereas the Pomme de Terre and Sac rivers flow north into the Osage. The Gasconade River generally flows north into the Missouri River.

## Climate

The entirety of the Gasconade-Osage subregion is classified as warm temperate, fully humid, hot summer (Cfa), according to the Köppen-Geiger climate Classification (CCID 2018).

The subregion receives an average of 45 inches of rainfall each year and an average of 12 inches of annual snowfall. Temperatures in the Missouri portion reach an average maximum of 87˚F in the summer, with an average low of 66˚F, and an average maximum of 43˚F in the winter, with an average low of 23˚F as shown in **Table 2-12**.

**Table 2-12. Gasconade-Osage Subregion Climate Data[1]**

| Mean Annual Rainfall (inches) | Mean Annual Snowfall (inches)[2] | Mean Maximum Summer (June–August) Temp (°F) | Mean Minimum Summer (June–August) Temp (°F) | Mean Maximum Winter (December–February) Temp (°F) | Mean Minimum Winter (December–February) Temp (°F) |
|---|---|---|---|---|---|
| 45 | 12 | 87 | 66 | 43 | 23 |

[1]NOAA 2018b
[2]U.S. Climate Data 2018

## Land Use

In Missouri, the Gasconade-Osage subregion is primarily agricultural, with 36.1 percent of the subregion used for pasture and hay and an additional 8.9 percent used for cultivated crops, as shown in **Table 2-13**. An additional 40.7 percent is deciduous forest.

The Gasconade-Osage subregion includes several urban clusters in Missouri, including Bolivar, Buffalo, Butler, Camdenton, Clinton, El Dorado Springs, Eldon, Fort Leonard Wood, Harrisonville, Lebanon, Marshfield, Mountain Grove, Nevada, Osage Beach, Owensville, Pleasant Hill, Rolla, Village of Four Seasons, Warsaw, Willard, and Windsor. The subregion also contains two shared urbanized areas: Lee's Summit, which is split across this subregion and the Lower Missouri subregion, and Springfield, which is split between this subregion and the Upper White subregion (NRCS 2015).

**Table 2-13. Gasconade-Osage Subregion Land Use Data[1]**

| Land Cover | Land Use Area within Missouri (Acres) | Percent Cover (%) |
|---|---:|---:|
| Open Water | 183,554 | 2.0% |
| Developed, Open Space | 375,530 | 4.1% |
| Developed, Low Intensity | 104,919 | 1.1% |
| Developed, Medium Intensity | 24,437 | 0.3% |
| Developed, High Intensity | 7,705 | 0.1% |
| Barren Land (Rock/Sand/Clay) | 14,850 | 0.2% |
| Deciduous Forest | 3,723,338 | 40.7% |
| Evergreen Forest | 156,738 | 1.7% |
| Mixed Forest | 80,682 | 0.9% |
| Shrub/Scrub | 48,741 | 0.5% |
| Grassland/Herbaceous | 127,882 | 1.4% |
| Pasture/Hay | 3,313,860 | 36.1% |
| Cultivated Crops | 814,879 | 8.9% |
| Woody Wetlands | 157,472 | 1.7% |
| Emergent Herbaceous Wetlands | 23,957 | 0.3% |
| **Total** | **9,158,544** | **100.0%** |

[1]USGS 2014

## 2.3.7 Lower Missouri Subregion

The Lower Missouri subregion (HUC 1030) is in central Missouri, extending from Kansas City in the west to St. Louis in the east. The subregion is 10,341 square miles, 10,182 square miles of which are in Missouri, or 98 percent of the subregion (USGS and NRCS 2018). The remainder is in eastern Kansas. The principle tributary within the subregion is the Missouri River, which flows east to the Mississippi River.

## Climate

The majority of the Lower Missouri subregion is classified as warm temperate, fully humid, hot summer (Cfa), according to the Köppen-Geiger climate classification, but there is small portion to the northwest that is classified as continental, fully humid, hot summer (Dfa) (CCID 2018).

The subregion receives an average of 43 inches of rainfall each year with an average of 15 inches of annual snowfall. Temperatures in the Missouri portion reach an average maximum of 86°F in the summer, with an average low of 65°F, and an average maximum of 41°F in the winter, with an average low of 22°F as shown in **Table 2-14**.

**Table 2-14. Lower Missouri Subregion Climate Data[1]**

| Mean Annual Rainfall (inches) | Mean Annual Snowfall (inches)[2] | Mean Maximum Summer (June–August) Temp (°F) | Mean Minimum Summer (June–August) Temp (°F) | Mean Maximum Winter (December–February) Temp (°F) | Mean Minimum Winter (December–February) Temp (°F) |
|---|---|---|---|---|---|
| 43 | 15 | 86 | 65 | 41 | 22 |

[1]NOAA 2018b
[2]U.S. Climate Data 2018

## Land Use

The Lower Missouri subregion is primarily agricultural, with 29.3 percent used for pasture and hay and 27.0 percent used for cultivated crops, as shown in **Table 2-15**. Additionally, 26.9 percent is deciduous forest.

The Lower Missouri subregion includes several urban clusters in Missouri, including Ashland, Boonville, Buckner, California, Carrollton, Eldon, Excelsior Springs, Fayette, Fulton, Higginsville, Jefferson City, Kearney, Lexington, Marshall, Odessa, Richmond, Sedalia, Tipton, Warrensburg, Warrenton, Washington, and Whiteman Air Force Base. The subregion also contains four urbanized areas in Missouri, including Columbia, Kansas City, Lee's Summit, and St. Louis (NRCS 2015). Lee's Summit is split between this subregion and the Gasconade-Osage subregion.

**Table 2-15. Lower Missouri Subregion Land Use Data[1]**

| Land Cover | Land Use Area within Missouri (Acres) | Percent Cover (%) |
|---|---|---|
| Open Water | 100,409 | 1.5% |
| Developed, Open Space | 342,857 | 5.3% |
| Developed, Low Intensity | 225,886 | 3.5% |
| Developed, Medium Intensity | 79,540 | 1.2% |
| Developed, High Intensity | 34,950 | 0.5% |
| Barren Land (Rock/Sand/Clay) | 10,601 | 0.2% |
| Deciduous Forest | 1,750,817 | 26.9% |
| Evergreen Forest | 41,078 | 0.6% |
| Mixed Forest | 29,195 | 0.4% |
| Shrub/Scrub | 24,673 | 0.4% |
| Grassland/Herbaceous | 80,827 | 1.2% |
| Pasture/Hay | 1,913,277 | 29.3% |
| Cultivated Crops | 1,762,112 | 27.0% |
| Woody Wetlands | 107,679 | 1.7% |
| Emergent Herbaceous Wetlands | 16,469 | 0.3% |
| **Total** | **6,520,374** | **100.0%** |

[1]USGS 2014

### 2.4.8 Upper White Subregion

The Upper White subregion (HUC 1101) is in southern Missouri, south of the Gasconade-Osage subregion. The subregion is 22,337 square miles, 10,606 square miles of which are in Missouri, or 47 percent of the subregion (USGS and NRCS 2018). The remainder is in northern Arkansas. Major rivers include the Current and Black rivers, which flow south to the White River. The White River flows to the southeast through Arkansas to meet the Mississippi River.

#### Climate

The entirety of the Upper White subregion is classified as warm temperate, fully humid, hot summer (Cfa), according to the Köppen-Geiger climate classification (CCID 2018).

The subregion receives an average of 46 inches of rainfall each year and an average of 10 inches of snowfall. In the Missouri portion, temperatures reach an average of 87°F in the summer, with an average low of 65°F, and an average maximum of 45°F in the winter, with an average low of 24°F as shown in **Table 2-16**.

**Table 2-16. Upper White Subregion Climate Data[1]**

| Mean Annual Rainfall (inches) | Mean Annual Snowfall (inches)[2] | Mean Maximum Summer (June–August) Temp (°F) | Mean Minimum Summer (June–August) Temp (°F) | Mean Maximum Winter (December–February) Temp (°F) | Mean Minimum Winter (December–February) Temp (°F) |
|---|---|---|---|---|---|
| 46 | 10 | 87 | 65 | 45 | 24 |

[1]NOAA 2018b
[2]U.S. Climate Data 2018

#### Land Use

In Missouri, the Upper White subregion is primarily forested, with 56.4 percent deciduous forest, as shown in **Table 2-17**. There is also significant agricultural land use, with 22.9 percent used for pasture and hay.

The Upper White subregion includes several urban clusters in Missouri, including Ava, Branson, Cassville, Forsyth, Kimberling City, Poplar Bluff, Rogersville, Thayer, and West Plains. The subregion also contains most of the urbanized area of Springfield (NRCS 2015).

**Table 2-17. Upper White Subregion Land Use Data[1]**

| Land Cover | Land Use Area within Missouri (Acres) | Percent Cover (%) |
|---|---:|---:|
| Open Water | 67,285 | 1.0% |
| Developed, Open Space | 249,258 | 3.7% |
| Developed, Low Intensity | 71,345 | 1.1% |
| Developed, Medium Intensity | 26,053 | 0.4% |
| Developed, High Intensity | 8,578 | 0.1% |
| Barren Land (Rock/Sand/Clay) | 11,720 | 0.2% |
| Deciduous Forest | 3,832,301 | 56.4% |
| Evergreen Forest | 294,577 | 4.3% |
| Mixed Forest | 261,259 | 3.8% |
| Shrub/Scrub | 40,272 | 0.6% |
| Grassland/Herbaceous | 111,065 | 1.6% |
| Pasture/Hay | 1,555,976 | 22.9% |
| Cultivated Crops | 210,507 | 3.1% |
| Woody Wetlands | 48,963 | 0.7% |
| Emergent Herbaceous Wetlands | 1,085 | <0.1% |
| **Total** | **6,790,244** | **100.0%** |

[1]USGS 2014

## 2.4.9 Neosho-Verdigris Subregion

The Neosho-Verdigris subregion (HUC 1107) is in the southwestern corner of Missouri and includes portions of Kansas, Oklahoma, and Arkansas. The subregion is 20,804 square miles, 2,908 of which are in Missouri, or 14 percent of the subregion (USGS and NRCS 2018). Major rivers include the Elk and Spring rivers, both of which generally flow west to the Neosho River.

### Climate

The entirety of the Neosho-Verdigris subregion is classified as warm temperate, fully humid, hot summer (Cfa), according to the Köppen-Geiger climate classification (CCID 2018).

The subregion receives an average of 47 inches of rainfall each year with an average of 10 inches of snowfall. Temperatures in the Missouri portion reach an average maximum of 87°F in the summer, with an average low of 65°F, and an average maximum of 46°F in the winter, with an average low of 25°F as shown in **Table 2-18**.

**Table 2-18. Neosho-Verdigris Subregion Climate Data[1]**

| Mean Annual Rainfall (inches) | Mean Annual Snowfall (inches)[2] | Mean Maximum Summer (June–August) Temp (°F) | Mean Minimum Summer (June–August) Temp (°F) | Mean Maximum Winter (December–February) Temp (°F) | Mean Minimum Winter (December–February) Temp (°F) |
|---|---|---|---|---|---|
| 47 | 10 | 87 | 65 | 46 | 25 |

[1]NOAA 2018b
[2]U.S. Climate Data 2018

### Land Use

In Missouri, the Neosho-Verdigris subregion is primarily agricultural, with 50.3 percent used for pasture and hay and 12.1 percent used for cultivated crops, as shown in **Table 2-19**. There is also a significant amount of forest, with 26.6 percent deciduous forest,

The Missouri portion of the Neosho-Verdigris subregion includes the urban clusters of Aurora, Carthage, Cassville, Lamar, Monett, Mount Vernon, and Neosho, and the urbanized area of Joplin (NRCS 2015).

**Table 2-19. Neosho-Verdigris Subregion Land Use Data[1]**

| Land Cover | Land Use Area within Missouri (Acres) | Percent Cover (%) |
|---|---|---|
| Open Water | 4,657 | 0.3% |
| Developed, Open Space | 90,585 | 4.9% |
| Developed, Low Intensity | 35,518 | 1.9% |
| Developed, Medium Intensity | 11,013 | 0.6% |
| Developed, High Intensity | 5,148 | 0.3% |
| Barren Land (Rock/Sand/Clay) | 4,765 | 0.3% |
| Deciduous Forest | 495,151 | 26.6% |
| Evergreen Forest | 3,430 | 0.2% |
| Mixed Forest | 720 | <0.1% |
| Shrub/Scrub | 5,796 | 0.3% |
| Grassland/Herbaceous | 20,846 | 1.1% |
| Pasture/Hay | 936,769 | 50.3% |
| Cultivated Crops | 225,849 | 12.1% |
| Woody Wetlands | 21,328 | 1.1% |
| Emergent Herbaceous Wetlands | 582 | <0.1% |
| **Total** | **1,862,157** | **100.0%** |

[1]USGS 2014

## 2.5 Groundwater Province Descriptions

Groundwater provinces are delineated in Missouri based on aquifer boundaries, aquifer types, groundwater quality, and distinct geologic features. There are seven distinct groundwater provinces defined in Missouri, as shown in **Figure 2-5**. These seven groundwater provinces include the St. Francois Mountains, Salem Plateau, Springfield Plateau, Southeastern Lowlands, Northeastern Missouri, Northwestern Missouri, and West-central Missouri. The alluvial valleys of the Mississippi and the Missouri rivers are distinct subprovinces located in and across the seven primary groundwater provinces found in the state. The following sections characterize the geology, hydrogeology and groundwater contamination potential of the provinces and subprovinces.

An **aquifer** is a body of rock that is sufficiently permeable to conduct groundwater and to yield economically significant quantities of water to wells and springs.

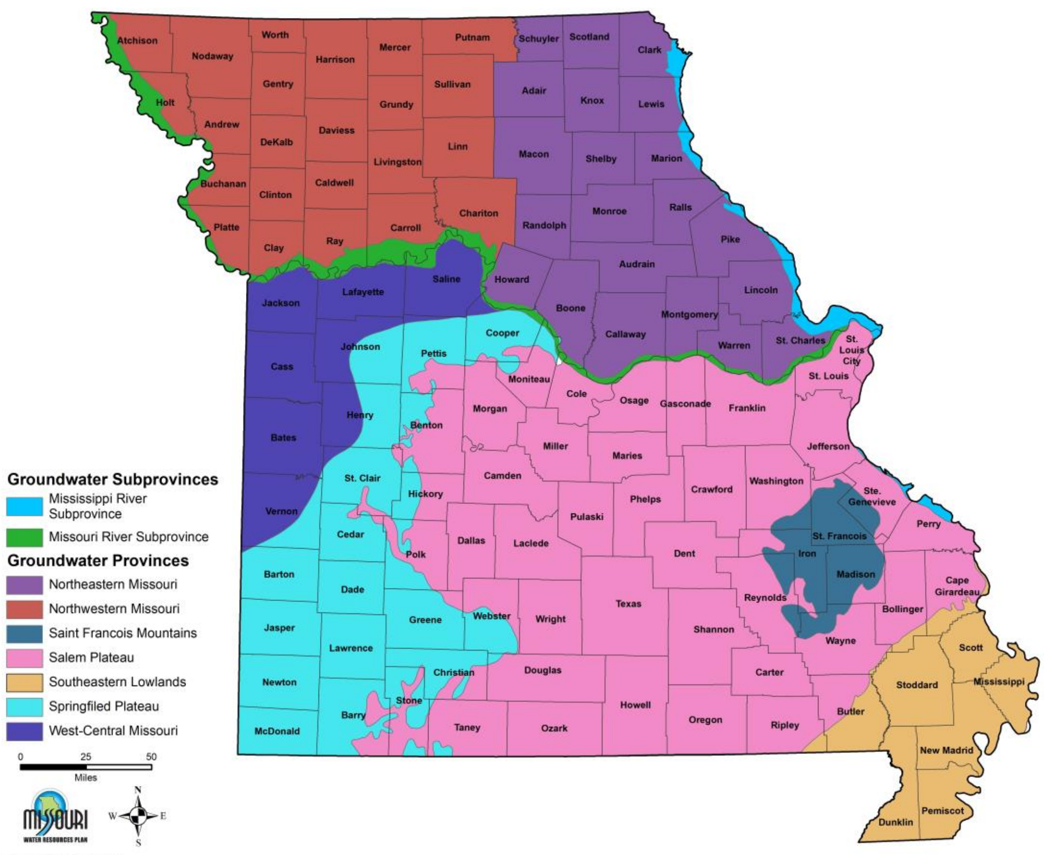


**Figure 2-5. Groundwater Provinces of Missouri**

### 2.5.1 St. Francois Mountains Groundwater Province

The St. Francois Mountains province is associated with the highest elevations in Missouri. Precambrian igneous rock and Upper Cambrian-age clastic and carbonate units make up the rock outcropping in this area. The core of the St. Francois Mountains is made up of Precambrian igneous rock while younger sedimentary units dip or tilt away from the core. This gradual dip in sedimentary units results in a progressive deepening as distance from the St. Francois Mountains increases. The groundwater province is approximately 1,300 square miles in area and includes all or parts of Iron, Madison, Reynolds, St. Francois, Ste. Genevieve, Wayne, and Washington counties (Miller and Vandike 1997).

### Geology

Sedimentary rock deposition in the Ozarks began in the latter part of the Cambrian Period when the seas transgressed over the Ozark region. Deposition continued through the remainder of the Cambrian and the Lower Ordovician Periods. While the entire midcontinent was submerged in vast inland seas, the Precambrian igneous rocks of the St. Francois Mountains, which form the core of the Ozark uplift, were emergent. Over time, erosion caused the emergent igneous rocks to break down into sand and small rock fragments. Eventually, the core was eroded to a point where the uplift became submerged and the moving seas allowed for the deposition of younger sediment. Over time, uplift of the Ozark Dome, and subsequent erosion, resulted in reemergence of some of the igneous rock formations that are now the St. Francois Mountains.

Precambrian rocks underlie all of Missouri and outcrop mostly in the St. Francois Mountains, representing the oldest exposed rocks in the state. Most of the exposed Precambrian igneous rocks consist of either rhyolites or granites (University of Missouri Extension Agricultural Electronic Bulletin Board [AgEBB] 2018). Rapid cooling of magma on the Earth's surface formed extrusive rhyolites while intrusive granites formed where magma could cool more slowly. Both the rhyolites and granites contain mafic igneous rocks (diabase and basalt) in the form of vertical dikes and horizontal sills.

The Cambrian System is made up of stratigraphic sections, including Lamotte Sandstone, Bonneterre Formation, Davis Formation, Derby-Doerun Dolomite, Potosi Dolomite, and Eminence Dolomite. Refer to **Appendix A**, **Table A-1** for a detailed depiction of all stratigraphic sediment layers within the province.

### Hydrogeology

The basement confining unit of Precambrian igneous rocks in this region may potentially yield small amounts of water through secondary permeability produced by fracturing. In these areas, residents are forced either to construct a well (water yield through fracturing) or depend on cisterns and hauled water for their supply.

The major aquifer system of the St. Francois Mountains groundwater province is the St. Francois Aquifer. The Lamotte Sandstone and overlying Bonneterre Formation of this aquifer are composed of sediment-filled basins with high permeability and high potential water yields. The St. Francois Aquifer is bounded below by the Precambrian igneous rocks that form the basement confining unit. In places where the Davis Formation and Derby-Doerun Dolomite are present, there is an upper confining unit called the St. Francois Confining Unit that results in the potential for artesian conditions. In this province, most private and public water supply wells acquire water from the St. Francois Aquifer. The St. Francois Aquifer in the St. Francois groundwater province contains over 900 billion gallons of usable groundwater storage and has the potential to yield as much as 400 gallons per minute (gpm) per drilled well, but averages around 60 to 150 gpm. However, low vertical hydraulic conductivity and limited horizontal circulation within portions of the aquifer may reduce potential groundwater yields and are important aspects to consider when determining yield capabilities of proposed wells.

The Ozark Aquifer in the St. Francois Mountains area is typically unconfined and consists of the Potosi and Eminence dolomites. Due to its relatively high topographic and stratigraphic positioning, the saturated thickness of the Ozark Aquifer is generally less than its total thickness, and well yields are correspondingly low. The aquifer supplies numerous private domestic wells in this province, but large quantities of water are generally not available from this aquifer.

## 2.5.2 Salem Plateau Groundwater Province

The Salem Plateau groundwater province is the largest in the state and in the Ozarks region. A total of 49 counties fall within this province that encompasses a total area of approximately 24,760 square miles. The province includes two aquifer systems, the Ozark Aquifer and the St. Francois Aquifer.

## Geology

A total of 17 stratigraphic formations are present within the Salem Plateau groundwater province, ranging from the Cambrian to Pennsylvanian systems. Refer to **Appendix A**, **Table A-2** for a detailed depiction of all stratigraphic units within the province. The Cambrian begins with the Lamotte Sandstone, which sits unconformably on the Precambrian basement rocks. The Lamotte is a water-bearing unit with the potential to yield moderate quantities of water. In order from bottom to top, the Bonneterre Formation, Davis Formation, Derby-Doerun Dolomite, Potosi Dolomite, and Eminence Dolomite sit atop the Lamotte Sandstone unit and make up the rest of the Cambrian-age formations. The system is primarily comprised of dolomite, sandstone, shale, and limestone conglomerates of varying grain size and color. The Davis Formation and the Derby-Doerun Dolomite make up the St. Francois Confining Unit that separates the deeper St. Francois Aquifer from the shallow Ozark Aquifer.

The Ordovician System lies above the Cambrian and includes six major formations. Lithologically, grain sizes are fine to medium sandy dolomites with some coarse crystalline dolomite and sandstone, making it an ideal water-bearing system. Most of the Ozark Aquifer falls within the Ordovician System, with the exception of the Cambrian-age Potosi and Emincence dolomites. The formations, in order from bottom to top, include the Gasconade Dolomite (including the Gunter Sandstone, Lower Gasconade, and Upper Gasconade members), Roubidoux Formation, Jefferson City Dolomite, Cotter Dolomite, Everton Formation, and St. Peter Sandstone. Overlying the St. Peter Sandstone are several other Ordovician through Mississippian-age formations whose occurrence is location dependent. These formations are generally only present along the eastern part of the province.

The Pennsylvanian Subsystem is the youngest bedrock formation in the province. It includes a layer of undifferentiated sandstone, shale, and thin, interbedded limestone up to 100 feet thick that overlies the Ordovician and Mississippian systems. The Pennsylvanian rocks have a limited outcrop area in the northern portion of the province.

## Hydrogeology

Groundwater yields vary throughout the Salem Plateau groundwater province, depending on the drill location and depth of the well. Generally, the deeper wells will produce higher yields than shallower wells in the same location. There are two aquifers present within this province: the deep St. Francois Aquifer and the shallow Ozark Aquifer.

The St. Francois Aquifer is a mostly confined aquifer system that underlies all of the Salem Plateau. Depth to the top of the aquifer ranges from less than 500 feet near the St. Francois Mountains to more than 5,000 feet in extreme eastern Missouri in Cape Girardeau and Perry counties. The total aquifer thickness varies from less than 100 feet near the Precambrian igneous highs to approximately 1,100 feet at the edge of the Ozark Escarpment. The St. Francois Aquifer is confined above by the low permeability Davis Formation and Derby-Doerun Dolomite of the St. Francois Confining Unit and below by the Precambrian basement confining unit. Recharge to the St. Francois Aquifer originates from two sources: the outcrop region in the St. Francois Mountains and the slow downward moving water coming from the Ozark Aquifer through a leaky confining unit. Water yields from wells producing from the St. Francois Aquifer normally range from 70 to 125 gpm (University of Missouri Extension AgEBB 2018). However, this aquifer system is generally not used as a water source due to its depth and the presence of usable, shallower aquifers, except near the St. Francois Mountains in the eastern part of the province.

The Ozark Aquifer is the most important and widely used aquifer system in the Salem Plateau. The Ozark Aquifer crops out throughout the Salem Plateau, and its thickness varies from approximately 200 feet near the St. Francois Mountains to as much as 2,000 feet along the Arkansas border near the Bootheel. Recharge for this aquifer system is primarily from precipitation infiltration through the highly permeable carbonate bedrock. Additionally, the surface and subsurface weathering of the carbonates has created numerous karst groundwater-recharge features like sinkholes and losing streams that allow for rapid movement of water from the surface to subsurface. Average yearly recharge rates range from a few inches to as much as 14 inches per year (in/yr). Well yields vary, depending on the well location and depth but can range anywhere from 5 to over 1,000 gpm. The Salem Plateau also features thousands of springs and outlet points for groundwater moving through karst groundwater systems to the surface. Just over half of Missouri's springs are located within the Salem Plateau groundwater province, most of which are connected to the Ozark Aquifer.

### 2.5.3 Springfield Plateau Groundwater Province

The Springfield Plateau groundwater province, located in the southwestern and west-central part of the state, includes all or parts of 27 counties in Missouri. The province covers approximately 8,900 square miles and is bounded on the east by the Eureka Springs Escarpment, to the northwest by the fresh- to saline-water transition zone, and to the south and southwest by parts of Arkansas, Oklahoma, and Kansas.

#### Geology

The geologic characteristics of the Springfield Plateau and the Salem Plateau are similar. They differ in that the Springfield Plateau has a thick sequence of Mississippian-age rocks that overlie the Ordovician System in southwestern Missouri. Refer to **Appendix A**, **Table A-3** for a detailed depiction of all stratigraphic sediment layers within the province. These Mississippian rocks are primarily limestone and weather differently than dolomites. This results in the development of different types of karst than what is seen in the Salem Plateau. The extensive weathering seen in the Salem Plateau is absent in this province, resulting in a smaller groundwater conduits. This has resulted in many more springs that are smaller in size. Additionally, many caves have developed with openings within sinkholes rather than in bluffs or hillsides as in the Salem Plateau.

The deep weathering of the Salem Plateau is generally absent in the Springfield Plateau, and structural features, such as faults, folds, and fractures, are much more visible in the Springfield Plateau. Thick mantles or residual materials that generally obscure the structural features in the Salem Plateau are generally absent in the Springfield Plateau. Faulting is commonly the result of crustal movements that displace adjacent blocks or bodies of rock in relation to one another. This displacement causes shattering and fracturing of the rock units adjacent to the fault plane. Wells constructed next to or near major fault systems in this and other groundwater provinces will generally have higher water yields due to the increased water movement capabilities through fractured rock. However, these wells are also more likely to encounter weathered materials, such as mud or clay, and have a higher likelihood of having construction or water quality problems.

#### Hydrogeology

As in the Salem Plateau, the St. Francois Aquifer in the Springfield Plateau consists of the Bonneterre Formation and the Lamotte Sandstone. Because of its depth and the generally adequate yields from shallower aquifers, the St. Francois Aquifer is not commonly used within this province. However, groundwater reserves within the St. Francois Aquifer in the Springfield Plateau province are estimated to be approximately 4.1 trillion gallons.

The Ozark Aquifer is a confined aquifer located throughout most of the Springfield Plateau. In terms of yield, this aquifer is the most prolific in the southwestern part of the state and provides municipal, industrial, and agricultural water supply. Artesian conditions may be present in wells that are cased in the Springfield Aquifer and completed in the Ozark Aquifer below. Joplin, Neosho, and Springfield primarily use surface water to meet their water supply needs; however, the Ozark Aquifer offers emergency sources of water or supplemental water when necessary. Fully penetrating Ozark Aquifer wells in the Springfield Plateau generally yield 200 to 2,000 gpm (University of Missouri Extension AgEBB 2018). Lower yields generally occur in western Missouri from Joplin south to McDonald County. The highest yields from this aquifer occur in the northwestern part of the province and in the Springfield area. Due to the high usage of groundwater from the Ozark Aquifer, lowering of the groundwater table has occurred in some areas. Drawdown of the groundwater table may locally decrease the saturated thickness of the Ozark Aquifer and thus its transmissivity. As transmissivity decreases, well yields may decrease while pumping costs may increase.

The Springfield Plateau Aquifer in southwestern Missouri, which ranges in thickness from 0 to 450 feet and can produce up to 20 gpm (University of Missouri Extension AgEBB 2018), is unconfined throughout most of the region and recharged primarily by precipitation in the outcrop area. Diffuse recharge moving through residual materials likely adds more water to storage than does discrete recharge from losing streams or through sinkholes. Recharge of this aquifer system in the western part of the province is restricted by the low permeability Pennsylvanian deposits. In localized areas of the Springfield Plateau Aquifer along the western edge of the province, elevated levels of total dissolved solids and hydrogen sulfide gas have been observed. Substantial karst, cave, and cavern development have a profound impact on the speed and direction of water movement throughout this aquifer system. An estimated 5.7 trillion gallons of groundwater are stored within the Springfield Plateau Aquifer. The majority of wells that withdraw groundwater from the Springfield Plateau Aquifer are for private domestic and farm water supplies.

### 2.5.4 Southeastern Lowlands Groundwater Province

The Southeastern Lowlands groundwater province is in the southeastern portion of the state and encompasses approximately 3,916 square miles. The Southeastern Lowlands in Missouri makes up the northern portion of the Mississippi Alluvial Plain and is bounded on the north and west by the bedrock formations cropping out along the Ozark Escarpment and on the east by the Mississippi. The area is nearly flat with fertile alluvial soils and a warm, moist climate, making this one of the more productive agricultural regions in Missouri. Although this province only makes up about 6 percent of the state, it contains approximately 15 percent of usable groundwater (Miller and Vandike 1997).

#### Geology

Much of the Southeastern Lowlands groundwater province is underlain by Quaternary-age alluvial sediments deposited by the ancestral and modern Mississippi and Ohio river systems on top of older Tertiary, Cretaceous, and Paleozoic strata. Refer to **Appendix A**, **Table A-4** for a detailed depiction of all stratigraphic sediment layers within the province. The province is considered the most structurally active and complex area of the state and has experienced extreme structural downwarping and deformation. This structural subsidence created a trough in Missouri that is greatest in the extreme southeastern corner of the state. This trough formed during the Cretaceous period and led to thickened Tertiary deposits.

#### Hydrogeology

There are five separate and distinct aquifers in the Southeastern Lowlands groundwater province, with different hydrogeologic characteristics. Two of the aquifers consist of Paleozoic consolidated rock units while the other three are comprised mostly of younger, unconsolidated sediments. The Paleozoic bedrock aquifers include the Ozark Aquifer and the St. Francois Aquifer. The Ozark Aquifer is generally only utilized between Crowley's Ridge and the Ozark Escarpment. Little is known about the St. Francois Aquifer in this province because of its great depth and the presence of ample water in numerous shallower aquifer zones. Yields for both Paleozoic aquifers vary depending on location, depth, and zones open to the aquifer.

The McNairy Aquifer underlies 3,328 square miles, or nearly 85 percent of the Southeastern Lowlands groundwater province. This aquifer is widely used for municipal water because it is under considerable artesian head in some areas and the potentiometric surface can be several feet above ground level. These characteristics make is easy to access. Water quality in the McNairy Aquifer is typically good; however, a large area in southeastern Stoddard County and most of New Madrid County have total dissolved solids and chloride levels that exceed drinking water standards. Yields of wells penetrating the McNairy range from approximately 150 to 750 gpm (University of Missouri Extension AgEBB 2018). The McNairy Aquifer receives recharge from precipitation at the Crowley's Ridge outcrops and from overlying alluvium west of Crowley's Ridge. The total volume of potable water stored in the McNairy Aquifer is estimated to be about 12.1 trillion gallons.

The Wilcox Aquifer underlies an area of 2,346 square miles, or about 60 percent of the Southeastern Lowlands groundwater province. The aquifer system is composed of mostly sand, but clay and lignite beds in the formation reduce hydraulic conductivity in parts. Generally, the lowest 250 to 400 feet of the formation contain the greatest quantity of clean sand. Properly constructed wells penetrating the Wilcox generally yield from approximately 200 to as much as 1,700 gpm (University of Missouri Extension AgEBB 2018). Iron and manganese levels tend to be higher than drinking water standards within this aquifer and treatment is necessary before use as a drinking water source. The Wilcox Aquifer likely contains a greater volume of fresh water—an estimated 31.9 trillion gallons—than any other aquifer in southeastern Missouri.

The alluvial aquifers of the Southeastern Lowlands groundwater province are the most widely used aquifer systems in the region. The alluvium underlies about 92 percent of the province (University of Missouri Extension AgEBB 2018), covering an area of approximately 3,677 square miles. High levels of dissolved iron are present in the alluvial aquifer in this area and treatment is often required before use for drinking water purposes. Groundwater is stored and transmitted in the alluvium through intergranular pore spaces. The gradient of the water table is generally south and low. Well yields depend on the saturated thickness of the alluvium, the diameter of the well, the length of the well screen, and the hydraulic conductivity of the alluvial materials. Properly located and constructed wells generally yield 500 to 3,000 gpm. The alluvial aquifer receives most of its recharge from precipitation and is generally greatest where the surficial materials contain high proportions of sandy sediments compared to silt or clay. The greatest use of water is for agricultural irrigation in this area; however, private wells and public water supply wells also tap the aquifer. An estimated 19.5 trillion gallons of groundwater is stored in the alluvium.

### 2.5.5 Mississippi River Alluvium

The Mississippi River Alluvium exists along the Mississippi River in the Southeastern Lowlands groundwater province and to the north in eastern parts of Clark, Lewis, Lincoln, Marion, Perry, Pike, St. Charles, St. Louis, and Ste. Genevieve counties. The alluvial aquifer underlies the floodplains of the Mississippi River and encompasses a total surface area of approximately 440 square miles in Missouri, excluding the portions in the Bootheel.

#### Geology

Where present, the alluvium thickness ranges from a featheredge to approximately 170 feet. The thickest portions are generally adjacent to the Mississippi River. The meandering of the Mississippi River over time has caused significant variability in the sedimentary stratigraphy. The composition of the Mississippi River Alluvium is similar to the Southeastern Lowlands groundwater province, with primarily sand, gravel, silt, and clay deposits of varying particle size present throughout. Due to the significant variability of sediment throughout the province, the alluvium can be characterized by county. Refer to **Appendix A**, **Table A-5** for a detailed depiction of all stratigraphic sediment layers within the province.

#### Hydrogeology

The Mississippi River Alluvial Aquifer is capable of producing yields of up to 2,000 gpm in localized areas, but due to its relatively small geographic distribution, it is not considered a major water source in Missouri. The majority of water wells utilizing the Mississippi River Alluvial Aquifer are used for private water supply, municipal uses, or for irrigation.

### 2.5.6 Missouri River Alluvium

The Missouri River Alluvial Aquifer is a widely used water resource in the state. Nearly all 25 counties bordering the Missouri River use water from the alluvial aquifer in some capacity. The alluvial aquifer underlies the Missouri River floodplain, and reaches a maximum width of about 12 miles, with the widest portions in Carroll and Chariton counties. The aquifer begins in extreme northwestern Missouri and ends at its confluence with the Mississippi River at the eastern edge of the state.

#### Geology

The Missouri River Alluvial Aquifer is confined is some areas, and unconfined in others. Confining layers consist of 20 to 30 feet of low-permeability sediment layers of clay and silt. In some areas, the confining layers may be below the potentiometric surface, causing artesian conditions. In other areas, the clay and silt layers are thin, and the uppermost alluvial materials contain sandy, highly permeable sediments where unconfined conditions exist. The alluvial materials of the Missouri River Valley include clays, silts, fine to coarse sands, and fine to medium gravel. Particle size generally increases with depth, with finer-grained materials present primarily close to the surface. These relatively impermeable surface caps result in slower infiltration rates and lower rates of recharge from precipitation. Alluvium thickness ranges from a featheredge at the edge of the valley to as much as 150 feet near the center of the valley near the Missouri River.

The Missouri River Alluvial Valley is separated into four reaches based on USGS surveys. These reaches include the Iowa border to Kansas City, Kansas City to Miami in Saline County, Miami to Jefferson City, and Jefferson City to St. Charles. Refer to **Appendix A**, **Table A-6** for a detailed depiction of all stratigraphic sediment layers within the province.

#### Hydrogeology

Water wells drilled into the Missouri River Alluvial Aquifer are generally used by rural water districts, towns, and cities including Colombia, Independence, Kansas City, and St. Charles. Additionally, hundreds of high-yield water wells are also used for irrigation. This groundwater resource has a strong surface water connection with the Missouri River; therefore, most water table changes are dependent on fluctuations in surface water. Under normal flow conditions, the groundwater gradient in the alluvial aquifer flows toward the Missouri River at low velocities. Low velocity groundwater movement in this aquifer is due to intergranular flow rather than water flow through sediment voids, cracks, or crevices.

Aquifer recharge is primarily from the Missouri River, from the bedrock adjacent to and underlying the alluvium, from precipitation that falls within the floodplain area, and from downward leakage from other streams flowing across the alluvium. The total volume of water stored in the Missouri River Alluvial Aquifer is estimated to be about 3.3 trillion gallons, with the greatest volume of storage present in Holt County where the alluvial aquifer underlies an area of about 182 square miles. Gasconade County contains the lowest volume of groundwater where only about 7 square miles of alluvium are present and about 18 billion gallons of water storage is available. In general, only a small portion of the available groundwater stored within this aquifer is being used.

### 2.5.7 Northwestern Missouri Groundwater Province

The Northwestern Missouri groundwater province consists of all or portions of 23 counties and encompasses an area of approximately 12,117 square miles in northern Missouri. Groundwater resources are less available in the northern half of the state compared to the Ozarks and Southeastern Lowlands groundwater province, primarily because water-bearing layers are significantly deeper and more difficult to access. Additionally, bedrock groundwater in the northern portion of Missouri tends to have higher mineralization and salinity levels compared to other groundwater provinces, limiting its potential uses.

### Geology

Most of this groundwater province is covered by thick Pleistocene-age glacial sediments and recent alluvial deposits. Pennsylvanian-age and older bedrock formations are present within the deeper stratigraphic layers. In some areas, the lithology consists of mostly sand and to a lesser extent gravel. Refer to **Appendix A**, **Table A-7** for a detailed depiction of all stratigraphic sediment layers within the province. Erosion in localized areas has removed the glacial deposits of sand and gravel, leaving Pennsylvanian bedrock visible at the surface.

### Hydrogeology

The stratigraphic and geomorphic characteristics of this province are generally complex and site-specific. Pre-Pennsylvanian- and Pennsylvanian-age units house highly mineralized waters that are not viable groundwater sources unless extensive treatment is performed prior to use. Additionally, Pennsylvanian-age units offer low yields compared to the shallower alluvial, glacial, and preglacial fill.

Glacial sediments offer the highest quality and most usable groundwater resource in northwest Missouri. Depending on the thickness of the glacial layers, yields can range from less than 1 to as much as 500 gpm. The total volume of groundwater contained in the glacial drift aquifer portion of the Northwestern Missouri groundwater province is estimated to be about 8.8 trillion gallons. However, recharge and recirculation rates are generally low, resulting in higher than typical residence times and the potential for poor water quality.

Areas with recent alluvial deposits, excluding the Missouri River alluvium described previously, have the potential to yield 50 to 500 gpm. A conservative estimate of potential groundwater storage capacity for the alluvial aquifers of northwest Missouri is over 390 billion gallons.

## 2.5.8 Northeastern Missouri Groundwater Province

The Northeastern Missouri groundwater province encompasses an area of approximately 11,708 square miles that is south of the Missouri-Iowa border, west of the Mississippi River, north of the Missouri River, and east of the Northwestern Missouri groundwater province. The province contains glacial drift deposits that are underlain by Pennsylvanian and older bedrock and has diverse groundwater conditions.

The northern and western parts of the province feature moderately thick glacial drift with low permeability. This glacial drift, which generally yields poor quality water, is underlain by Pennsylvanian strata (University of Missouri Extension AgEBB 2018). Glacial drift also exists in the eastern part of the province, albeit thinner, and is underlain by Mississippian-age bedrock, which can yield moderate quantities of potable water. In the southern part of the province, near the Mississippi River, early Mississippian, Devonian, and Ordovician rocks are apparent at the surface due to uplift along the Lincoln Fold. Water yields vary among these deposits as does water quality. The freshwater-saline water transition zone crosses the southern part of the province, rendering the bedrock aquifers to the north of the zone unimportant as aquifers; however, south of the transition zone, Mississippian-, Ordovician-, and Cambrian-age bedrock units can supply between 10 and 1,000 gpm of good quality, potable water, depending on depth (University of Missouri Extension AgEBB 2018).

### Geology

Hydrologically significant bedrock units within the province range in age from Cambrian to Pennsylvanian. Refer to **Appendix A**, **Table A-8** for a detailed depiction of all stratigraphic sediment layers within the province. The Davis Formation and Derby-Doerun Dolomite, which are overlain by a thick sequence of Upper Cambrian and Ordovician formations, are present within the province hydrologically separating the water-bearing strata above from the deeper Bonneterre Formation and Lamotte Sandstone below.

The Maquoketa Shale is found in the eastern and southeastern parts of the province and may reach 140 feet in thickness. Also, within the province are Silurian-age and Devonian-age strata, with a combined thickness ranging from 0 feet at their outcrop areas to the south, to 320 feet in the northwestern corner of the province.

Several Mississippian-age formations are present in the Northeastern Missouri groundwater province, including many that are also present in the Springfield Plateau province. These Mississippian units are predominant throughout, except where they have been removed by erosion along the Lincoln Fold and where older rock units form the bedrock surface in the southern part of the province.

Most of the northern portion of the Northeastern Missouri groundwater province and the western part of the province are underlain by Pennsylvanian-age bedrock that is comprised of generally fine-grained clastics and thin limestones with coal seams interspersed throughout. Within the province, there is an ancient Pennsylvanian-age sandstone channel that has been eroded into Pennsylvanian rocks. The channel is east-west trending and approximately 40 miles in length and known as the Weldon River Sandstone Member of the Shale Hill Formation.

Throughout most of the province, Pleistocene-age glacial sediments, which include glacial drift and loess, overlie the bedrock. The glacial drift deposits are not generally well sorted into zones and are interspersed with clay and silt.

### Hydrogeology

The Northeastern Missouri groundwater province encompasses the freshwater-saline water transition zone. South of the transition zone, there is ample water for irrigation and for municipal and rural public water supply. North of the transition zone, the groundwater is highly mineralized and cannot be used as a potable supply without extensive treatment and is therefore generally not used.

The most significant bedrock aquifer within the province is comprised of the same bedrock units as the Ozark Aquifer in the Salem and Springfield Plateaus provinces; however, in the Northeastern Missouri groundwater province it is referred to as the Cambrian-Ordovician Aquifer since it is not part of the Ozark Aquifer flow system and the Missouri River hydraulically separates the groundwater in the two aquifers. Significant water-yielding units include the St. Peter Sandstone, Roubidoux Formation, lower Gasconade Dolomite, Gunter Sandstone Member, Eminence Dolomite, and Potosi Dolomite.

Located above the Cambrian-Ordovician Aquifer and below the shallower Mississippian Aquifer is the Mississippian-Devonian-Silurian Confining Unit, which is a thick sequence of low-permeability limestone and shale, up to 300 feet thick that impedes the flow of water between the two aquifers.

The Mississippian Aquifer, located above the Cambrian-Ordovician Aquifer, can supply modest quantities of quality groundwater, yielding approximately 5 to 15 gpm.

The Pennsylvanian formations are not generally considered to be an important water-supply source because of their low permeability. Yields from the Pennsylvanian units average less than 3 gpm throughout the Northeastern Missouri groundwater province.

North of the freshwater-saline water transition zone, the Glacial Drift Aquifer is typically the only groundwater source available that does not require extensive treatment for most uses, including as a source for public water supply. This aquifer contains relatively thick sequences of medium- to coarse-grained sand and fine to medium gravel that yield only small to moderate amounts of water with slow recharge.

The Northeastern Missouri groundwater province also includes alluvial deposits of the Missouri and Mississippi rivers, both of which have been discussed above.

### 2.5.9 West-Central Missouri Groundwater Province

The West-Central Missouri groundwater province is located northwest of the Springfield Plateau groundwater province, south of the Missouri River, and east of the Kansas-Missouri state line. The area encompasses 5,080 square miles and is located primarily within the Osage Plains physiographic region. The province boundary to the east and south coincides with the freshwater-saline water transition zone indicating that the deeper aquifers contain highly mineralized water, much of which is not potable.

#### Geology

Much of the bedrock surface throughout the West-Central Missouri groundwater province is made up of Pennsylvanian-age formations, with some areas of Mississippian-age bedrock. Also present in the subsurface are older Mississippian, Ordovician, and Cambrian formations that contain highly mineralized water. Refer to **Appendix A**, **Table A-9** for a detailed depiction of all stratigraphic sediment layers within the province.

The Pennsylvanian deposits consists of repetitive occurrences of lithologic types and overlie the Mississippian strata. The Pennsylvanian units, from deepest to shallowest, include the Atokan Stage, Cherokee Group, Marmaton Group, Pleasanton Group, and Kansas City Group. The Atokan is dominated by the Riverton Shale. The Cherokee Group is comprised of thick shale, which contains thin coal seams, and sandstone sequences. Thin marine limestone beds are also present within the province.

Above the Cherokee Group is the Marmaton Group, which has fewer sandstone, more thin limestone, and thick shale sequences. The Marmaton Group is overlain by the Pleasanton Group, which is made up of a thick sequence of shale, with a basal siltstone and very fine-grained sandstone. The upper half of the group is made of the Weldon River Sandstone Member, which is comprised of two thick channel sandstone bodies.

The Kansas City Group overlays the Pleasanton Group, which is primarily made up of thick limestones with intervening shale formations. This group is in contrast to underlying groups, which are dominated by shale and very limited limestone.

#### Hydrogeology

This groundwater province does not have significant groundwater resources. The greatest groundwater potential within this province is along the northern edge where there are alluvial and drift-filled preglacial valley deposits. The Pennsylvanian-age bedrock common throughout the area is only capable of yielding modest quantities of marginal quality groundwater. The Sprinfield Plateau and Ozark aquifers can be utilized along the transiton zone at the southern edge of the province.

The West-Central Missouri groundwater province also includes two buried channels in the forms of unconsolidated alluvial or glacial drift aquifers that have the potential to supply relatively large quantities of good quality groundwater. The first is an alluvial aquifer that is 16 miles long and 1 to 2 miles wide, located in the northern part of the province at the southern edge of the Missouri River in Jackson County. The buried channel most likely formed due to ice damming of the Missouri River during the last Ice Age.

The second buried channel within the West-Central Missouri groundwater province flows through Saline County and likely developed during the Pleistocene, also due to glacial ice damming of the Missouri River. The western part of this channel is considered a terrace deposit of coarse sand and gravels with yields approaching 1,000 gpm. East of the terrace deposit, it becomes a more traditional channel with much lower well yields. In some places within the channel, water yields can reach 100 gpm; however, in other locations, well logs indicate yields of little or no water.

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# Section 3 Statewide Demographic and Water Use Forecast

## 3.1 Introduction

To properly plan and manage Missouri's water resources now and in the future, it is critical to have a reasonable understanding and characterization of how water is currently used across the state as well as quantifiable estimates of how much water is being withdrawn and consumed by water users. Comprehensive state water planning provides a blueprint that ensures that 6.12 million Missourians and the businesses they own and operate have sustainable access to clean, abundant water. Another critical component is a reasonable determination of how much water will be needed in the future to support a growing population and economy. A water demand forecast lays the groundwork for understanding how and where water is used, and identifies areas of the state where potential future water use could exceed available water supplies.

This section of the Missouri WRP describes the water users throughout the state, both consumptive and nonconsumptive, who constitute the primary demand for water. Where appropriate and practical, quantified estimates of consumptive demands are provided by county and source of supply from a recent historical year (typically 2016) through 2060 by decade. For some users, nonconsumptive water withdrawals are quantified.

Throughout this section, water demands are quantified by county and by the source of the supply. Groundwater and surface water resources in Missouri and a summary of demands by subregion are described in **Section 4**. The methodology and data sources used to quantify consumptive demands is detailed in **Appendix B**. Tables presenting water demands to 2060 as well as other supporting data by county are provided in **Appendix C**.

Quantifying current and future water demand requires an estimate of the number of people and businesses currently relying upon the water and a projection of these data into the future. Historical, current, and future data on population and employment are provided in **Section 3.2**.

**Consumptive demand** refers to water that is withdrawn from the source and consumed in a way that makes its use all or partially unavailable for other purposes or uses.

**Nonconsumptive demand** refers to water that is withdrawn from the source or required to be in the stream, river, or lake to support the demand but is not consumed and remains available for other uses.

For analysis purposes, it is useful to group water demands according to similar user characteristics and delivery modes. This is a common approach to understanding and characterizing water demands. For example, USGS categorizes water use according to common users in their bidecade reports. Similarly, water demand use categories, or sectors, were defined in support of the Missouri WRP. These sectors were determined according to data availability, shared elements affecting water use (e.g., population or employment), and/or similarity in water use characteristics. The water use sectors, both consumptive and nonconsumptive, are described in the bulleted list in the overview on the following page. **Section 3.9** provides a summary of the combined demands for the consumptive use sector withdrawals to 2060.

## Overview of Section 3 Statewide Demographic and Water Use Forecast

- Section 3.2 Demographics, Economics, and Trends – This section presents the current and future population and employment data that are used as the foundation of the water demand projections in various water use sectors.

### Consumptive Demand Sectors:

- Section 3.3 Major Water Systems – Water provided by larger municipal and public water supply entities to homes, businesses, and light industries. This sector covers 608 community water systems servicing nearly 5.07 million people in Missouri.
- Section 3.4 Self-Supplied Nonresidential – Water used by nonresidential establishments that is supplied by the establishment's own source. This sector includes industries, mining entities, golf courses, universities, hotels, food processing plants, ethanol plants, nursing homes, and prisons.
- Section 3.5 Self-Supplied Domestic and Minor Systems – Water used by homes, subdivisions, or mobile home parks that is supplied by a privately owned and operated well or supplied by a smaller public water system. This sector provides water to 1.05 million people in Missouri.
- Section 3.6 Thermoelectric Power Generation – Water required for generating electricity that is produced with steam-driven turbine generators. In Missouri, fossil fuels are the primary fuel type; however, Missouri has a single nuclear generating facility. The portion of water withdrawn and consumed to support thermoelectric power generation varies, depending on fuel type and configuration. Both the total withdrawals and consumed portion are quantified.
- Section 3.7 Livestock – Water required for raising and producing livestock animals such as hogs, cattle, dairy cows, horses, poultry, and sheep and goats. The water use includes that used to maintain animal health, sanitation, and waste removal at both concentrated animal feeding operations (CAFOs) and pasture operations.
- Section 3.8 Agriculture Irrigation – Water withdrawn for irrigating row crops such as rice, soybeans, and corn, and specialty crops such as orchards, berries, and hay. This sector covers the water applied to supplement effective rainfall in Missouri's crop production industry.

### Nonconsumptive Demand Sectors:

- Section 3.10 Hydroelectric Power Generation – In-stream water that is used for generating hydroelectric power as it passes through a turbine system.
- Section 3.11 Commercial Navigation – In-stream water for transporting barges and boats that carry grain, raw materials, and other bulk freight on Missouri's rivers.
- Section 3.12 Wetlands – Water that supports wetland functionality. Estimates are provided that quantify the amount of water withdrawn from sources to artificially create or supplement effective rainfall at seasonal wetlands.
- Section 3.13 Water-Based Outdoor Recreation – Water in streams, lakes, and reservoirs that support human recreational activities such as fishing, swimming, motorboating, kayaking, paddle boarding, floating, and canoeing.
- Section 3.14 Aquaculture and Fish Hatcheries – Water withdrawals that support the farming and cultivating of cold- and warm-water organisms such as fish or crustaceans for food, restoration, conservation, or sport fishing.

## 3.2 Demographics, Economics, and Trends

> Missouri and the surrounding region is projected to have population and employment growth rates just below the national average through 2050. Population and employment are forecasted to increase at average annual rates of 0.59 and 0.99 percent, respectively, from 2016 to 2050, with regional variations in that growth (Woods & Poole 2017).

The demand for water is driven by the people, establishments, and economic sectors that rely on it for drinking water, personal hygiene, sanitation, filling swimming pools, washing cars, keeping lawns green, producing food, generating electricity, business uses, and manufacturing processes, to name a few. This section presents the current and future population and employment data that are used as the foundation of the water demand projections in various water use sectors described throughout this section. Historical trends in population and employment are evaluated and presented in addition to future projections through 2060. The data sources, methodologies, and assumptions used to develop the demographic projections by county to 2060 are presented in **Appendix B**.

According to Woods & Poole Economics, Inc. (Woods & Poole), an independent group that produces annual projections of population and employment for the entire United States, the United States economy is projected to grow steadily and modestly through 2050, with an average annual increase of 1.9 percent in gross domestic product (2017). In the long run, the national civilian unemployment rate is projected to be 4.8 percent by 2050. The U.S. population is projected to grow from the 2015 estimate of 321.4 million to 428.1 million by 2050.

Rural agricultural areas that do not have mining activities or other manufacturing sectors are forecasted to experience population declines. Innovations in seeds, fertilizers, insecticides, irrigation, planting, and harvesting have increased crop yields and had a net labor-saving effect. Farming is an exporting sector within a regional economy. Because of this, agriculture income and employment support the demand for locally produced goods and services. Flat growth in the number of farm workers can ripple through a regional economy, creating slow growth in employment in retail trade, construction, finance, and services. This translates to an eventual population migration out of the county. Despite the decline in farm employment, the trend in increasing farm productivity is expected to continue through 2050 in response to increased international demand for food (Woods & Poole 2017).

In contrast to trends of decreasing population in agricultural areas, most metropolitan statistical areas (MSAs) in the Missouri region are forecasted to have net gains in employment. The Kansas City MO-KS MSA is expected to create 684,000 jobs. The St. Louis MO-IL MSA is forecasted to create 630,000 jobs (Woods & Poole 2017).

### 3.2.1 Population

Population data herein are aligned with census coverage of people who reside in a county. For a given county, the data include populations living in residential housing, student housing, prisons and jails, and nursing homes. Military personnel are counted at the barracks where they live, or the place where they live and sleep most often if they do not live in barracks.

**Figure 3-1** shows historical Missouri population from 1970 to 2015. The annual population growth rate is presented on the right axis. Statewide population increased at an average rate of about 0.5 percent per year from 1970 to 1989. In the 1990s, population growth rate increased to about 0.9 percent per year. From 2000 to 2010, population grew at about 0.7 percent per year. The effect of the 2009 to 2011 recession on population growth, due in part to the decrease in job migration and declines in fertility rates, is evident after 2010, when population grew at about 0.3 percent per year up to 2015. Overall, population in Missouri grew at an average rate of about 0.6 percent per year from 1970 to 2015 (Woods & Poole 2017).

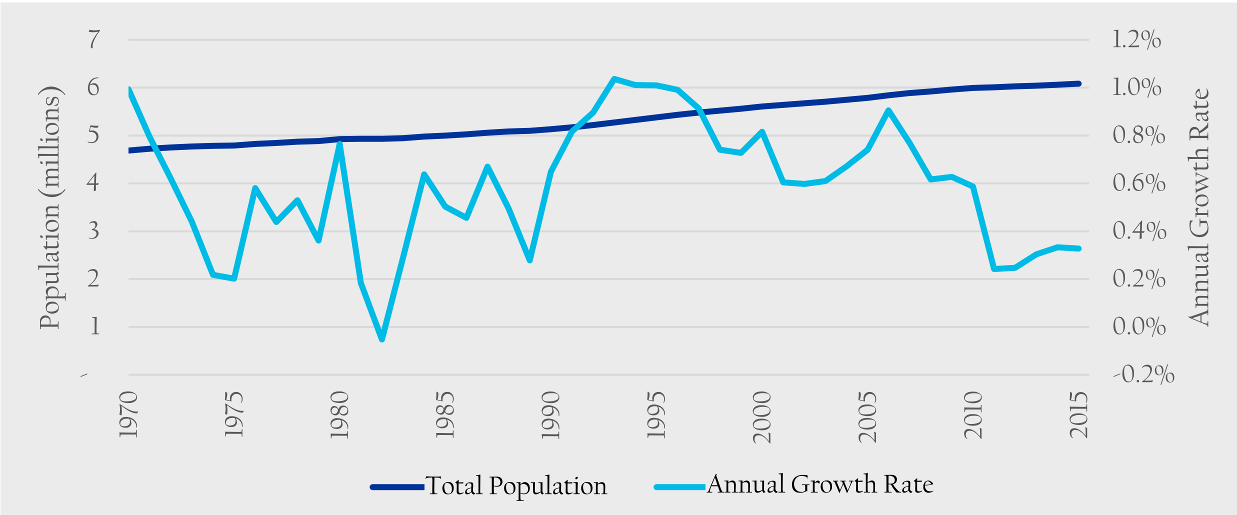


**Figure 3-1. Missouri Historical Population and Annual Growth Rate from 1970 to 2015**
*Source: Derived from Woods & Poole 2017*

Growth in population has varied by county as shown in **Figure 3-2**. About 44 percent of counties in the state have growth rates between 0 and 1 percent. About 23 percent of counties have average annual growth rates between 1 and 2 percent, 6 counties have growth rates from 2 to 3 percent, and 3 counties have growth rates above 3 percent. St. Louis City has the lowest average annual growth rate at approximately -1.5 percent, due to urban sprawl and economic activity densification. Christian County, located in the Ozarks, had the highest average annual growth rate at 3.8 percent. Including St. Louis City, there are 29 counties (25 percent) with negative average annual growth rates over this period (**Figure 3-2**).

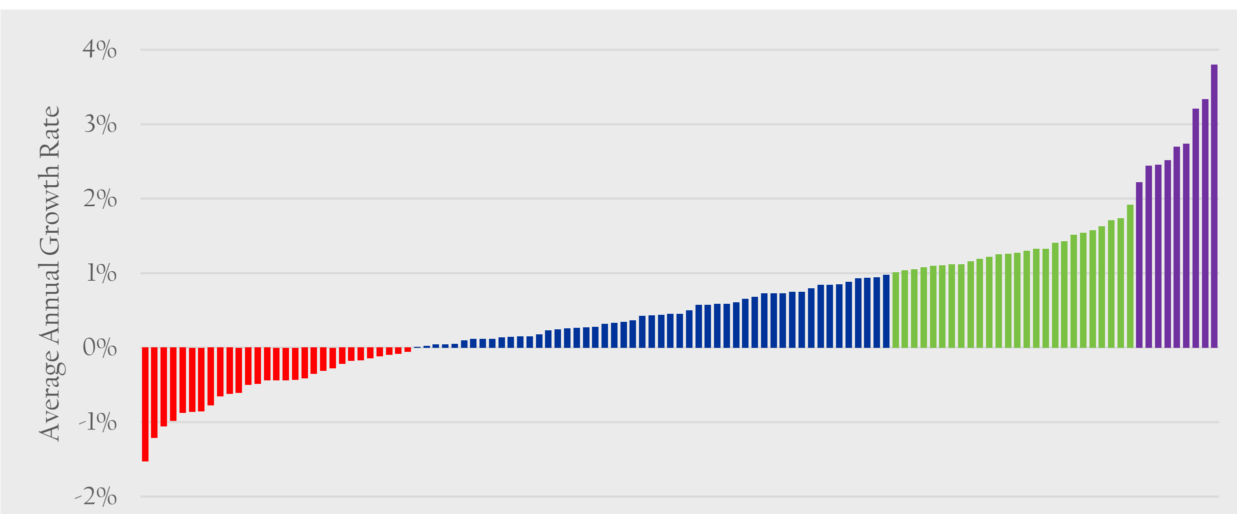


**Figure 3-2. Average Annual Growth Rate in Population for Missouri Counties from 1970 to 2015**
*Source: Derived from Woods & Poole 2017*

As of 2016, 6.12 million people reside in Missouri. The most populous county in the state is St. Louis County, located in the St. Louis MSA, with just over 1 million people or 16 percent of the state's population. The second most populous county is Jackson County, located in the Kansas City MSA, at nearly 690,000 people. The third and fourth most populous counties, St. Louis City and St. Charles, respectively, are also located in the St. Louis MSA. The fifth most populous county, Greene County, is the home of Springfield in the Ozarks region.

Regionally, the highest percentage growth in population is projected in the Ozarks area. The seven counties surrounding Springfield (Christian, Dallas, Greene, Polk, Stone, Taney, and Webster) are projected to grow by a combined 58 percent from 2016 to 2060.

Population in Missouri is projected to increase from 6.12 to 7.48 million by 2060 (22 percent) as shown in **Figure 3-3** (Woods & Poole 2017). The change in population varies significantly across the state as shown in **Figure 3-4**. The Kansas City area, which is comprised of Cass, Clay, Jackson, Platte, and Ray counties, is projected to grow by more than 350,000 people (31 percent). Boone County, where Columbia and the University of Missouri are located, is projected to grow by nearly 135,000 people (76 percent). The county where the Lake of the Ozarks is primarily located, Camden County, is projected to grow by 25,500 (57 percent). Camden County has experienced significant historical population growth, thought to be driven by retirees moving to the area (Lake of the Ozarks Council of Local Governments 2017). St. Louis County is projected to have a stable population through 2060, while St. Louis City is projected to decline in population by 26 percent over that same period. St. Charles, Lincoln, Jefferson, and Warren counties are all projected to grow significantly by 2060 (70, 62, 49, and 41 percent, respectively). Most of the northern part of the state is projected to have a slight to significant decrease in population over the next 40 years. The same is true of several counties in the southeastern region.

**Appendix C** provides the population projections for each county and decade to 2060.

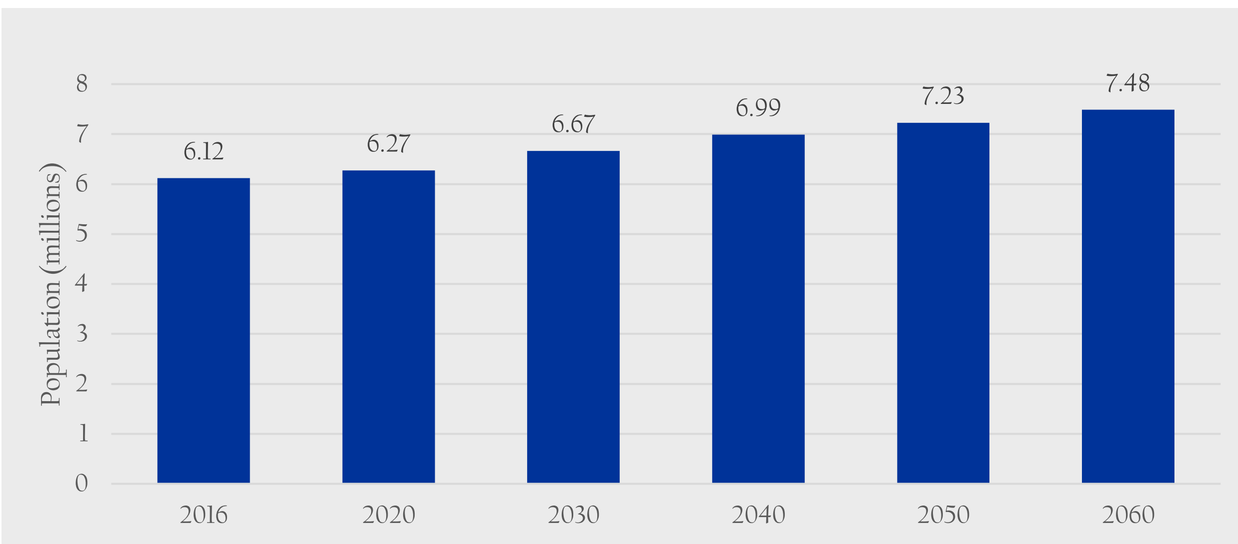


**Figure 3-3. Missouri Statewide Population Projections from 2016 to 2060**
*Source: Woods & Poole 2017*

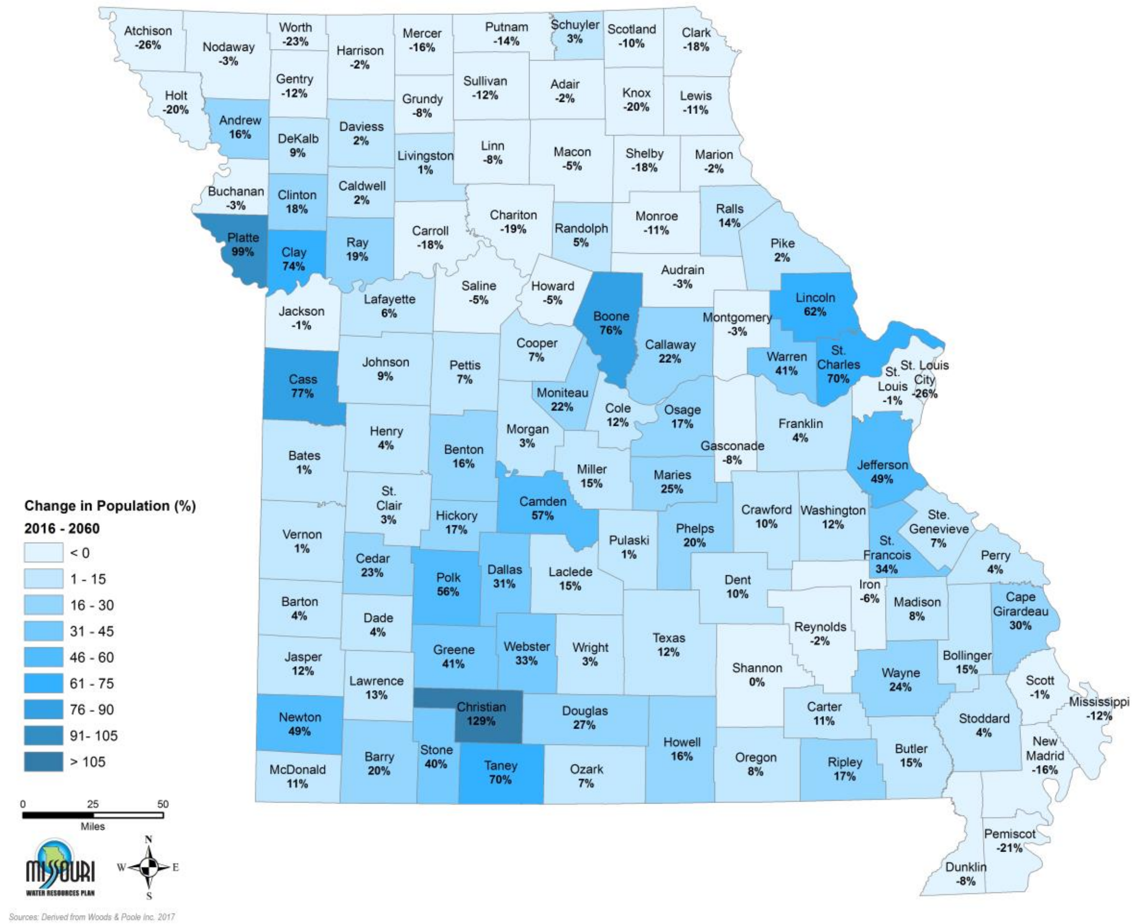


**Figure 3-4. Population Growth by County from 2016 to 2060**
*Source: Woods & Poole 2017*

### 3.2.2 Employment

Historical estimates and future projections of employment by county presented herein are summarized from the Woods & Poole series (2017). There are several sources for historical county employment data. The Woods & Poole series utilizes reported historical estimates from the Bureau of Economic Analysis, which offers the most comprehensive count of people employed in all sectors within a county, including students, elected officials, farm laborers, contractors, military personnel, and the self-employed.

**Figure 3-5** presents total employment in Missouri from 1970 to 2015. The historical trend shows periodic dips in employment due to economic recessions and periods of higher unemployment. Statewide, employment reached a peak of 3.6 million in 2007, just before the 2009 to 2011 recession. The 2015 employment level shows a recovery to prerecession levels, with employment reaching 3.7 million.

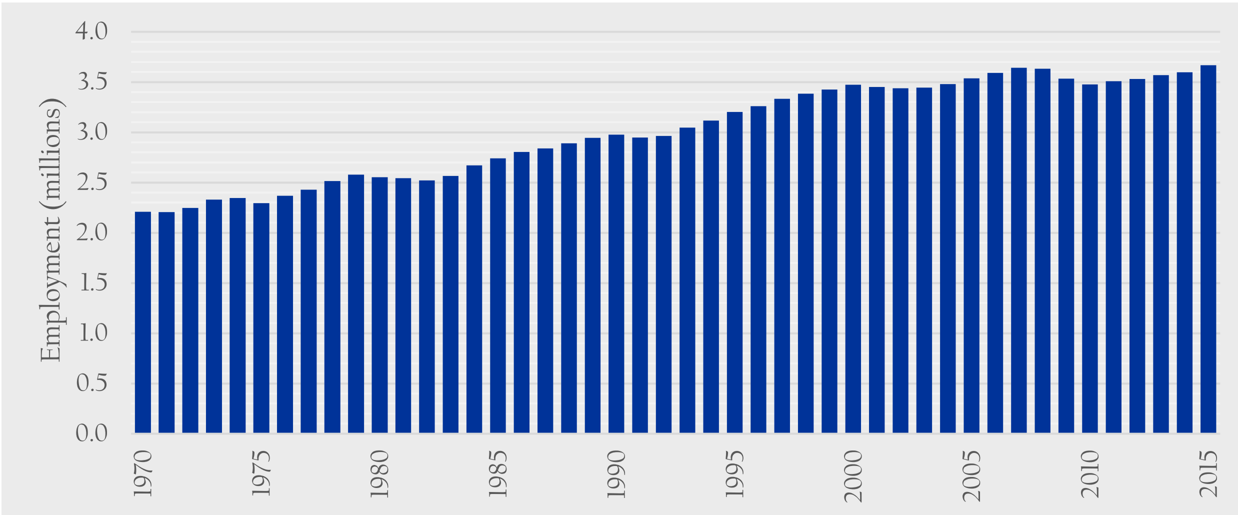


**Figure 3-5. Missouri Statewide Historical Employment from 1970 to 2015**
*Source: Woods & Poole 2017*

Employment data are collected and reported according to the 2002 North American Industry Classification System (NAICS). This system classifies employment given an industry's primary activity at an establishment (typically a single physical business location). For example, a secretary for a trucking company is considered a transportation worker while an accountant at a small plumbing company is considered a construction worker. Employees who work at an establishment's headquarters are considered management regardless of the type of services offered by the establishment. Definitions of the primary NAICS employment categories used herein are described in **Appendix B**.

**Figure 3-6** presents historical employment in Missouri by NAICS employment categories. From 1970 to 2015, there has been a steady decline in statewide employment in the manufacturing, farming, and federal government employment, which follows national trends for these sectors. Overall, farming employment has decreased by 40 percent, manufacturing has experienced a 33 percent decline, and federal government has declined by 28 percent. All remaining employment groups have experienced increases in employment of the 45-year period. The most significant increases have been in professional and technical services (238 percent), health care and social services (217 percent), education (212 percent), and administrative services (194 percent).

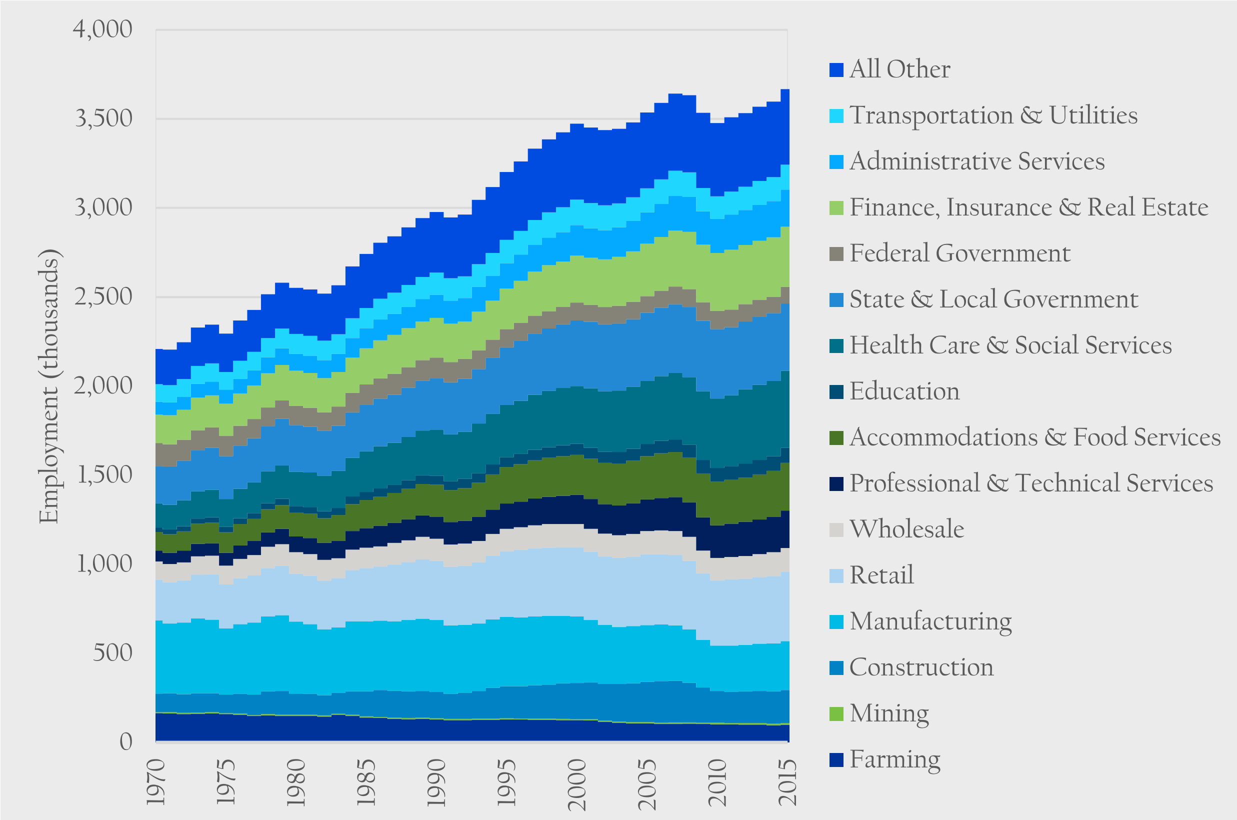


**Figure 3-6. Missouri Statewide Historical Employment by Major Categories from 1970 to 2015**
*Source: Woods & Poole 2017*

Statewide, historical trends in employment are projected to continue in Missouri. As shown in **Table 3-1**, farming employment is projected to decrease slightly by 2060 while manufacturing jobs are projected to decline by 20 percent. The highest growth in the workforce is projected for the professional and technical services category (90 percent); followed by education (86 percent); health care and social services (83 percent); and finance, insurance, and retail trade (68 percent).

Overall, statewide employment is projected to increase by 43 percent from 2016 to 2070. This increase is higher than the projected growth in state population. The difference is primarily attributed to two factors. First, the projections assume that people will participate in the workforce longer. Second, people who live in neighboring states, such as Illinois and Kansas, will continue to find employment in Missouri.

In alignment with population growth, the Ozarks region has the highest projected growth in employment, estimated at 60 percent. Within the Ozarks region, Christian County is projected to have the highest growth, with a 130 percent increase in employment. In the most populous county in the Ozarks region, Greene County, employment is projected to grow by an additional 111,000 jobs.

Most other regions are projected to have moderate job gains, with growth ranging from 42 percent in the central part of the state to 28 percent in the northeast. In the northwest, job growth is projected to be a modest 7 percent. Seven counties are projected to experience declines in employment: Adair, Grundy, Linn, Saline, Schuyler, Sullivan, and Worth. **Appendix C** provides a table of employment projections by county from 2016 to 2060.

**Table 3-1. Projected Employment by Major Category**

| Category | Employment Projections by Category | | | | | | Growth 2016–2060 |
|---|---|---|---|---|---|---|---|
| | 2016 | 2020 | 2030 | 2040 | 2050 | 2060 | |
| Farming | 99,047 | 100,339 | 101,633 | 100,312 | 96,564 | 93,021 | -6% |
| Mining | 9,251 | 9,650 | 10,676 | 11,837 | 13,134 | 14,634 | 58% |
| Construction | 190,823 | 203,700 | 225,977 | 235,685 | 247,028 | 259,370 | 36% |
| Manufacturing | 276,831 | 278,581 | 268,578 | 252,969 | 236,228 | 221,661 | -20% |
| Retail | 394,381 | 417,397 | 455,861 | 494,839 | 535,176 | 581,883 | 48% |
| Wholesale | 138,268 | 144,155 | 152,787 | 156,503 | 154,923 | 153,960 | 11% |
| Professional and Technical Services | 211,946 | 223,518 | 256,677 | 296,509 | 344,039 | 402,478 | 90% |
| Accommodations and Food Services | 272,235 | 284,616 | 313,259 | 332,196 | 356,699 | 384,714 | 41% |
| Education | 85,077 | 91,313 | 108,908 | 126,219 | 140,862 | 158,196 | 86% |
| Health Care and Social Services | 439,929 | 470,824 | 555,467 | 640,195 | 716,541 | 805,517 | 83% |
| State and Local Government | 382,485 | 399,631 | 434,432 | 457,202 | 472,347 | 490,340 | 28% |
| Federal Government | 93,283 | 94,304 | 96,885 | 99,456 | 102,007 | 104,802 | 12% |
| Finance, Insurance, and Real Estate | 344,578 | 370,554 | 431,255 | 483,707 | 528,339 | 580,045 | 68% |
| Administrative Services | 210,324 | 218,962 | 246,569 | 273,295 | 295,718 | 322,377 | 53% |
| Transportation and Utilities | 136,715 | 133,696 | 139,238 | 144,415 | 147,033 | 150,365 | 10% |
| All Other | 426,499 | 439,830 | 477,281 | 512,176 | 540,115 | 572,067 | 34% |
| **STATE TOTAL** | **3,711,672** | **3,881,070** | **4,275,483** | **4,617,515** | **4,926,753** | **5,295,430** | **43%** |

*Source: Woods & Poole 2017*

## 3.3 Major Water Systems

### 3.3.1 Introduction and Definitions

The Major Water Systems sector represents most of the community public water systems in Missouri. A public water system, as defined by the U.S. Safe Drinking Water Act, is an entity that provides water for human consumption through pipes or other conveyance systems to at least 15 connections or an average of 25 people for at least 60 days each year (U.S. Environmental Protection Agency [EPA] 2018). These systems provide water to homes, businesses, and light industries in towns, cities, and metropolitan areas across the state. Missouri has 2,733 public water systems, 1,426 of which supply water to the same population year-round (known as community water systems) (MoDNR 2016). The remaining public water systems are considered noncommunity and are generally commercial or institutional establishments that supply either a regularly changing population (such as a restaurant) or semiregular changing population (such as a school). The community water systems are the focus of this sector.

The data available to quantify and forecast water demands for community water systems vary in quality and level of detail. For example, data are available for all systems that identify their general source of water, such as groundwater, surface water, or purchase (MoDNR 2016), but more detailed information regarding the precise location of the water source is available only for those systems that have registered water use with MoDNR. The self-reported data requires significant effort to process and verify. Because more precise detail is needed for assessing demand impacts on water supplies, a subset of 608 community water systems were selected for inclusion in the Major Water Systems sector. All systems serving 1,000 persons or more are included as well as systems that serve 275 persons or more and register and report their water use with MoDNR. Additionally, community systems that have their own surface water sources or purchase surface water from another system were typically included. As described in the **Section 2.3.2**, these 608 major water systems cover 95 percent Missouri's population supplied by a community water system. Water demand for the remaining community systems and population not serviced by a community system is quantified in the Self-Supplied Domestic and Minor Systems sector (**Section 2.5**). The primary data sources used to estimate current and future water use for the Major Water Systems sector include:

- MoDNR's Major Water Users database, which is a database of the annual data collected by MoDNR from the state's major water users who are defined as, "any person, firm, corporation or the state of Missouri, its agencies or corporations and any other political subdivision of this state, their agencies or corporations, with a water source and equipment necessary to withdraw or divert one hundred thousand gallons or more per day from any stream, river, lake, well, spring or other water source," in accordance with Missouri Statute 256.400 (RSMo 2019)
- Census of Missouri Public Water Systems (MoDNR 2016)
- Woods & Poole 2017 Complete Economic and Demographic Data Source
- Public Drinking Water Wells geographic information system (GIS) shapefile, which is a geodatabase developed by MoDNR based on Safe Drinking Water Information System (SDWIS) data

The remaining sections characterize the Major Water Systems sector. Population is the driver of the demand forecast and is discussed in **Sections 3.3.2** and **3.3.5**. The average rate of use for the Major Water Systems sector is expressed as gallons per capita per day (GPCD). Current and future estimates of GPCD were developed by system as discussed in **Sections 3.3.3** and **3.3.6**. The sources of supply for meeting the demands are presented in **Section 3.3.4**. The per capita and population projections are combined to forecast water demand for the sector to 2060 as described in **Section 3.3.7**. **Appendix B** provides additional details on how this sector was defined, primary data sources utilized, which water systems are included within this sector, and how the water demand forecast was estimated.

### 3.3.2 Population Served

Community water systems provide water to 5.34 million people in Missouri (MoDNR 2016). The Major Water Systems sector covers 5.07 million people, which is 95 percent of the community water systems' population served and 83 percent of the state's total population. **Figure 3-7** highlights the variation in the population served by the Major Water Systems. Seventy-seven percent of Major Water Systems service a population of 5,000 or less. Only 13 systems serve a population that exceeds 50,000 people. In addition to residential populations, numerous businesses get their water from a community water system and are included in this sector. **Appendix C** provides population served for the Major Water Systems summarized by county.

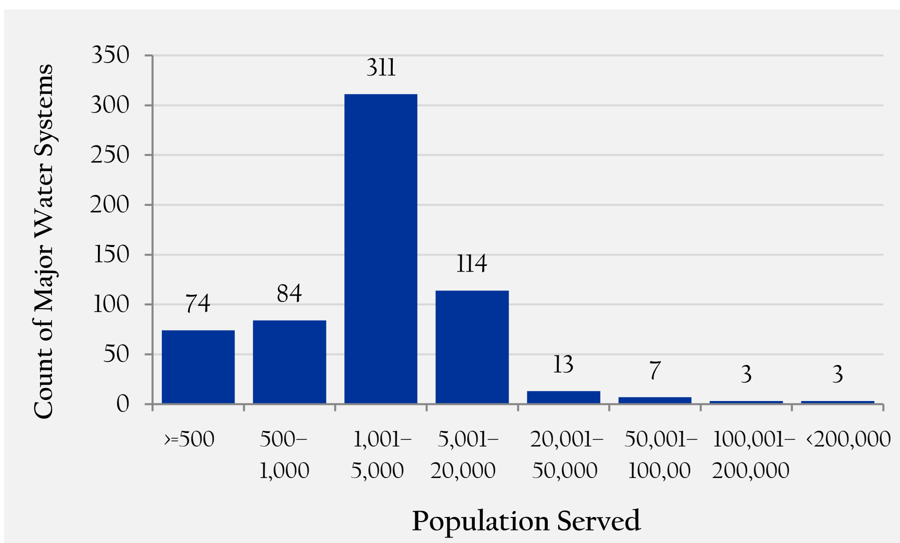


Figure 3-7. Major Water Systems Current Population Served

### 3.3.3 Current Water Use Characteristics

Statewide, the 608 major water systems use approximately 807 million gallons per day (MGD) during an average year. With a population served of 5.07 million people, this equates to an average use rate of 160 GPCD. The GPCD rate of a system will vary, depending on the types of customers and use levels that occur within the service area. Major Water Systems that service large, regional economic centers with low populations will naturally have a higher GPCD than a system that serves primarily residential areas. Providing water to an industry or other large user will also result in a higher GPCD. In addition to economic activity within a service area, the extent of landscape irrigation, affluency, age of homes, and many other factors impact the per capita rate of use. **Figure 3-8** presents the GPCD distribution for the Major Water Systems. The GPCD for each system was calculated based on the population served and water use information collected through the annual Census of Missouri Public Water Systems and MoDNR's Major Water Users database. These GPCD values represent the average rate from 2013 to 2016 to avoid capturing any weather extremes that may be present in a single-year calculation. As shown, 75 percent of Major Water Systems use 125 GPCD or less, and nearly all systems use 250 GPCD or less.

**Missouri's Major Water Systems:**

- 608 systems
- 5.07 million people served
- 160 average GPCD
- 807 MGD annually

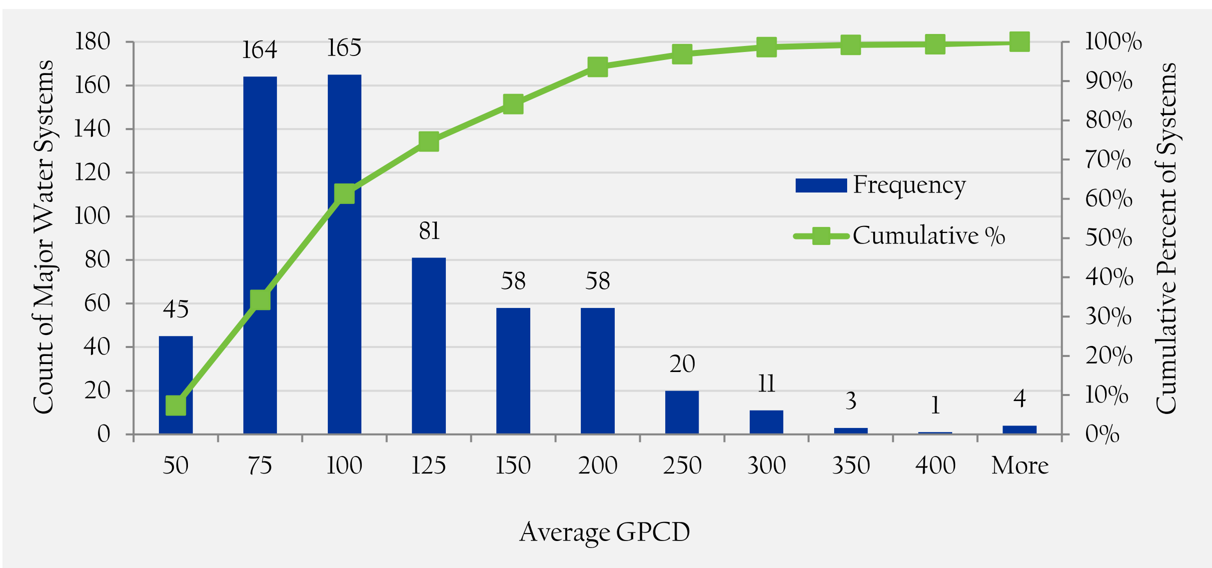


**Figure 3-8. Distribution of Major Water Systems Current GPCD**

The GPCD calculation represents water provided to households and businesses that is used both inside and outside the home or building for various activities. Examples of indoor water uses include water for bathing, flushing, washing, cooking, and drinking. Indoor uses of water remain fairly constant throughout the year. Examples of outdoor water uses include landscape irrigation, car and home washing, and filling swimming pools. Outdoor uses can fluctuate widely in response to annual weather patterns and impact the demand for water during summer months and during dry or wet years. **Figure 3-9** displays the average seasonal pattern of demand for the Major Water Systems. Approximately 7.5 percent of annual water demand occurs during each winter month when water use is essentially limited to indoors. Monthly water use begins to increase in June when swimming pools are filled, gardens and landscapes require watering, and people are generally using water outside the home. Water use peaks in August, at 10.6 percent of annual use, and then begins to decrease. There is variation in this pattern from region-to-region and system-to-system, where weather fluctuations and outdoor irrigation practices of the customer base impact these patterns.

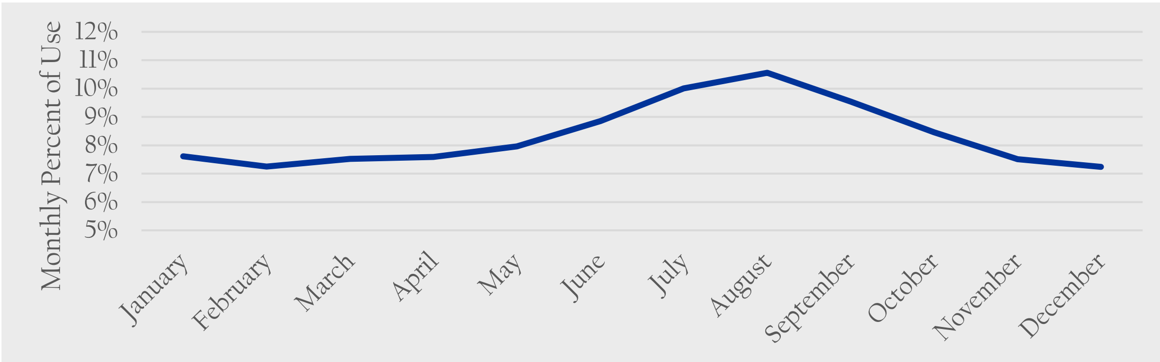


**Figure 3-9. Major Water Systems Average Seasonal Demand Pattern**

Given the GPCD rate and population served for each system, average demand is estimated for each system in the Major Water Systems sector. There are several ways to summarize this information, including the geographic location where the demand for water occurs. Water can be piped and moved from one location to another, sold from one system to another, and many water systems provide service to residents of more than one county. However, the demand for water occurs at the tap, in the homes and businesses where the water is needed. **Figure 3-10** presents current, average water demand summarized by the county where the water is consumed. Following the pattern of population, the counties with the highest water use are those in and around the metropolitan areas of St. Louis and Kansas City (includes Clay, Jackson, St. Charles, and St. Louis counties). St. Louis County has the highest overall total water demand at 160 MGD. Greene County, including Springfield, in southwest Missouri, also has significant water demand for this sector. **Appendix C** provides a table of total water demand for the Major Water Systems summarized by county.

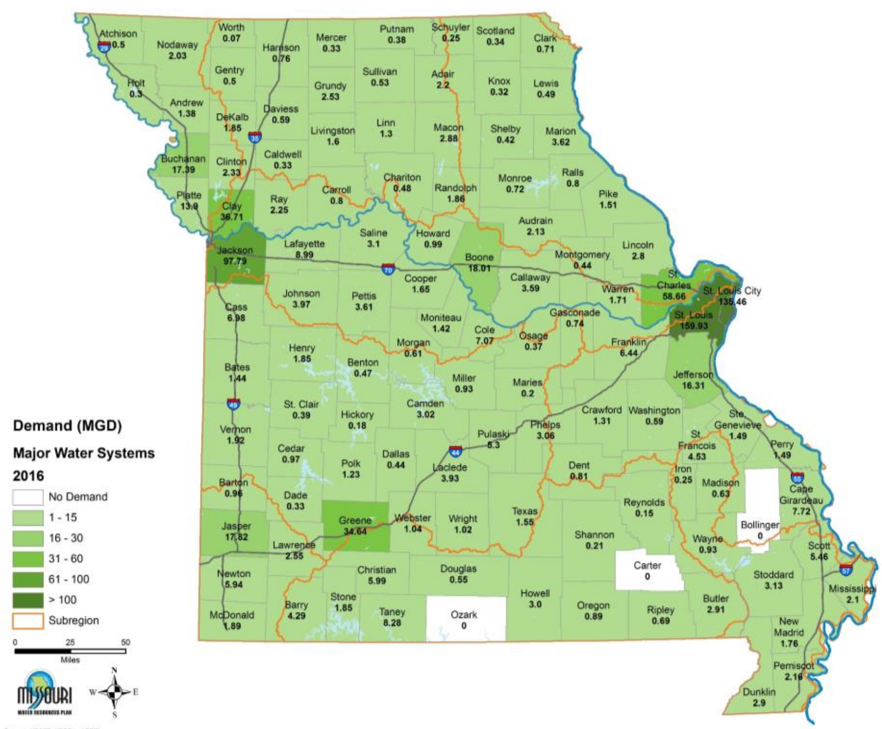


**Figure 3-10. Major Water Systems Current Water Demand by County**[1]

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[1]Demands are shown for the Major Water Systems sector, which includes 608 community systems in the state. There are nearly 900 additional smaller water systems throughout Missouri. The water demand for these systems and homes with wells is quantified in the Self-Supplied Domestic and Minor Systems sector, described in **Section 3.5**.

### 3.3.4 Sources of Water Supply

Missouri's Major Water Systems demand supplied by:

- 36% groundwater
- 64% surface water

Characterizing the source of water for the Major Water Systems is a critical step in understanding the demand on Missouri's water resources. The source of the water was determined for each system using information reported to MoDNR's Major Water Users database and stored in the Public Drinking Water Wells GIS shapefile. As shown in **Table 3-2**, 67 percent of community water systems in the Major Water Systems sector have groundwater wells and 8 percent have surface water intakes. However, not all systems have their own source of supply. Regional water systems may sell water to other systems on a regular, semiregular, or emergency basis. In fact, there are several regional wholesale providers in the state whose primary mission is to supply water to communities and public water supply districts. Of the 608 systems in the sector, 23 percent receive all of their water supply as a wholesale purchase, with roughly a 50/50 split of that use coming from groundwater and surface water (**Table 3-2**). While the count of systems with surface water sources is small (less than 50), 64 percent of total water use is supplied by surface water. This is due to both the large volume surface water systems on the Missouri and Mississippi rivers supplying water to large population areas and the wholesale surface water providers that sell water to numerous smaller systems. Nearly 70 percent of water systems in the sector have their own groundwater sources, yet groundwater makes up only 36 percent of the water consumed.

**Table 3-2. Major Water Systems Summary of Current Source of Water**

| Source of Water | Count of Community Systems in Major Water Systems Sector | Total Groundwater Use (MGD) | Total Surface Water Use (MGD) | Total Water Use (MGD) |
|---|---|---|---|---|
| Groundwater | 406 (67%) | 219.8 | 0 | 219.8 |
| Surface Water | 49 (8%) | 0 | 365.8 | 365.8 |
| Combination[1] | 11 (2%) | 34.2 | 121.2 | 155.4 |
| Wholesale Only | 142 (23%) | 32.5 | 33.4 | 65.9 |
| **TOTAL** | **608** | **286.5** | **520.4** | **806.9** |

[1]Combination is a mix of surface water and groundwater sources or a mix between own sources and wholesale purchases

Source demands by water system were further assessed to understand the specific resource utilized to meet the demand. Groundwater demands are defined according to the producing aquifer, and surface water sources are identified according to subregions as summarized in **Table 3-3**. Of the 36 percent of the water used by the Major Water Systems coming from groundwater, half is pumped from alluvial sources and an additional 40 percent from the Lower Ozark Aquifer. In **Table 3-3** (and subsequent tables of this section), groundwater demands from the Cambrian-Ordovician Aquifer, which is present north of the Missouri River, are lumped into the Upper and Lower Ozark Aquifer. Of surface water withdrawals, over 50 percent are withdrawn in the Lower Missouri subregion.

**Table 3-3. Major Water Systems Current Water Use by Detailed Source**

| | Source | Annual Demand (MGD) | Percent of Total Use |
|---|---|---|---|
| GROUNDWATER BY AQUIFER | Alluvial | 141.9 | 18% |
| | Glacial Deposits | 5.1 | 1% |
| | Wilcox | 7.94 | 1% |
| | McNairy | 4.3 | 1% |
| | Springfield Plateau | 0.38 | 0% |
| | Upper Ozark | 4.16 | 1% |
| | Lower Ozark | 117.3 | 15% |
| | St. Francois | 5.45 | 1% |
| | GROUNDWATER TOTAL | 288.5 | 36% |
| SURFACE WATER BY SUBREGION | Chariton-Grand | 13.4 | 2% |
| | Gasconade-Osage | 15.2 | 2% |
| | Lower Mississippi-St. Francis | 0.54 | 0% |
| | Lower Missouri | 264.8 | 33% |
| | Missouri-Nishnabotna | 88.7 | 11% |
| | Neosho-Verdigris | 13.0 | 2% |
| | Upper Mississippi-Kaskaskia-Meramec | 89.9 | 11% |
| | Upper Mississippi-Salt | 9.86 | 1% |
| | Upper White | 24.9 | 3% |
| | SURFACE WATER TOTAL | 520.4 | 64% |
| **STATE TOTAL** | | **806.9** | |

## 3.3.5 Future Population Served

Based on the county population forecast described in **Section 3.2.1**, more than 1 million additional people will be serviced by Major Water Systems in 2060, as shown in **Figure 3-11**. The forecast for population served includes an adjustment factor that is applied to account for growth in daytime population, reflected in the dashed blue line. The adjustment factor considers growth in both resident population (two-thirds weight) and employment (one-third weight). This is important in capturing increased demand for water in areas that are projected to become economic centers, where people commute to work and use water during the day but return to home in the evenings and where people visit businesses such as retail centers or hospitals and use water. In these areas, the population may be increasing only slightly, remaining constant, or declining, but employment is increasing at higher rates. With the adjustment, the population served by Major Water Systems is estimated to reach 6.5 million people in 2060. **Appendix C** provides the projection of population served by Major Water Systems summarized by county.

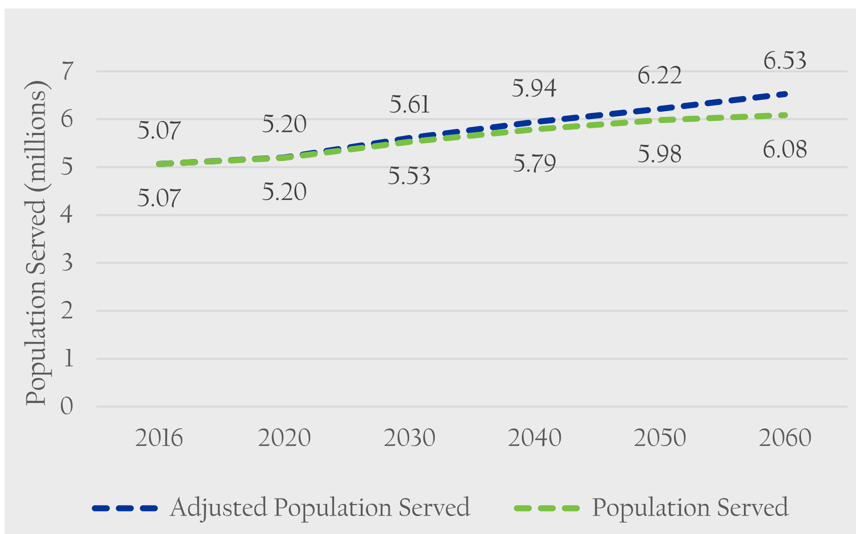


**Figure 3-11. Major Water Systems Statewide Growth in Population Served**

### 3.3.6 Trends in Per Capita Use from Passive Conservation

Often referred to as *passive conservation*, water use inside homes and businesses has declined naturally over time with the replacement of older, inefficient or leaking fixtures with more efficient ones. This is due, in large part, to the enactment of the Energy Policy Act (EPAct) of 1992 that set maximum water consumption standards for showerheads, faucets, urinals, and toilets. For example, the EPAct set a maximum flow rate of 1.6 gallons per flush (gpf) for toilets. Prior to that act, standards were 5 gpf in the 1980s and 3.5 gpf in the early part of the 1990s. Efficiencies in fixtures can go beyond the minimum requirements set forth by the EPAct. The market is now abundant with even more efficient fixtures that display the WaterSense label, such as 1.28 gpf toilets. Similar increases in efficiency have been experienced in appliances such as dishwashers and clothes washers, even though they are not regulated by the EPAct. Clothes washers, which once used 51 gallons per load in the 1980s, are now available with water use averages of 16 gallons per load. Residential dishwasher water use has declined from 14 gallons per cycle to current rates of 5 gallons per cycle (DeOreo et al. 2016).

Impacts of the EPAct and market prevalence of efficient water-using fixtures will continue to reduce indoor water use at homes and businesses into the future. A recent study of indoor residential water uses across the United States indicated a decline from 1999 to 2016 of approximately 10.7 GPCD (69.3 to 58.6 GPCD), or a 15 percent reduction (DeOreo et al. 2016). Overall, the high efficiency benchmark achievable for indoor water use is estimated at approximately 42 GPCD, which represents market efficient fixtures beyond federal plumbing codes (DeOreo et al. 2016).

Homes and businesses throughout Missouri will inevitably achieve additional indoor water savings in the future through natural replacements of fixtures but these savings will eventually plateau as older, higher water-using fixtures are no longer in homes. Quantifying the impacts of passive conservation on a statewide basis is challenging. Conservatively, per capita water use is assumed to decline from its current use levels by 0.25 percent annually from 2016 through 2030. As the Major Water Systems have a range of per capita use levels (see **Figure 3-7**), the impact of the assumed reduction varies as shown in **Figure 3-12**. Most of the community systems included in the Major Water Systems sector are estimated to have a decrease in water use ranging from 2 to 6 GPCD by 2030. Additional water savings are possible as water utilities across Missouri expand or adopt active water conservation programs; however, these savings are not quantified. Additional information on future options for water conservation programs can be found in **Section 7.2.5**.

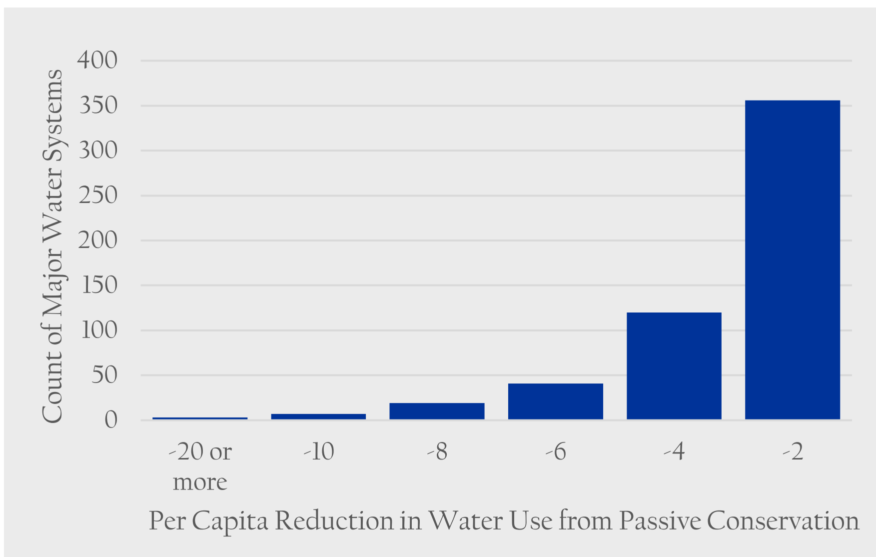


**Figure 3-12. Major Water Systems Per Capita Reductions Due to Passive Conservation from 2016–2030**

### 3.3.7 Future Water Demand

Future water demand for Major Water Systems is projected for each system in the sector given the forecast of population served and the estimated per capita reduction from passive conservation. **Figure 3-13** presents the statewide water demand forecast for the Major Water Systems sector. Overall, water demand from these 608 users is projected to exceed 960 MGD by 2060, a 19 percent increase from current use. Assuming sources used today to meet water demand for each system are utilized proportionally to meet future demand, statewide groundwater and surface water withdrawals are forecasted to increase by 29 and 14 percent, respectively. **Table 3-4** presents water demands by the detailed source of supply. The prominent increases in groundwater withdrawals are expected to be from both alluvial sources and the Lower Ozark Aquifer. Surface water increases are estimated to be nearly 36 MGD for the Lower Missouri and 25 MGD for the Missouri-Nishnabotna subregions.

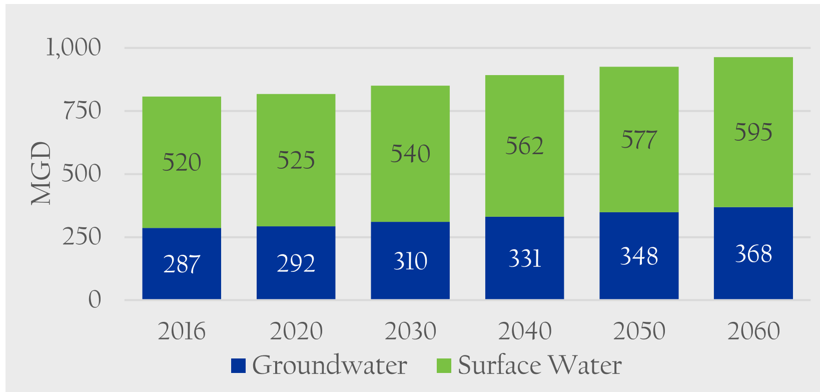


**Figure 3-13. Statewide Major Water Systems Demand Forecast by Source of Supply**

**Table 3-4. Major Water Systems Demand Forecast by Detailed Source**

| Source | | Major Water Systems Demand (MGD) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2016 | 2020 | 2030 | 2040 | 2050 | 2060 |
| GROUNDWATER BY AQUIFER | Alluvial | 141.9 | 144.5 | 153.0 | 163.0 | 171.5 | 181.2 |
| | Glacial Deposits | 5.12 | 5.26 | 5.61 | 5.91 | 6.13 | 6.38 |
| | Wilcox | 7.94 | 7.94 | 7.94 | 7.91 | 7.78 | 7.65 |
| | McNairy | 4.31 | 4.33 | 4.39 | 4.50 | 4.55 | 4.60 |
| | Springfield Plateau | 0.38 | 0.38 | 0.41 | 0.42 | 0.42 | 0.42 |
| | Upper Ozark | 4.16 | 4.26 | 4.60 | 5.01 | 5.39 | 5.79 |
| | Lower Ozark | 117.3 | 119.9 | 127.9 | 137.5 | 145.9 | 155.1 |
| | St. Francois | 5.45 | 5.60 | 6.04 | 6.51 | 6.88 | 7.27 |
| | GROUNDWATER TOTAL | 286.5 | 292.2 | 309.9 | 330.8 | 348.5 | 368.5 |
| SURFACE WATER BY SUBREGION | Chariton-Grand | 13.44 | 13.27 | 13.38 | 13.41 | 13.19 | 12.97 |
| | Gasconade-Osage | 15.16 | 15.48 | 16.47 | 17.65 | 18.64 | 19.71 |
| | Lower Mississippi-St. Francis | 0.54 | 0.55 | 0.56 | 0.58 | 0.59 | 0.61 |
| | Lower Missouri | 264.8 | 267.1 | 274.8 | 285.5 | 292.6 | 300.5 |
| | Missouri-Nishnabotna | 88.7 | 90.3 | 95.6 | 102.0 | 107.5 | 113.8 |
| | Neosho-Verdigris | 13.03 | 13.26 | 13.93 | 14.72 | 15.33 | 15.97 |
| | Upper Mississippi-Kaskaskia-Meramec | 89.9 | 89.34 | 87.81 | 87.44 | 86.27 | 85.46 |
| | Upper Mississippi-Salt | 9.86 | 9.80 | 9.89 | 10.04 | 10.04 | 10.04 |
| | Upper White | 24.91 | 25.68 | 27.95 | 30.64 | 33.06 | 35.67 |
| | SURFACE WATER TOTAL | 520.4 | 524.8 | 540.4 | 562.0 | 577.1 | 594.7 |
| **STATE TOTAL** | | **806.9** | **817.0** | **850.4** | **892.8** | **925.6** | **963.2** |

Spatially, increases in demand generally follow trends in population and employment projections across the state. **Figure 3-14** presents the 2060 water demand forecast for the Major Water Systems summarized by the county in which the demand occurs. The greatest growth in demand is projected for St. Charles County, with an increase of 43 MGD. Clay County has significant projected increases of 26 MGD. Significant increases are also projected for Boone, Green, Jefferson, Platte, and St. Louis counties. **Appendix C** provides a table of water demand projections for the Major Water Systems summarized by county.

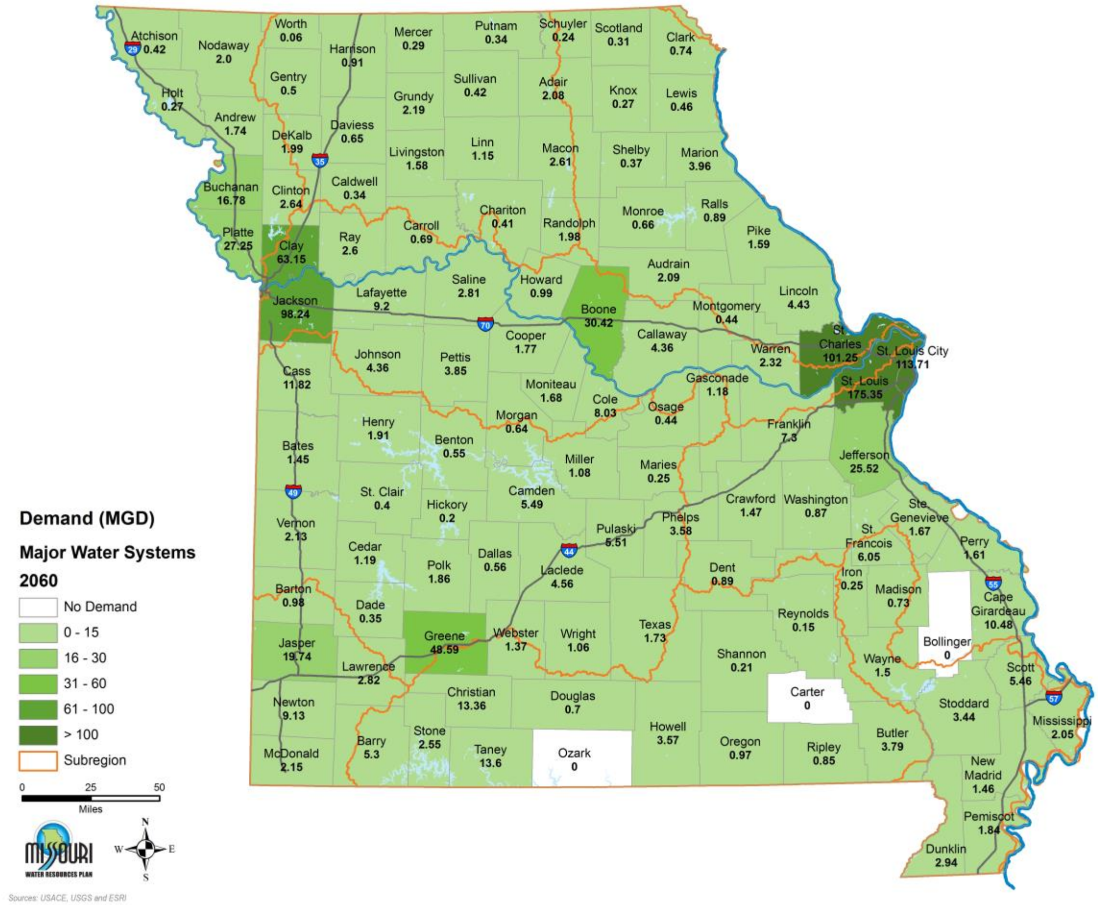


**Figure 3-14. Major Water Systems Water Demand Forecast by County in 2060[2]**

## 3.4 Self-Supplied Nonresidential

### 3.4.1 Introduction and Definition

The Self-Supplied Nonresidential sector includes commercial, institutional, and industrial water use that is not supplied from a community water system. This sector also includes golf courses and state and federal properties that are not accounted for in other sectors, such as state parks and recreation areas. Self-Supplied Nonresidential water users by county were identified primarily from MoDNR's Major Water Users database. Therefore, only entities with withdrawals large enough to meet the reporting requirements and those that comply and register use are captured[3]. Additionally, a small number of community water systems in the Census of Missouri Public Water Systems were identified as being a nonresidential establishment (such as a nursing home, school, or prison). Because these systems reported water use and source of water to the Census of Missouri Public Water Systems, their use could be included and quantified in the Self-Supplied Nonresidential sector. Even with the supplemental data, Self-Supplied Nonresidential water use data are limited; thus, the sector is known to be underestimated. The primary data sources used to estimate current and future water use for the Self-Supplied Nonresidential sector include:

[2] Demands are shown for the Major Water Systems sector, which includes 608 community systems in the state. There are nearly 900 additional smaller water systems throughout Missouri. The water demand for these systems is quantified in the Self-Supplied Domestic and Minor Systems sector, described in **Section 3.4**.
[3] This sector of MoDNR's Major Water Users database is known to be under registered and reported.

- MoDNR's Major Water Users Database
- Census of Missouri Public Water Systems
- Woods & Poole 2017 Complete Economic and Demographic Data Source
- Well Information Management System (WIMS) geodatabase

The Self-Supplied Nonresidential withdrawals associated with commercial, institutional, and industrial use are assumed to increase over time according to projected employment growth for the respective county and business classification. Withdrawals associated with golf courses are assumed to increase over time per the projected population growth of the county. Water withdrawals associated with state parks and recreation areas are assumed to remain the same in the future as they are today. **Appendix B** contains additional details regarding data sources, methodology, and assumptions.

**Missouri's Self-Supplied Nonresidential Sector:**

- 135 commercial, institutional, and industrial users
- 50 MGD to produce food and goods, mine natural resources, and provide services

### 3.4.2 Current Water Use Characteristics

**Figure 3-15** presents the current water demands for Self-Supplied Nonresidential water users by county. Not all counties have identified self-supplied users. **Table 3-5** summarizes the number of Self-Supplied Nonresidential water users and current annual water use by major employment category. Statewide, the food manufacturing and mining sectors account for 37 and 20 percent of Self-Supplied Nonresidential water use, respectively. Hotels and motels represent the greatest number of registered Self-Supplied Nonresidential water users.

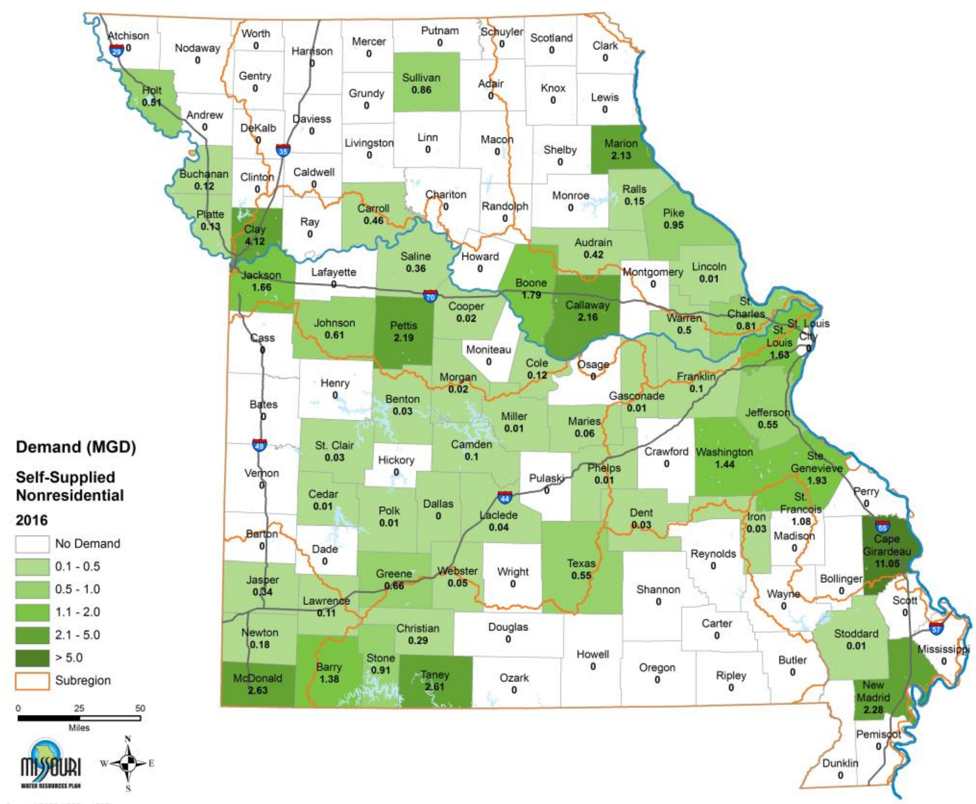


Figure 3-15. Self-Supplied Nonresidential Current Water Demand by County

**Table 3-5. Self-Supplied Nonresidential Current Water Use by Employment Category**

| Employment Category[4] | User Count | Annual Demand (MGD) | Percent Industries | Percent Demand |
|---|---|---|---|---|
| Food Manufacturing | 15 | 18.3 | 11% | 37% |
| Mining (Except Oil and Gas) | 16 | 10.1 | 12% | 20% |
| Miscellaneous Manufacturing | 6 | 3.7 | 4% | 7% |
| Educational Services | 8 | 3.6 | 6% | 7% |
| Paper Manufacturing | 1 | 2.9 | 1% | 6% |
| Chemical Manufacturing | 3 | 2.2 | 2% | 4% |
| Federal Government, Excluding Post Office | 4 | 1.6 | 3% | 3% |
| State Government, Excluding Education and Hospitals | 17 | 1.5 | 13% | 3% |
| Amusement, Gambling, and Recreation Industries | 12 | 1.3 | 9% | 3% |
| Petroleum and Coal Products Manufacturing | 6 | 1.3 | 4% | 2% |
| Accommodation, Including Hotels and Motels | 19 | 1.0 | 14% | 2% |
| Computer and Electronic Product Manufacturing | 2 | 0.8 | 1% | 2% |
| Federal Government, Military | 1 | 0.6 | 1% | 1% |
| Beverage and Tobacco Product Manufacturing | 1 | 0.5 | 1% | 1% |
| Printing and Related Support Activities | 1 | 0.3 | 1% | 1% |
| Social Services | 11 | 0.1 | 8% | <1% |
| Real Estate | 1 | 0.1 | 1% | <1% |
| Hospitals | 1 | 0.1 | 1% | <1% |
| Religious, Grantmaking, Civic, Professional, and Similar | 2 | 0.1 | 1% | <1% |
| Motor Vehicle and Parts Dealers | 1 | 0.1 | 1% | <1% |
| Wood Product Manufacturing | 2 | <0.1 | 1% | <1% |
| Data Processing, Hosting, and Related Services | 1 | <0.1 | 1% | <1% |
| Miscellaneous Store Retailers | 1 | <0.1 | 1% | <1% |
| Machinery Manufacturing | 1 | <0.1 | 1% | <1% |
| Air Transportation | 1 | <0.1 | 1% | <1% |
| Funds, Trusts, and Other Financial Vehicles | 1 | <0.1 | 1% | <1% |
| **STATE TOTAL** | **135** | **50.2** | | |

### 3.4.3 Sources of Water Supply

Characterizing the sources of water used for water supply is a critical step in identifying the strains, if any, placed upon Missouri's water resources. The detailed source of water was identified for each user in the Self-Supplied Nonresidential sector using MoDNR's Major Water Users database and the WIMS geodatabase. **Table 3-6** summarizes the Self-Supplied Nonresidential current water use by producing aquifer and surface water subregion. About 83 percent of the water for these users comes from groundwater, with approximately 53 percent pumped from the Lower Ozark Aquifer and 43 percent from alluvial sources. Of surface water withdrawals, 47 percent are withdrawn from the Upper Mississippi-Kaskaskia-Meramec and an additional 38 percent from the Upper Mississippi-Salt subregions.

[4] Employment categories are defined in **Appendix A**.

**Table 3-6. Self-Supplied Nonresidential Current Water Use by Detailed Source**

| Source | | Annual Demand (MGD) | Percent of Total Use |
|---|---|---|---|
| GROUNDWATER BY AQUIFER | Alluvial | 18.1 | 36% |
| | Upper Ozark | 0.55 | 1% |
| | Lower Ozark | 21.9 | 44% |
| | St. Francois | 1.11 | 2% |
| | Precambrian | <0.1 | <1% |
| | GROUNDWATER TOTAL | 41.6 | 83% |
| SURFACE WATER BY SUBREGION | Chariton-Grand | 0.86 | 2% |
| | Lower Missouri | 0.07 | 0% |
| | Neosho-Verdigris | 0.21 | 0% |
| | Upper Mississippi-Kaskaskia-Meramec | 4.03 | 8% |
| | Upper Mississippi-Salt | 3.23 | 6% |
| | Upper White | 0.15 | 0% |
| | SURFACE WATER TOTAL | 8.54 | 17% |
| **STATE TOTAL** | | **50.2** | |

### 3.4.4 Growth in County Employment

**Section 3.2.2** discusses employment projections by county and employment (NAICS) category. The growth rate by employment category and county was matched to the Self-Supplied Nonresidential water use based on the employment sector reported by the water users to MoDNR's Major Water Users database. For all self-supplied users except for state parks, the current water use was increased into the future based upon the corresponding growth rate for the county and employment category. The underlying assumption is that as the manufacturing of goods and services increases, so does the number of employees needed to produce these goods. Thus, regardless of the primary driver of water use within the nonresidential establishment (e.g., occupancy rate at a hotel or units of food produced), employment serves as a proxy for growth in water use.

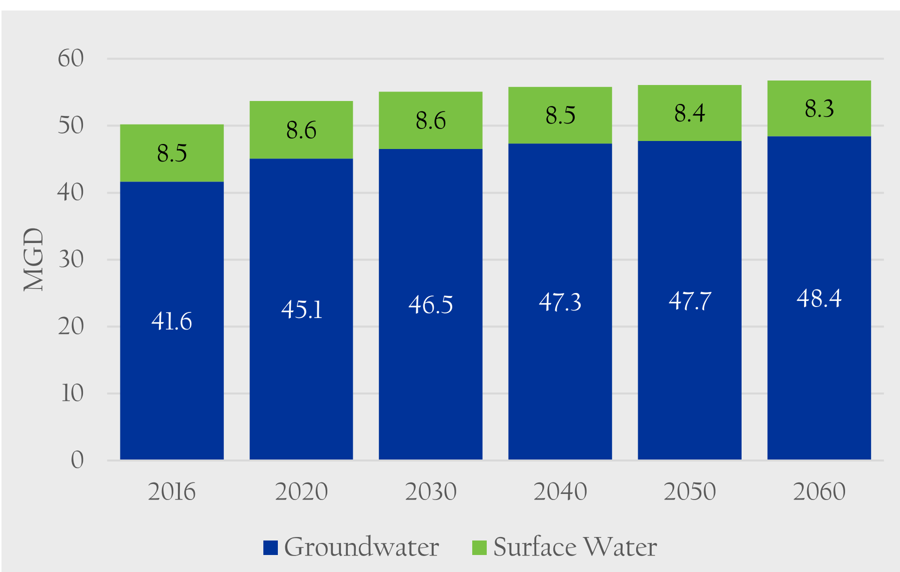


**Figure 3-16. Statewide Self-Supplied Nonresidential Demand Forecast by Source of Supply**

As noted in **Section 3.2.2**, employment for manufacturing is projected to decline statewide in the future, which is a continuation of recent trends. Therefore, for some self-supplied users, projected water use likewise declines in future years.

### 3.4.5 Future Water Demand

**Figure 3-16** shows the statewide future water demand for Self-Supplied Nonresidential water users. Overall, water demand from these users is projected to increase by 13 percent, or 6.5 MGD, from 2016 to 2060. Statewide demands are projected to reach 56.7 MGD by 2060. Groundwater demands are forecasted to increase by 16 percent while surface water demands are forecasted to decrease by 3 percent due to the statewide forecasted decline in mining. **Table 3-7** summarizes the Self-Supplied Nonresidential water demand forecast by detailed source of supply. Withdrawals from the Lower Ozark Aquifer are forecasted to increase by 41 percent and represent the greatest amount of withdrawals from any source for the Self-Supplied Nonresidential sector in 2060.

**Table 3-7. Self-Supplied Nonresidential Demand Forecast by Detailed Source**

| Source | | Self-Supplied Nonresidential Demand (MGD) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2016 | 2020 | 2030 | 2040 | 2050 | 2060 |
| GROUNDWATER BY AQUIFER | Alluvial | 18.1 | 18.2 | 17.6 | 16.7 | 15.7 | 14.9 |
| | Lower Ozark[1] | 21.9 | 25.2 | 26.9 | 28.4 | 29.5 | 30.9 |
| | Upper Ozark[1] | 0.55 | 0.57 | 0.64 | 0.73 | 0.82 | 0.92 |
| | St. Francois | 1.11 | 1.17 | 1.32 | 1.46 | 1.59 | 1.74 |
| | Precambrian | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| | GROUNDWATER TOTAL | 41.6 | 45.1 | 46.5 | 47.3 | 47.7 | 48.4 |
| SURFACE WATER BY SUBREGION | Chariton-Grand | 0.86 | 0.87 | 0.87 | 0.85 | 0.82 | 0.80 |
| | Lower Missouri | 0.07 | 0.07 | 0.08 | 0.08 | 0.07 | 0.07 |
| | Neosho-Verdigris | 0.21 | 0.21 | 0.22 | 0.22 | 0.23 | 0.23 |
| | Upper Mississippi-Kaskaskia-Meramec | 4.03 | 4.07 | 4.24 | 4.44 | 4.61 | 4.80 |
| | Upper Mississippi-Salt | 3.23 | 3.22 | 2.96 | 2.65 | 2.35 | 2.10 |
| | Upper White | 0.15 | 0.16 | 0.20 | 0.23 | 0.27 | 0.31 |
| | SURFACE WATER TOTAL | 8.54 | 8.61 | 8.56 | 8.48 | 8.35 | 8.30 |
| **STATE TOTAL** | | **50.2** | **53.7** | **55.1** | **55.8** | **56.1** | **56.7** |

[1] In many cases, the Upper Ozark Aquifer is producing along with the Lower Ozark Aquifer and in many cases the Lower Ozark Aquifer contributes more water to the well.

**Figure 3-17** presents the projected county water demands for Self-Supplied Nonresidential water users in 2060. Nearly all counties have modest changes in future demands, with a few exceptions. Increases of between 2 and 2.5 MGD are projected for Boone, McDonald, and Taney counties. These additional withdrawals support establishments such as hotels and educational services in Taney County, food production in McDonald County, and educational services in Boone County.

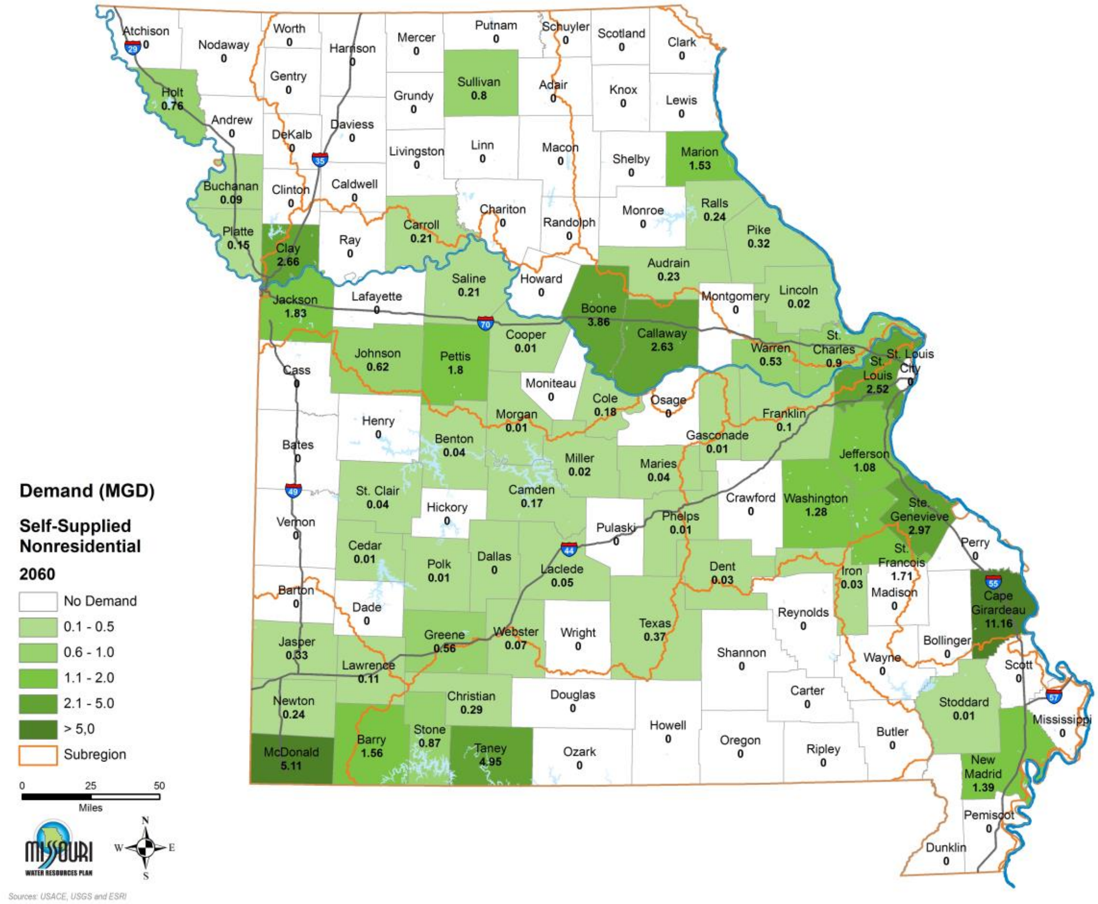


**Figure 3-17. Self-Supplied Nonresidential Water Demands by County in 2060**

## 3.5 Self-Supplied Domestic and Minor Systems

### 3.5.1 Introduction and Definitions

The Self-Supplied Domestic and Minor Systems sector represents water that is used by homes, subdivisions, small villages, estates, and mobile home parks that is supplied by a privately owned and operated well or smaller community water system. As previously stated, Missouri has 1,426 community water systems, which are defined as public water systems that supply water to the same population year-round (MoDNR 2016). Of these, the Self-Supplied Domestic and Minor Systems sector captures the water used by the population served by approximately 800 of these systems plus the population served by privately owned and operated domestic wells. In rural areas where groundwater is economically accessible and no public water system exists, homes typically have their own wells that supply water for indoor and outdoor uses. Essentially, this sector captures the water used by the residential population that is not included in the Major Water Systems sector (**Section 3.3**).

The primary data sources used to estimate current and future water use for the Major Water Systems sector include:

- Census of Missouri Public Water Systems
- Woods & Poole 2017 Complete Economic and Demographic Data Source
- USGS Estimated Use of Water in the United States (Maupin 2014)
- Public Drinking Water Wells GIS shapefile and the WIMS geodatabase

The current and future population included in the Self-Supplied Domestic and Minor Systems sector is discussed in **Sections 3.5.2** and **3.5.5**, respectively. Water demands are assumed to be supplied by groundwater. Detailed analysis of the producing aquifers supporting these demands is discussed in **Section 3.5.4**. The average rate of use for the Self-Supplied Domestic and Minor Systems model is expressed as GPCD. Current and future estimates of GPCD were developed by county as discussed in **Sections 3.5.3** and **3.5.6**. The future population served and GPCD rate of use are combined by county to project water demands to 2060 for the Self-Supplied Domestic and Minor Systems sector. Results are presented in **Section 3.5.7**. **Appendix B** provides additional details on how this sector was defined, primary data sources utilized, and how the water demand forecast was estimated.

### 3.5.2 Population Served

According to the annual Census of Missouri Public Water Systems, nearly 5.3 million people receive their water from a community water system (MoDNR 2016). Considering a population of 5.07 million served by the Major Water Systems sector (**Section 3.3**), an estimated 200,000 people who receive their water from a smaller rural system are included in the Self-Supplied Domestic and Minor Systems sector. With a state total population of 6.12 million (Woods & Poole 2017), an estimated 800,000 additional people rely on their own well for domestic water demands. In total, this sector covers a population of approximately 1.05 million people. This population is not evenly distributed throughout the state. Half of this population resides in the southern third of the state as shown in **Figure 3-18**. Concentrations of populations on private wells and those served by smaller systems stretch diagonally from outside of St. Louis to the southwest corner of the state.

**Self-Supplied Domestic and Minor Systems Sector:**

- 1.05 million people
- 200,000 served by smaller community systems
- 800,000 people rely on private wells

USGS reports on the self-supplied, domestic population by county in their water use reports. These data were assessed to determine historical trends in the self-supplied population. The USGS calculation of the self-supplied population is similar to the method employed in support of water demand calculations. The USGS definition of self-supplied is a residence with a private well, whereas the Self-Supplied Domestic and Minor Systems sector includes many smaller systems that serve less than 1,000 people. Nonetheless, assessing trends in USGS data is useful for understanding how this sector is growing or declining with time.

The USGS data show that historically self-supplied populations are increasing but not proportionately with total population (Solley et al. 1998, Solley et. al. 1993, Hutson et al. 2005, Kenny et al. 2009, Maupin et al. 2014). The 1990 USGS series indicates that the self-supplied population was 20 percent of the total state population. By 2010, this had declined to 15 percent. The trend varies by county. In most, the self-supplied population is growing proportionally to total county population, meaning the percent of population served to total county population is fairly constant over time. In other counties, the self-supplied population is holding constant over time regardless of population growth within a county. This indicates that new development occurs in places where community water systems provide drinking water. Examples of counties where population on private wells is generally constant over time include Butler, Camden, Morgan, and Washington counties. Some counties are experiencing declines in the self-supplied population, such as Andrew, Daviess, DeKalb, Gentry, Harrison, Holt, Jefferson, Mississippi, Vernon, and Wayne counties. Many of these counties are found in the northern half of the state. Declines in the domestic population on wells occur as water districts form or as rural population declines.

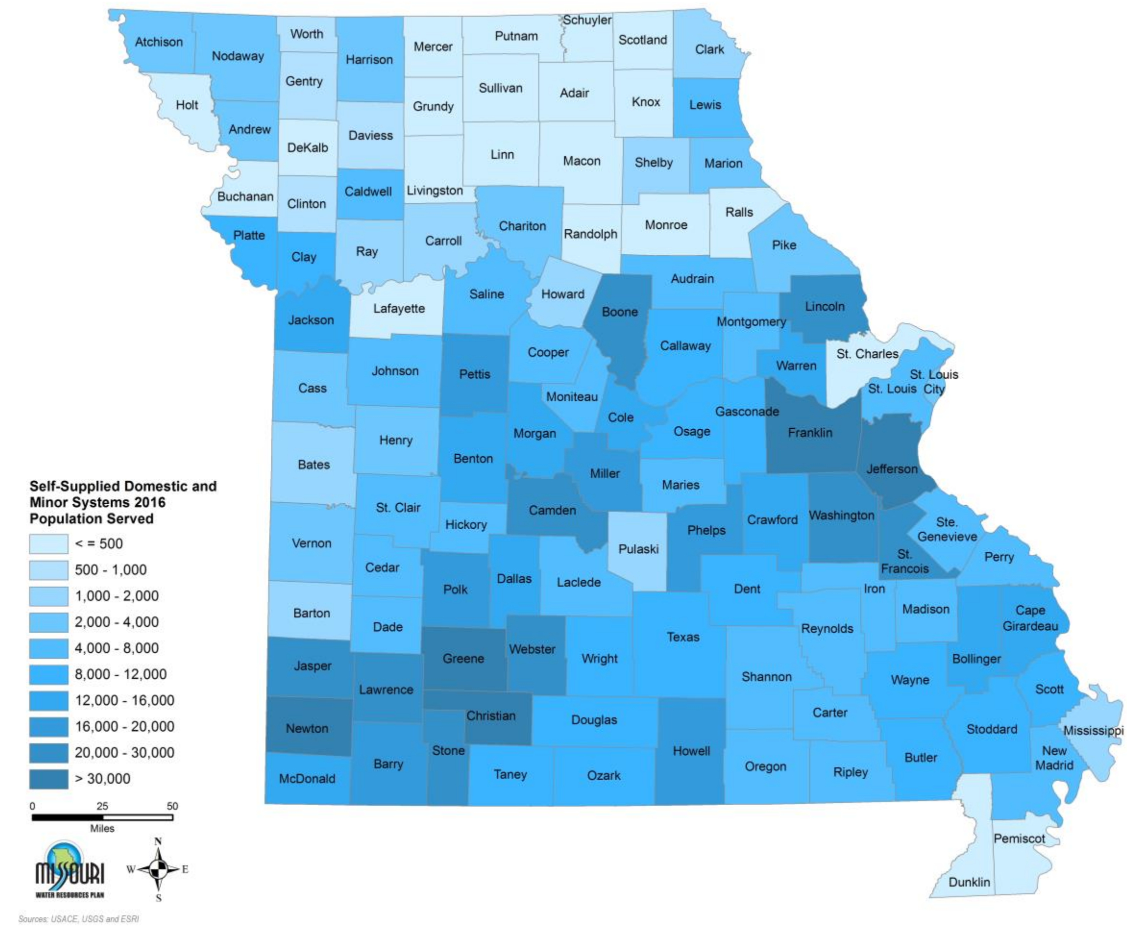


**Figure 3-18. Self-Supplied Domestic and Minor System Current Population by County**

### 3.5.3 Current Water Use Characteristics

On average, the population in the Self-Supplied Domestic and Minor Systems category uses 70 GPCD and ranges from 49 to 93 GPCD (Maupin et al. 2014). **Appendix C** provides a table of current GPCD assumptions by county for the Self-Supplied Domestic and Minor Systems sector. Statewide, this equates to 73 MGD of water withdrawn from groundwater sources. **Figure 3-19** presents the current water use by Self-Supplied Domestic and Minor Systems by county. Christian, Franklin, Greene, Jefferson, and Newton counties have the greatest withdrawals in this sector.

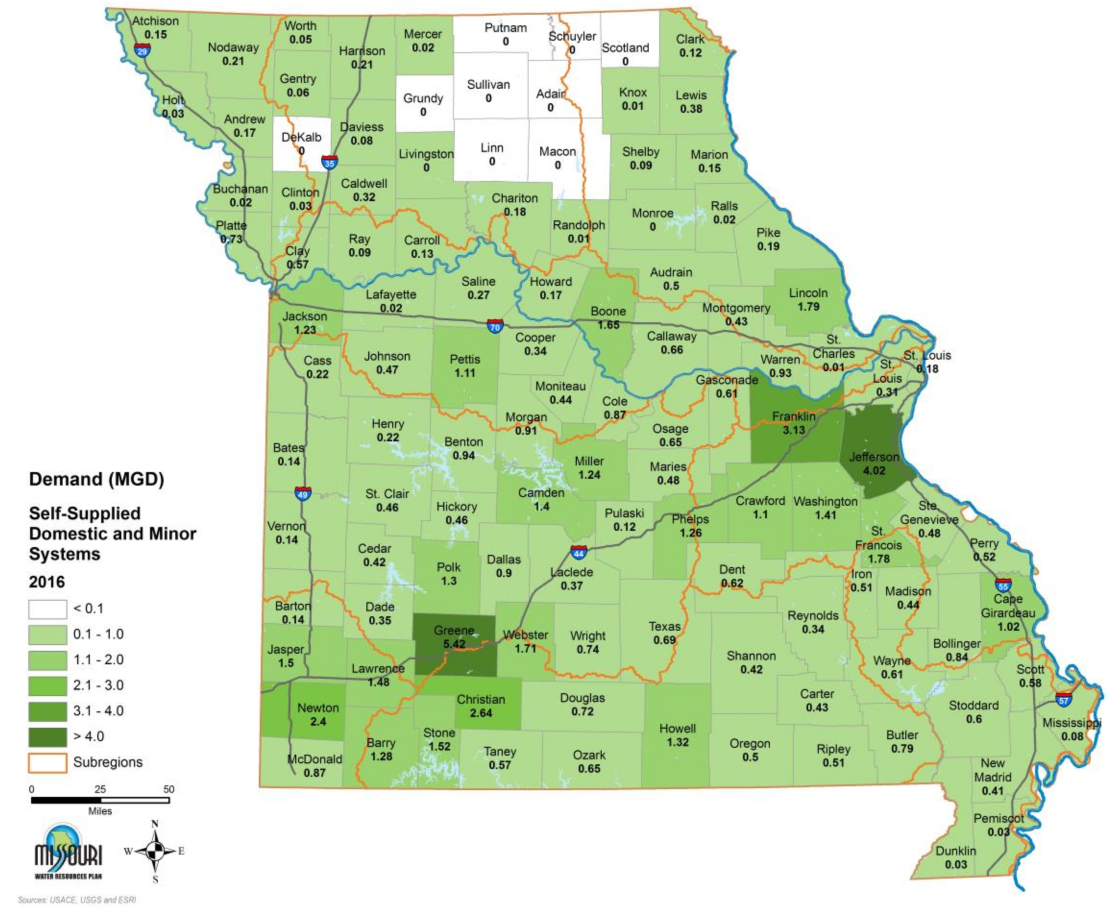


Figure 3-19. Self-Supplied Domestic and Minor Systems Water Demands by County in 2016

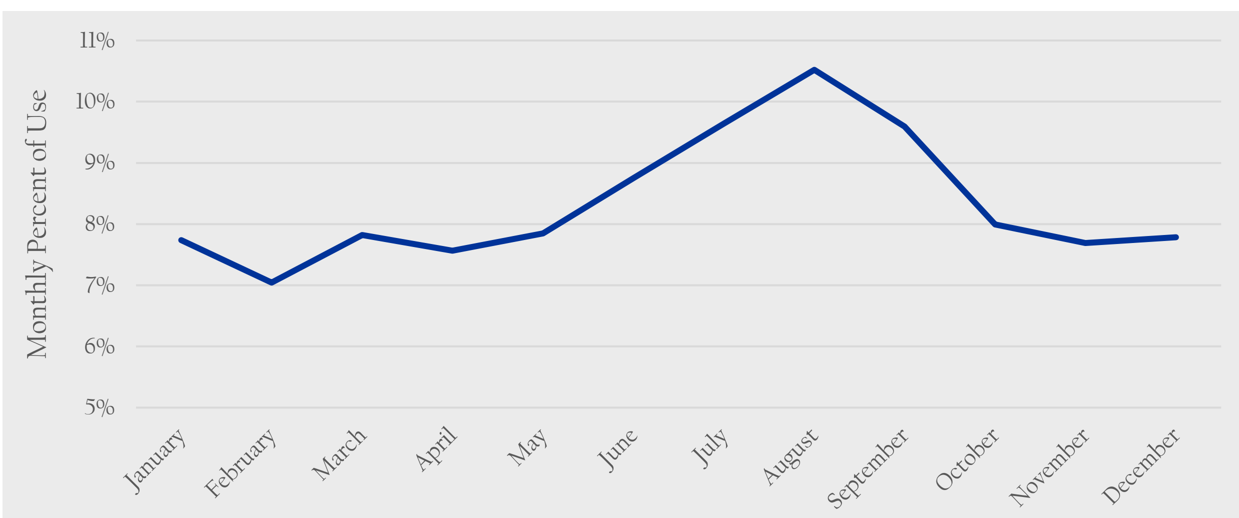


Figure 3-20. Self-Supplied Domestic and Minor Systems Seasonal Water Use Pattern

Water use varies throughout the year, with a peak in the summer months when outdoor water use occurs. **Figure 3-20** displays the seasonal patterns of Self-Supplied Domestic and Minor Systems water use. Approximately 7 to 8 percent of annual water demand occurs during each winter month when water use is mostly limited to indoors. As with the Major Water Systems sector, monthly water use begins to increase in June when swimming pools are filled, gardens and landscapes require watering, and people are generally using water outside the home. Water use peaks in August and then begins to decrease. There is variation in this pattern from region to region.

### 3.5.4 Sources of Water Supply

The demands of Self-Supplied Domestic and Minor Systems are assumed to be supplied by groundwater wells. Aquifer assumptions were made based on information known about public drinking wells and potable groundwater availability by county for each aquifer (assessed from the WIMS geodatabase and Public Drinking Water Wells GIS shapefile). Domestic wells are assumed to generally be shallower than public supply wells since they require less yield. As such, shallower aquifers were given more emphasis. **Table 3-8** provides detailed estimated current use data by groundwater aquifer. Three-quarters of the Self-Supplied Domestic and Minor Systems water use is supplied from the Lower Ozark Aquifer.

**Table 3-8. Self-Supplied Domestic and Minor Systems Current Water Use by Detailed Source**

| | Source | Annual Demand (MGD) | Percent of Total Use |
|---|---|---|---|
| GROUNDWATER BY AQUIFER | Alluvial | 5.04 | 7% |
| | Glacial Deposits | 2.11 | 3% |
| | Wilcox | 0.36 | <1% |
| | McNairy | 0.30 | <1% |
| | Pennsylvanian-age Bedrock | 1.21 | 2% |
| | Springfield Plateau | 1.89 | 3% |
| | Mississippian-age Bedrock | 1.25 | 2% |
| | Upper Ozark | 1.75 | 2% |
| | Lower Ozark | 55.5 | 76% |
| | St. Francois | 3.51 | 5% |
| | **STATE TOTAL** | **72.9** | |

### 3.5.5 Future Population Served

The trend in self-supplied population for each county was assessed from the USGS data from 1990 through 2010 (Solley et al. 1993, Solley et. al. 1998, Hutson et al. 2005, Kenny et al. 2009, Maupin et al. 2014). County trends that were measurable and notable were assumed to continue throughout the 2060 forecast horizon. **Figure 3-21** presents results of projecting the population captured in the Self-Supplied Domestic and Minor Systems sector to 2060 by county. Statewide, Self-Supplied Domestic and Minor Systems population holds steady at about 17 percent of total population, reaching a total of 1.29 million by 2060. The projection trend varies by county. **Appendix C** provides a table of Self-Supplied Domestic and Minor Systems population projections by county.

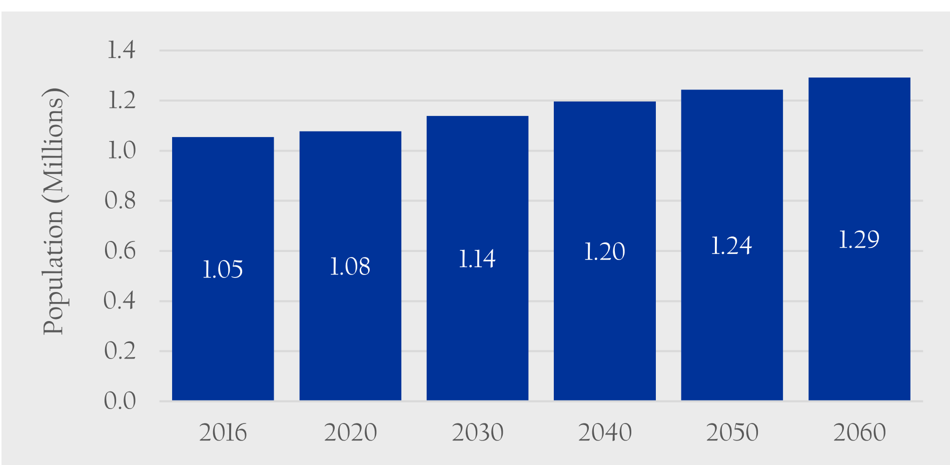


**Figure 3-21. Statewide Self-Supplied Domestic and Minor Systems Population Coverage Forecast**

### 3.5.6 Trends in Per Capita Use from Passive Savings

As described in **Section 3.3.6**, indoor water use has declined passively over time with the prevalence of water efficient fixtures in the market place and the replacement of older, inefficient or leaking fixtures with more efficient ones inside of homes. As with the Major Water Systems GPCD forecast, per capita water use for the Self-Supplied Domestic and Minor Systems sector is assumed to decline annually by 0.25 percent from 2016 through 2030, with a minimum of 50 GPCD. Under these assumptions, statewide indoor water demand for these users is projected to decline by 2.5 GPCD by 2030. Given the 1.14 million people projected to be served by this sector in 2030, this small reduction equates to over 2.8 million gallons (mgal) of water saved every day compared to 2016 use rates, or 1 billion gallons every year.

**Self-Supplied Domestic and Minor Systems Sector:**

The modest assumed reduction in per capita demand due to passive savings equates to water savings of 1 billion gallons each year for the users in this sector.

### 3.5.7 Future Water Demand

Given the trend in population that is self-supplied or served by smaller water systems and declining trends in per capita use, water demands for this sector can be estimated. **Figure 3-22** shows statewide future water demand for Self-Supplied Domestic and Minor Systems sector. Overall, water demand from these users is projected to increase by 18 percent from 2016 to 2060, or by 13.2 MGD. Statewide demands are projected to reach 86 MGD by 2060. **Figure 3-22** presents county water demands forecast to 2060.

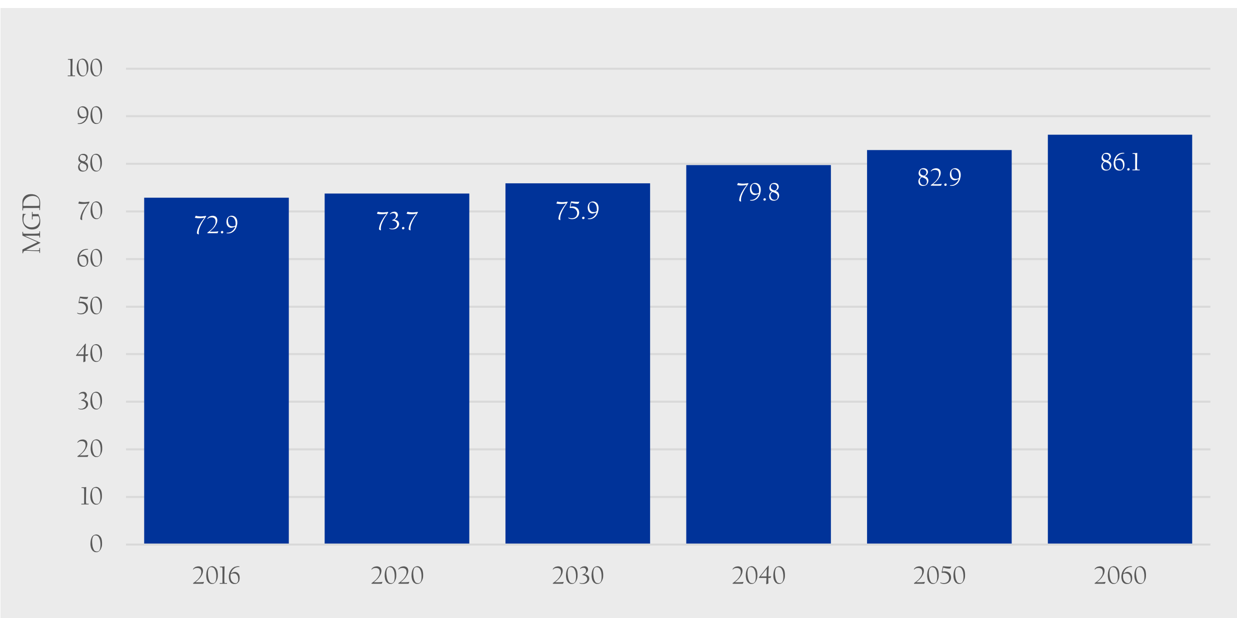


**Figure 3-22. Statewide Self-Supplied Domestic and Minor Systems Demand Forecast**

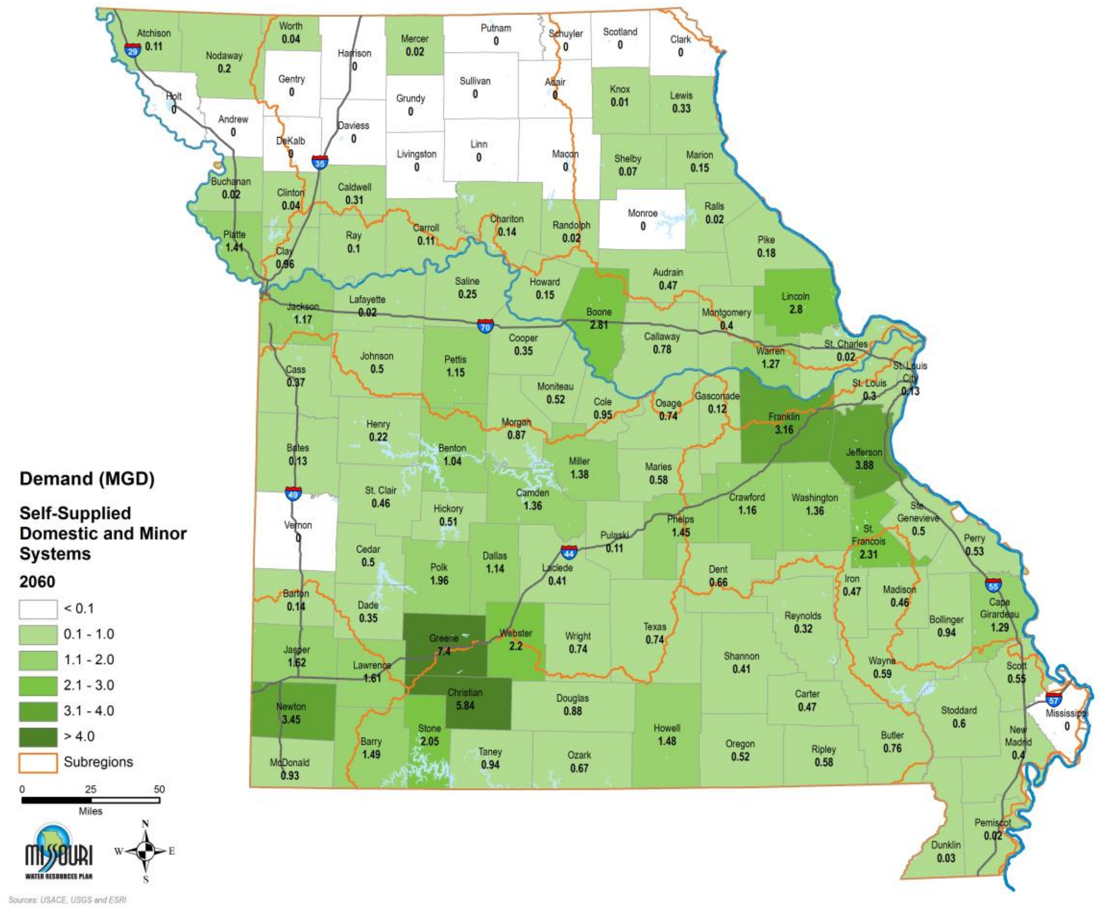


**Figure 3-23. Self-Supplied Domestic and Minor Systems Water Demand Forecast by County in 2060**

**Table 3-9** summarizes the Self-Supplied Domestic and Minor Systems water demand forecast by groundwater aquifer. Per the geographic location of the growth in the self-supplied population, significant increases are only projected for the Lower Ozark Aquifer. All other groundwater resources are projected to have minor changes in withdrawals.

**Table 3-9. Self-Supplied Domestic and Minor Systems Demand Forecast by Source**

| Source | | Self-Supplied Domestic and Minor Systems Demand (MGD) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2016 | 2020 | 2030 | 2040 | 2050 | 2060 |
| GROUNDWATER BY AQUIFER | Alluvial | 5.04 | 5.09 | 5.27 | 5.62 | 5.93 | 6.26 |
| | Glacial Deposits | 2.11 | 1.94 | 1.56 | 1.56 | 1.53 | 1.51 |
| | Wilcox | 0.36 | 0.34 | 0.31 | 0.31 | 0.30 | 0.30 |
| | McNairy | 0.30 | 0.29 | 0.27 | 0.27 | 0.27 | 0.27 |
| | Pennsylvanian-age Bedrock | 1.25 | 1.27 | 1.32 | 1.39 | 1.44 | 1.49 |
| | Springfield Plateau | 1.89 | 1.92 | 2.00 | 2.13 | 2.25 | 2.38 |
| | Mississippian-age Bedrock | 1.21 | 1.22 | 1.24 | 1.30 | 1.34 | 1.39 |
| | Upper Ozark | 1.75 | 1.80 | 1.93 | 2.09 | 2.24 | 2.39 |
| | Lower Ozark | 55.5 | 56.3 | 58.3 | 61.3 | 63.7 | 66.1 |
| | St. Francois | 3.51 | 3.56 | 3.65 | 3.80 | 3.89 | 3.98 |
| | **STATE TOTAL** | **72.9** | **73.7** | **75.9** | **79.8** | **82.9** | **86.1** |

## 3.6 Thermoelectric Power Generation

### 3.6.1 Introduction and Definitions

The generation of electricity from nonrenewable sources requires water for cooling and steam generation. Water for thermoelectric power is used when generating electricity with steam-driven turbines. The configuration, cooling system, and fuel type can vary from plant to plant and impacts the amount of water withdrawn and consumed. There are more than 100 thermoelectric power plants in Missouri, but only 25 produce more than 50,000 megawatt-hours (MWh) (U.S. Energy Information Administration [EIA] 2015a).

**Missouri's Thermoelectric Power Generation:**

- 25 thermoelectric plants (producing >50,000 MWH)
- 24 burn fossil fuels
- 1 nuclear fuel
- 3 receive municipal water
- 22 have own source and are quantified in the water demand sector

Configuration, fuel source, and water use were assessed for Missouri's 25 larger thermoelectric plants. Missouri has a single thermoelectric power plant that relies on nuclear fuel cells to produce electricity. In nuclear fission, atoms are split apart to form smaller atoms, releasing energy. The released energy is used to heat water and produce steam. Large turbines are turned with the steam to generate electricity. The remaining plants burn fossil fuels such as coal or natural gas. These plants generate electricity by burning fuel to heat a fluid called the prime mover, which turns a turbine and is then cooled. The prime mover may be steam or other gases, and the cooling process may be a once-through cooling system or a recirculating "closed-loop" system. For example, a steam plant with a once-through cooling system will use large volumes of water for both the prime mover and cooling, with large withdrawal volumes and large discharge volumes. However, a gas turbine with a closed-loop cooling system will only use a small amount of water for cooling. Thus, water withdrawal requirements and water consumption vary by the fuel type, prime mover, and cooling configuration of the generating unit. Of the 24 plants that burn fossil fuels, five burn coal or natural gas using a steam turbine and cooling tower; 11 burn coal or natural gas using a steam turbine and once-through cooling; and 9 burn natural gas using a combined cycle and cooling tower (one plant operates with two configurations).

Regardless of fuel type or configuration, power-generating capacity is measured in watts, kilowatts, megawatts (MW), and gigawatts. The power generated is calculated by multiplying the output of a generator by the number of hours the generator operated at a particular output level. Thus, the power generated is measured in watt-hours, kilowatt-hours, MWh, or gigawatt-hours. **Table 3-10** shows the water withdrawal and consumption rates in gallons per MWh for the common generating configurations in Missouri. Once-through cooling requires more water than other configurations, but the consumed portion is lower.

**Table 3-10. Water Requirements for Thermoelectric Power Generation**

| Generation Configuration | Withdrawal (Gallons per MWh) | Consumption (Gallons per MWh) | Consumed Percent |
|---|---|---|---|
| Coal or Natural Gas, Once-Through Cooling | 36,350 | 250 | <1% |
| Coal or Natural Gas, Cooling Towers | 1,005 | 687 | 68% |
| Nuclear, Cooling Towers | 1,101 | 672 | 61% |
| Natural Gas, Combined-Cycle, Cooling Towers | 253 | 198 | 78% |

*Source: MacKnick et al. 2011*

The source of water used by thermoelectric power plants varies throughout the state as discussed further in **Section 3.6.3**. Of the 25 largest thermoelectric power plants in Missouri, three receive their water from a municipal water system. Since these demands are reported by the municipal system and thus included in the Major Water Systems sector, the water use from these plants is excluded from the Thermoelectric Power Generation sector to avoid double-counting. The remaining 22 plants included in the Thermoelectric Power Generation sector are shown in **Figure 3-24**.

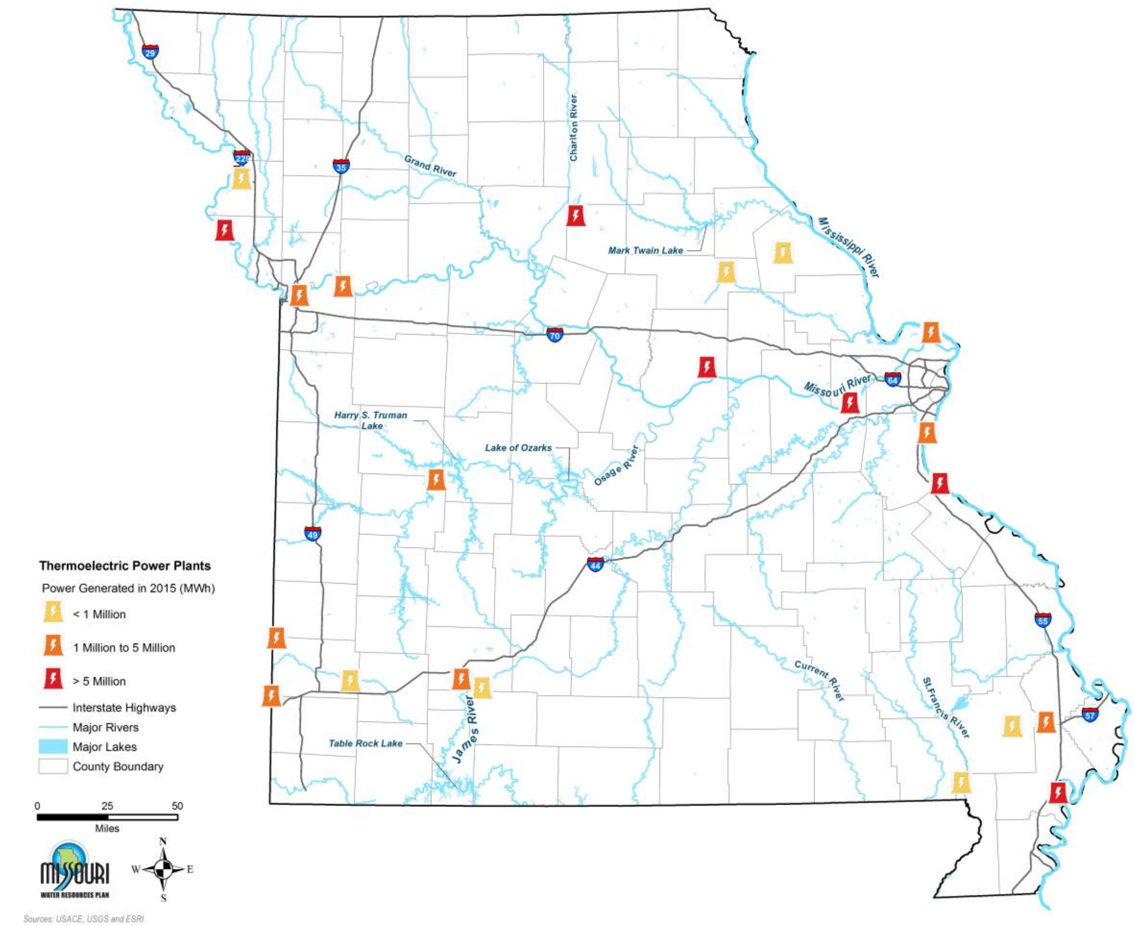


**Figure 3-24. Missouri's Thermoelectric Power Generation Plants Included in Water Demand Sector**

Using information regarding the withdrawal and use rates per generating hour and known plant configuration, fuel type, and net generation data, the amount of water withdrawn and consumed to produce thermoelectric power in Missouri is estimated as discussed in **Section 3.6.2**. The forecast of water demands for the Thermoelectric Power Generation sector relies upon the forecast of future power generation as discussed in **Section 3.6.4**. The primary data sources used to estimate current and future water use for the Thermoelectric Power Generation sector include:

- Woods & Poole 2017 Complete Economic and Demographic Data Source (growth in population)
- USGS Estimated Use of Water in the United States (Maupin 2014)
- Missouri's Major Water Users database
- EIA databases and reports
- Best available research for estimating the amount of water consumed during thermoelectric power generation (MacKnick et al. 2011)

### 3.6.2 Current Water Use Characteristics

The EIA, an analytical agency within the United States Department of Energy, collects and reports on electricity production data across the United States. From these data energy production for each facility is available as well as the plant configuration. With this and the water requirements data presented in **Table 3-10**, water withdrawals and consumption are estimated by facility. **Table 3-11** presents 2015 energy generation and estimated withdrawals and consumptive use amounts, summarized by configuration.

Approximately 96 percent of the power generated in Missouri is produced by the 22 facilities included in the Thermoelectric Power Generation sector (EIA 2015b). These facilities withdraw more than 6 billion gallons of water each day to support power generation but return all but 0.7 billion gallons to the source.

**Table 3-11. Thermoelectric Power Generation Current Water Use**

| Generation Configuration | Count[1] | 2015 Combined MWh[2] | 2015 Withdrawals (MGD)[3] | 2015 Consumption (MGD)[4] |
|---|---|---|---|---|
| Coal or Natural Gas, Steam Turbine, Cooling Tower | 4 | 4,401,009 | 12.2 | 8.31 |
| Coal or Natural Gas, Steam Turbine, Once-Through | 11 | 60,762,130 | 6,051 | 41.6 |
| Natural Gas, Combined Cycle, Cooling Tower | 7 | 2,639,691 | 2.53 | 1.98 |
| Nuclear, Steam, Cooling Tower | 1 | 10,440,082 | 31.5 | 19.2 |
| **TOTAL**[3] | **23** | **78,242,912** | **6,097** | **71.1** |

[1] One plant has two generators with different configurations; thus the total count of configurations is 23
[2] *Source: EIA 2015a*
[3] MoDNR's Major Water Users data were used to verify withdrawals; reported values were 6,106 MGD in 2015
[4] Estimated based on information found in **Table 3-10**

Electricity generation has seasonal peaks that translate to seasonal variations in water use. Monthly EIA data were analyzed to assess the seasonal trends in electricity production for Missouri facilities (EIA 2015b). As shown in **Figure 3-25**, electric generation peaks in January and July when the demand for heat and air conditioning is at its highest and is lower in spring and at the end of the year. Water withdrawals and consumptive amounts for thermoelectric power generation are assumed to follow this seasonal trend.

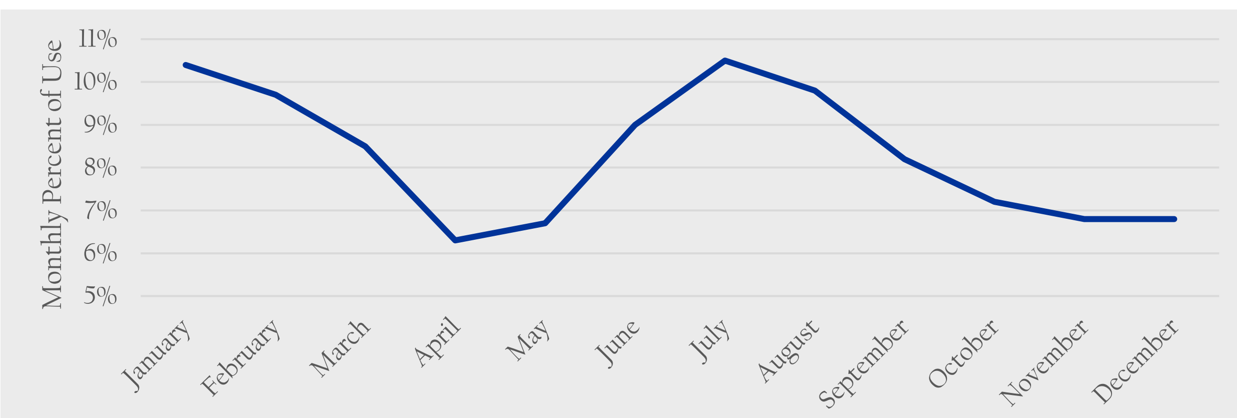


**Figure 3-25. Seasonal Generation of Thermoelectric Power**

### 3.6.3 Sources of Water Supply

87% of thermoelectric power generation water demands are met with surface water

Water demands for the facilities included in the Thermoelectric Power Generation sector were further analyzed to understand the source of water supply, which is estimated for each facility using information reported to MoDNR's Major Water Users and Public Wells databases. Understanding the demand of each source of water provides a foundation for identifying the strains, if any, placed upon Missouri's water resources. **Table 3-12** presents current water use by detailed surface water and groundwater sources for the Thermoelectric Power Generation sector. Eighty-seven percent of demands are met with surface water. More than half of the surface water demands are withdrawn from the Lower Missouri subregion, with an additional combined 22 percent coming from the Missouri-Nishnabotna and Upper Mississippi-Kaskaskia-Meramec subregions. Of groundwater demands, nearly 70 percent of use is withdrawn from the Lower Ozark Aquifer, with 31 percent supplied by alluvial sources.

**Table 3-12. Thermoelectric Power Generation Current Water Use by Detailed Source**

| Source | | Annual Withdrawals (MGD) | Annual Consumption (MGD) | Percent of Total Use |
|---|---|---|---|---|
| GROUND-WATER BY AQUIFER | Alluvial | 33.1 | 2.87 | 4% |
| | Upper Ozark | 0.10 | <0.1 | <1% |
| | Lower Ozark | 9.31 | 6.46 | 9% |
| | GROUNDWATER TOTAL | 42.5 | 9.41 | 13% |
| SURFACE WATER BY SUBREGION | Chariton-Grand | 763.4 | 5.25 | 7% |
| | Gasconade-Osage | 140.2 | 0.96 | 1% |
| | Lower Mississippi-Hatchie | 656.3 | 4.51 | 6% |
| | Lower Missouri | 2,165 | 33.7 | 48% |
| | Missouri-Nishnabotna | 912.0 | 6.65 | 9% |
| | Upper Mississippi-Kaskaskia-Meramec | 951.5 | 6.54 | 9% |
| | Upper Mississippi-Salt | 447.4 | 3.08 | 4% |
| | Upper White | 18.1 | 0.12 | <1% |
| | SURFACE WATER TOTAL | 6,054 | 60.9 | 87% |
| **STATE TOTAL** | | **6,096** | **70.3** | |

### 3.6.4 Future Thermoelectric Power Generation

The need for electricity is driven by the population, businesses, and industries that use it. **Figure 3-26** shows power generation in Missouri and the state's population from 1990 to 2015 and projections for both to 2060. The projected 7.5 million people and numerous businesses residing in Missouri will consume 113.5 million MWh of electricity by 2060, assuming per capita consumption of electricity remains at current levels.

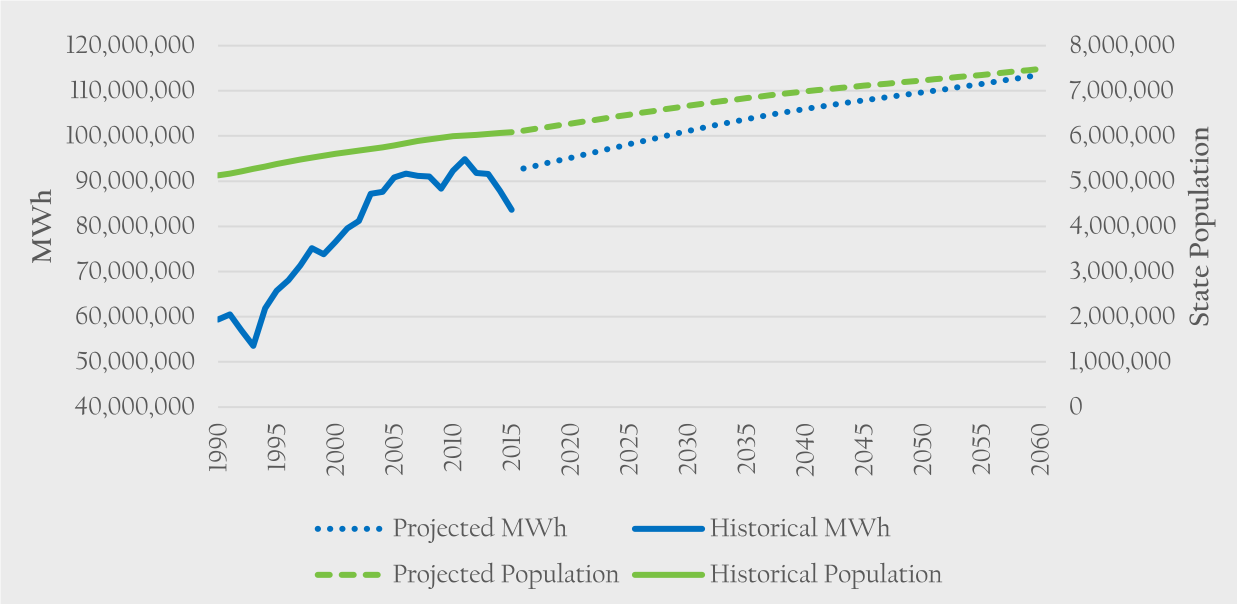


**Figure 3-26. Historical and Projected Missouri Population and Electricity Generation**

Not all the electricity used by Missouri's growing population will be produced by thermoelectric power facilities as some will be from renewable sources. Electricity is transmitted across the United States through a system of regional transmission organizations and independent system operators, referred to as energy pools. The U.S. Department of Energy and the Federal Energy Regulatory Commission regulate and monitor the transmission of power among pools. Missouri lies within the western portion of the Southeastern Electric Reliability Council-Gateway (SERC-G) energy pool and the eastern portion of the Southwest Power Pool-North (SPP-N) energy pool[5]. The EIA *Annual Energy Outlook 2017* report projects generation by fuel type to the year 2050 for the SERC-G and SPP-N energy pools as shown in **Table 3-13** (EIA 2017). The largest increase in power generation is anticipated from renewable sources. The projected decrease in petroleum power generation, natural gas-steam generation, and coal generation will have an impact on future water requirements for power generation. These generating technologies each use more water per MWh than natural gas, combined-cycle, or gas turbine technologies. Thus, the EIA projections for power generation in these two energy pools suggest a transition over time to more water-efficient power-generating technologies.

**Table 3-13. Forecast of Electricity Generation by Fuel Type of SPP-G and SERC-N Energy Pools (gigawatt-hours)**

| Fuel Type | 2015 | 2020 | 2030 | 2040 | 2050 | Percent Growth |
|---|---|---|---|---|---|---|
| Coal | 122,488 | 121,093 | 101,046 | 101,265 | 101,308 | -17% |
| Petroleum | 180 | 489 | 409 | 410 | 416 | 131% |
| Natural Gas | 5,775 | 6,175 | 8,664 | 8,792 | 12,336 | 114% |
| Nuclear | 27,734 | 18,879 | 20,454 | 21,124 | 16,566 | -40% |
| Renewable Sources | 16,879 | 36,423 | 48,878 | 56,593 | 67,489 | 300% |
| **Total Generation** | **172,986** | **183,008** | **179,400** | **188,134** | **198,065** | **14%** |

*Source: EIA 2017*

[5] Note that the Federal Energy Regulatory Commission pools changed in 2018.

Assuming that power generation within Missouri will reach the same proportions by fuel type as anticipated for the combined SPP-N and SERC-G regional energy pools by 2050, about 51 percent of power generation will be provided by coal, 6 percent from natural gas, 8 percent from nuclear energy, and 34 percent from renewable sources. The EIA projections do not distinguish between coal-fired, once-through cooling power generation and coal-fired, cooling tower power generation. Therefore, for this analysis, the proportion between these two sources is assumed to be constant within the state. Thus, the 51 percent of power generated that comes from coal is assumed to be about 48 percent from coal-fired, once-through cooling and about 3 percent from coal-fired, cooling tower generation. The statewide projection of power generation for all power-generating facilities is summarized in **Table 3-14**.

**Table 3-14. Estimated Future Thermoelectric Power Generation within Missouri from All Sources (MWh)**

| Fuel Type, Prime Mover, Cooling Type | 2020 | 2030 | 2040 | 2050 | 2060 |
|---|---|---|---|---|---|
| Coal or Natural Gas, Steam Turbine, Cooling Tower | 4,310,131 | 4,220,990 | 4,048,754 | 3,800,785 | 3,935,541 |
| Coal or Natural Gas, Steam Turbine, Once-Through | 59,290,982 | 58,064,740 | 55,695,424 | 52,284,311 | 54,138,044 |
| Natural Gas, Combined Cycle, Cooling Tower | 4,022,342 | 4,947,945 | 5,893,112 | 6,829,090 | 7,071,214 |
| Nuclear, Steam, Cooling Tower | 10,210,604 | 10,050,860 | 9,699,216 | 9,171,297 | 9,496,464 |
| *Subtotal Thermoelectric* | *77,834,059* | *77,284,535* | *75,336,506* | *72,085,482* | *74,641,262* |
| Other and Renewable | 17,334,182 | 23,823,739 | 30,638,334 | 37,565,743 | 38,897,631 |
| **STATE TOTAL** | **95,168,241** | **101,108,274** | **105,974,839** | **109,651,226** | **113,538,894** |

### 3.6.5 Future Water Demand

Thermoelectric Power Generation water demands are projected to decline as renewable sources are developed and older, water-intensive thermoelectric facilities are retired.

Statewide power generation and associated water requirements are estimated using the assumptions about future power generation presented in **Section 3.6.4** and the water requirements presented in **Table 3-10**. Estimated future power generation is allocated among corresponding thermoelectric power-generating facilities in the Thermoelectric Power Generation water demand sector. The statewide production of thermoelectric power is projected to decrease over time due to increases in renewable sources despite the increase in total electricity generation. This decline, coupled with the scheduled retirement of older, water-intensive facilities, results in a projected reduction in water demand for the Thermoelectric Power Generation sector of 9 percent as shown in **Figure 3-27**. Large facilities with once-through cooling that are scheduled to be retired include Meramec (St. Louis County in 2022), Sioux (St. Charles County in 2033), and two out of four generating units at Labadie (Franklin County in 2036) (Ameren Missouri 2017). These retirements are reflected in the decline in water use between the 2030 and 2040 planning periods. Statewide withdrawals are estimated to decline from current rates of over 6,100 to 5,434 MGD by 2060.

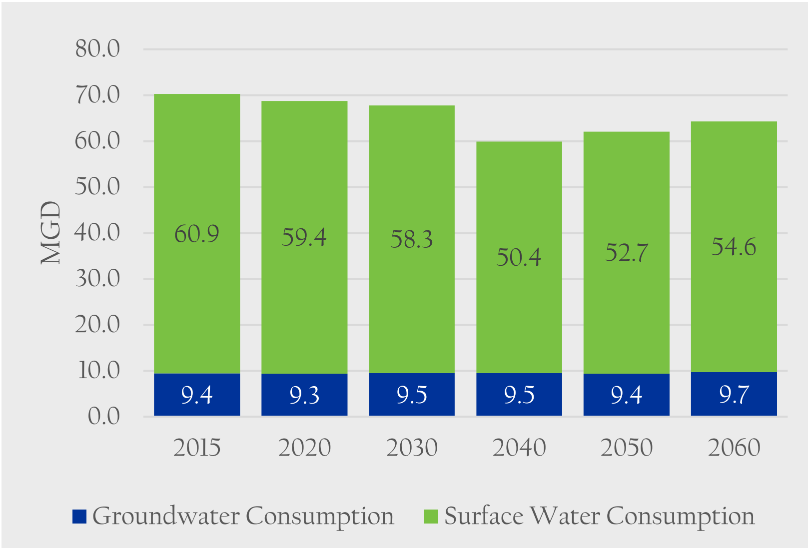


**Figure 3-27. Statewide Thermoelectric Power Generation Water Demand Forecast**

County water demand projections are presented in **Appendix C**. The retirement of large water-using facilities in St. Charles and St. Louis counties reduces overall water withdrawal and consumption in those counties. Franklin County will also experience a reduction in water requirements. Most of the other counties with thermoelectric power generation facilities will experience about a 17 percent increase in water withdrawals and consumption.

The forecasted water withdrawals and consumption by detailed water source are presented in **Table 3-15 and Table 3-16**. Groundwater withdrawals predominantly occur from alluvial aquifers. However, groundwater consumption is highest from the Lower Ozark Aquifer. Most of the surface water withdrawals and consumption occur in the Lower Missouri subregion.

**Table 3-15. Thermoelectric Power Generation Water Demand Withdrawal Forecast by Detailed Source**

| Source | | Thermoelectric Water Withdrawal Forecast (MGD) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2016 | 2020 | 2030 | 2040 | 2050 | 2060 |
| GROUND-WATER BY AQUIFER | Alluvial | 33.1 | 32.4 | 32.8 | 31.0 | 33.7 | 34.9 |
| | Upper Ozark | 0.10 | 0.11 | 0.14 | 0.16 | 0.19 | 0.20 |
| | Lower Ozark | 9.01 | 8.93 | 9.07 | 9.06 | 8.92 | 9.24 |
| | GROUNDWATER TOTAL | 43 | 42 | 42 | 41 | 43 | 45 |
| SURFACE WATER BY SUBREGION | Chariton-Grand | 763 | 745 | 756 | 785 | 865 | 896 |
| | Gasconade-Osage | 140 | 137 | 139 | 144 | 159 | 165 |
| | Lower Mississippi-Hatchie | 656 | 640 | 650 | 675 | 744 | 770 |
| | Lower Missouri | 2,165 | 2,112 | 2,142 | 1,405 | 1,543 | 1,598 |
| | Missouri-Nishnabotna | 912 | 890 | 903 | 938 | 1,033 | 1,070 |
| | Upper Mississippi-Kaskaskia-Meramec | 951 | 928 | 734 | 762 | 840 | 870 |
| | Upper Mississippi-Salt | 447.4 | 436.6 | 442.9 | 0 | 0 | 0 |
| | Upper White | 18 | 18 | 18 | 19 | 21 | 21 |
| | SURFACE WATER TOTAL | 6,054 | 5,907 | 5,784 | 4,728 | 5,205 | 5,389 |
| **STATE TOTAL** | | **6,096** | **5,949** | **5,827** | **4,768** | **5,248** | **5,434** |

**Table 3-16. Thermoelectric Power Generation Water Demand Consumptive Use Forecast by Detailed Source**

| Source | | Thermoelectric Water Consumptive Forecast (MGD) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2016 | 2020 | 2030 | 2040 | 2050 | 2060 |
| GROUND-WATER BY AQUIFER | Alluvial | 2.87 | 2.83 | 2.85 | 2.82 | 2.77 | 2.87 |
| | Upper Ozark | 0.08 | 0.09 | 0.11 | 0.13 | 0.15 | 0.15 |
| | Lower Ozark | 6.26 | 6.22 | 6.34 | 6.37 | 6.30 | 6.52 |
| | GROUNDWATER TOTAL | 9.4 | 9.3 | 9.5 | 9.5 | 9.4 | 9.7 |
| SURFACE WATER BY SUBREGION | Chariton-Grand | 5.25 | 5.12 | 5.20 | 5.40 | 5.95 | 6.16 |
| | Gasconade-Osage | 0.96 | 0.94 | 0.95 | 0.99 | 1.09 | 1.13 |
| | Lower Mississippi-Hatchie | 4.51 | 4.40 | 4.47 | 4.64 | 5.11 | 5.30 |
| | Lower Missouri | 33.7 | 33.0 | 32.9 | 27.2 | 27.2 | 28.2 |
| | Missouri-Nishnabotna | 6.65 | 6.49 | 6.57 | 6.80 | 7.43 | 7.70 |
| | Upper Mississippi-Kaskaskia-Meramec | 6.54 | 6.39 | 5.05 | 5.24 | 5.78 | 5.98 |
| | Upper Mississippi-Salt | 3.1 | 3.0 | 3.0 | 0 | 0 | 0 |
| | Upper White | 0.12 | 0.12 | 0.12 | 0.13 | 0.14 | 0.15 |
| | SURFACE WATER TOTAL | 60.9 | 59.4 | 58.3 | 50.4 | 52.7 | 54.6 |
| **STATE TOTAL** | | **70.3** | **68.8** | **67.8** | **59.9** | **62.1** | **64.3** |

## 3.7 Livestock

### 3.7.1 Introduction and Definitions

Animal agriculture accounts for about half the $9.1 billion of agricultural commodities sold in Missouri each year (U.S. Department of Agriculture [USDA] 2014a). The most common livestock commodities in Missouri are cattle, poultry products, and hogs; sales of these products totaled nearly $4.3 billion during 2012.

Water is critical to maintaining animal health on Missouri's farms. Livestock producers need water for animal consumption, animal cooling, sanitation, and waste removal (Maupin et al. 2014). The water demands estimated in this sector include water used at CAFOs as well as that consumed by pastured animals. The water needed to support animal processing, such as at packing plants, is captured in the Self-Supplied Nonresidential sector if the plant has its own source of water (**Section 3.4**) and the Major Water Systems (**Section 3.3**) and Self-Supplied Domestic and Minor Systems (**Section 3.5**) if the plant receives its water from a public water system.

On a county-by-county basis, this section presents estimates of current and future surface water and groundwater withdrawals to support animal agriculture in Missouri. Estimates and projections reflect use from the following animal sectors:

- Beef, including cows, steers, and heifers
- Dairy, including cows and heifers
- Hogs
- Horses
- Poultry, including turkeys, broilers, and laying hens
- Sheep and goats

For each animal sector, annual water demand was estimated by multiplying the average daily water requirement by the number of animals. That product was multiplied by the number of days per year an animal spends in Missouri, which varies by type of animal. For example, beef and dairy cows are assumed to be in Missouri for 365 days. However, market cattle (feeder calves and stocker cattle) are assumed to stay in Missouri for only a portion of the year. The primary data sources used to estimate current and future water use for the Livestock sector include:

- USDA Census of Agriculture (USDA 2014a)
- USGS Method for Estimating Water Withdrawals for Livestock in the United States (Lovelace 2009)
- Food and Agricultural Policy Research Institute (FAPRI) projections of meat consumption per capita (2018)

### 3.7.2 Current Water Use Characteristics

To derive current water use by animal agriculture in Missouri, county-level, base-year livestock numbers were obtained from the 2012 Census of Agriculture. These data provide the most widely accepted, independent assessment of livestock numbers in the state. The three previous USDA Census of Agriculture (2007, 2002, and 1997) surveys coupled with global demand projections from USDA and other agencies provided data to model a growth trend line and estimate animal inventory for 2016. It is noteworthy that USDA chooses not to disclose data for some counties when producer anonymity is questionable (for instance, a single, identifiable producer in a county). Thus, the ranked county profiles were interpolated to obtain a mathematical estimate for some of the livestock categories in some counties. Estimated county livestock numbers were summed for each livestock sector and compared to the state-reported total. A second interpolation was employed when needed to adjust county data such that the sum of all county numbers matched the state's total number.

**Table 3-17. Estimated Daily Water Needs Per Animal in Gallons and Days Spent in Missouri Per Year**

| Animal | Gallons Per Day | Days Per Year |
|---|---|---|
| Beef cows | 22.75 | 365 |
| Steers/Heifers | 18 | 120 |
| Dairy cows | 30 | 365 |
| Sows | 6 | 365 |
| Barrows/Gilts | 3 | 183 |
| Goats | 1.25 | 365 |
| Sheep | 2 | 365 |
| Broilers | 0.06 | 84 |
| Pullets | 0.04 | 183 |
| Layers | 0.05 | 365 |
| Turkeys | 0.09 | 120 |
| Horses | 11 | 365 |

*Source: Lovelace 2009*

To complete the current livestock water demand analysis, the *USGS Method for Estimating Water Withdrawals for Livestock in the U.S.* was used (Lovelace 2009). These data provide daily water requirements for each livestock group and include water used for drinking, cooling, sanitation, and waste removal. Literature was reviewed to verify the USGS water requirements. **Table 3-17** summarizes daily animal water requirements selected for the analysis and highlights the number of days per year each type of animal was assumed to be in Missouri.

Based on these assumptions, it is estimated that Missouri's animal agriculture industry currently uses 111 MGD of water. Livestock industries in the following counties required the most water: Vernon, 5.7 MGD; Barry, 3.2 MGD; Sullivan, 3.0 MGD; Lawrence, 2.8 MGD; and Newton, 2.8 MGD.

**Figure 3-28** presents the current water demands for livestock summarized by county. Demands tend to be strongest in southwest, south central, west central, central, and north central counties. Eastern counties use less water for animal agriculture.

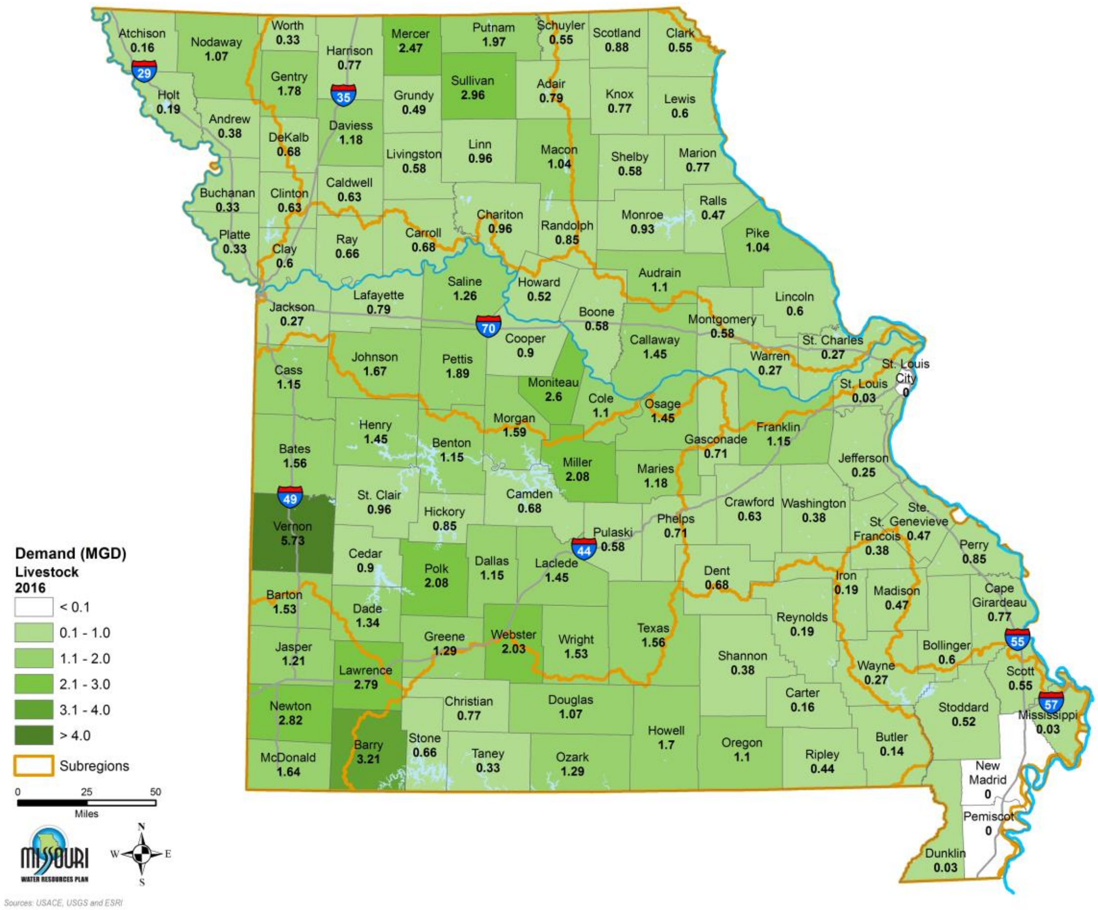


**Figure 3-28. Livestock Water Demand by County in 2016**

Beef cattle use the most water in Missouri. **Figure 3-29** shows the share of total animal agriculture water consumption by type. Beef cattle consume nearly three-quarters of the animal agriculture industry's total water demand. Hogs rank second. Collectively, poultry and other species such as goats, sheep, and horses use less than 10 percent of the total water consumed by animal agriculture.

The majority of the water consumed by Missouri's animal agriculture industry during 2016 originated from surface water sources. Of the total 111 MGD of water used by animal agriculture in 2016, **Figure 3-30** shows the proportion withdrawn from groundwater or surface water sources. As illustrated, 64 percent of total animal agriculture industry water demand was predominately satisfied by surface water sources compared with 36 percent from groundwater sources.

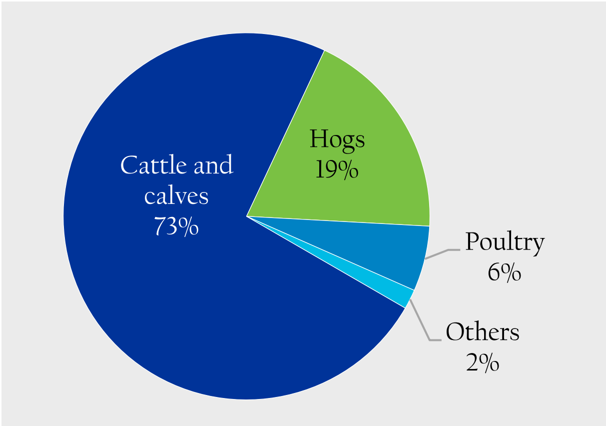


**Figure 3-29. Livestock Current Water Demand Percentage Use**

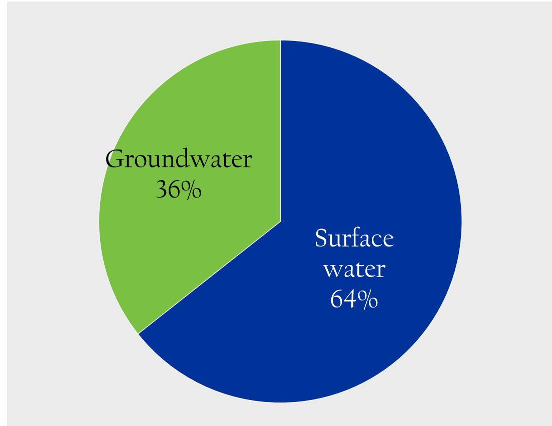


**Figure 3-30. Share of Current Livestock Water Demand by Source**

Surface water withdrawals vary by county according to the number of animals in the county and the surface water available therein. Surface water demands tend to be greatest in south central, southwest, west central, central, and northern counties. Eastern counties tend to withdraw less surface water to support animal agriculture production than counties in other regions. Counties that withdraw the most surface water for animal agriculture purposes are Mercer, 2.4 MGD; Putnam, 1.8 MGD; Sullivan, 1.8 MGD; Gentry, 1.7 MGD; and Moniteau, 1.64 MGD.

By region, Missouri animal producers rely on groundwater to support animal production to varying degrees. A survey of regional specialists within University of Missouri Extension indicated that groundwater use tends to increase along a latitudinal gradient from north to south within Missouri. Generally, the northern third of Missouri relies on groundwater to supply 10 to 15 percent of the water used for animal agriculture. In central Missouri counties, the percentage is 20 to 25. In the Ozarks area, groundwater supplies about 30 percent of the water for animal agriculture. The disparity between north and south Missouri relates to groundwater quality and availability, animal populations, and the partnership of public agencies with private enterprise to invest in water delivery systems. Soil and water conservation districts in southwest Missouri have historically invested more resources into water infrastructure as part of planned grazing systems than other parts of the state. Investing in public surface water impoundments for use by animal agriculture or designating cost-share funds to build ponds in northern Missouri is a proactive process to alleviate shortages in the future.

To support livestock production, groundwater use is greatest in south central, southwest, west central, and central Missouri. Similar to surface water withdrawals, groundwater withdrawals vary according to a county's livestock population and access to groundwater resources. Counties that withdraw the most groundwater for livestock purposes are Vernon, 4.7 MGD; Barry, 2.1 MGD; Newton, 1.5 MGD; Lawrence, 1.3 MGD; and Miller, 1.3 MGD.

### 3.7.3 Trends in Livestock Production

As indicated by data for the market value of livestock products sold, Missouri is a significant cattle, poultry, and hog producer. Additionally, Missouri is home to several other animal agriculture sectors. Demand for meat and animal by-products motivates livestock production decisions, which ultimately affect the livestock industry's water consumption. The FAPRI and Agricultural Markets and Policy group at the University of Missouri project that total meat consumption per capita will increase about 3 percent by 2027 (FAPRI 2018). Of total meat consumption, the greatest increase derives from broilers. In contrast, beef consumption is projected to decline slightly per capita by 2027. Consumption per capita for pork and turkey is projected to hold relatively steady during the forecast period. U.S. total fluid milk consumption per capita is projected to decline about 10 percent by 2027 (FAPRI 2018).

### 3.7.4 Future Water Demand

For Missouri livestock, future water demand hinges on two factors. First, changes in meat consumption dictate growth or contraction of the industry and therefore its water use. Second, changes in climate might influence how livestock producers access water. For example, declines in measured rainfall could cause producers to increase their reliance on groundwater sources.

To project beef cattle inventories by county through 2060, growth trend lines were developed from the USDA Census of Agriculture data from 1997 through 2012. Then, USDA global demand projections were fitted through 2027 to the historical trend line and continued to 2060. A similar process was used for hog and poultry inventories. The results showed annual increases in beef production of about 1 percent, pork increases of 0.68 percent, and poultry increases of 1.34 percent. A 1 percent annual increase was assumed for sheep, goats, and horses.

The University of Missouri College of Agriculture, Food, and Natural Resources funded the Show-Me-State Food, Beverage and Forest Products Manufacturing Initiative feasibility study in 2018 (University of Missouri College of Agriculture, Food and Natural Resources 2019). The study highlights the interdependent nature of Missouri's crop and livestock industries and concludes that finding profitable ways to expand livestock production is key to adding significant value to Missouri agriculture. If the strategic initiatives outlined are successfully implemented, the study projects statewide impact by 2027 that includes expanded total value-added agricultural and food manufacturing economic activity increases of more than $25 billion. Under this plan to grow Missouri's agricultural economy, water use will increase in several demand sectors beyond what is projected in the forecast.

Given these assumptions, **Figure 3-31** illustrates projected statewide water demand for the animal agriculture industry from 2020 to 2060. The industry is projected to require 115 MGD during 2020. Between 2020 and 2060, animal agriculture water demand is projected to increase roughly 45 percent and exceed 169 MGD in 2060.

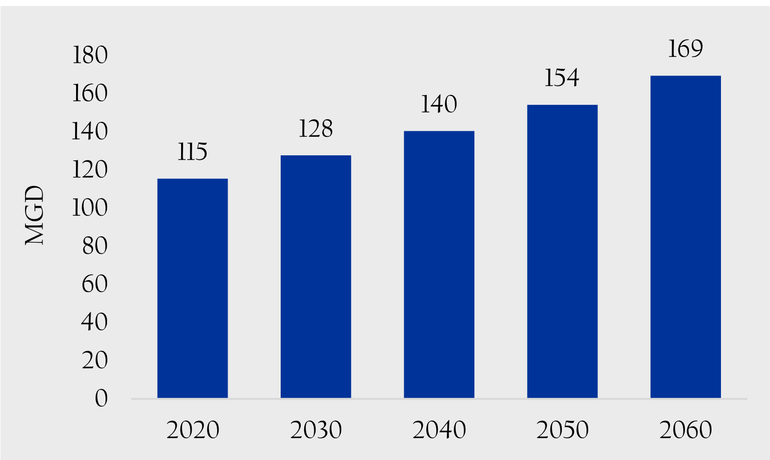


**Figure 3-31. Projected Water Demand for Livestock Industry from 2020 to 2060**

By 2060, 169 MGD of water is projected to be needed to support Missouri's livestock production; this includes water for pastured animals and at CAFO operations.

**Figure 3-32** presents the 2060 water demand forecast summarized by county for livestock. As described earlier, the counties estimated to lead in 2016 livestock water demand were Barry, Lawrence, Newton, Sullivan, and Vernon. The same five counties are projected to lead in water consumed by livestock during 2060; however, their rankings are projected to shift slightly.

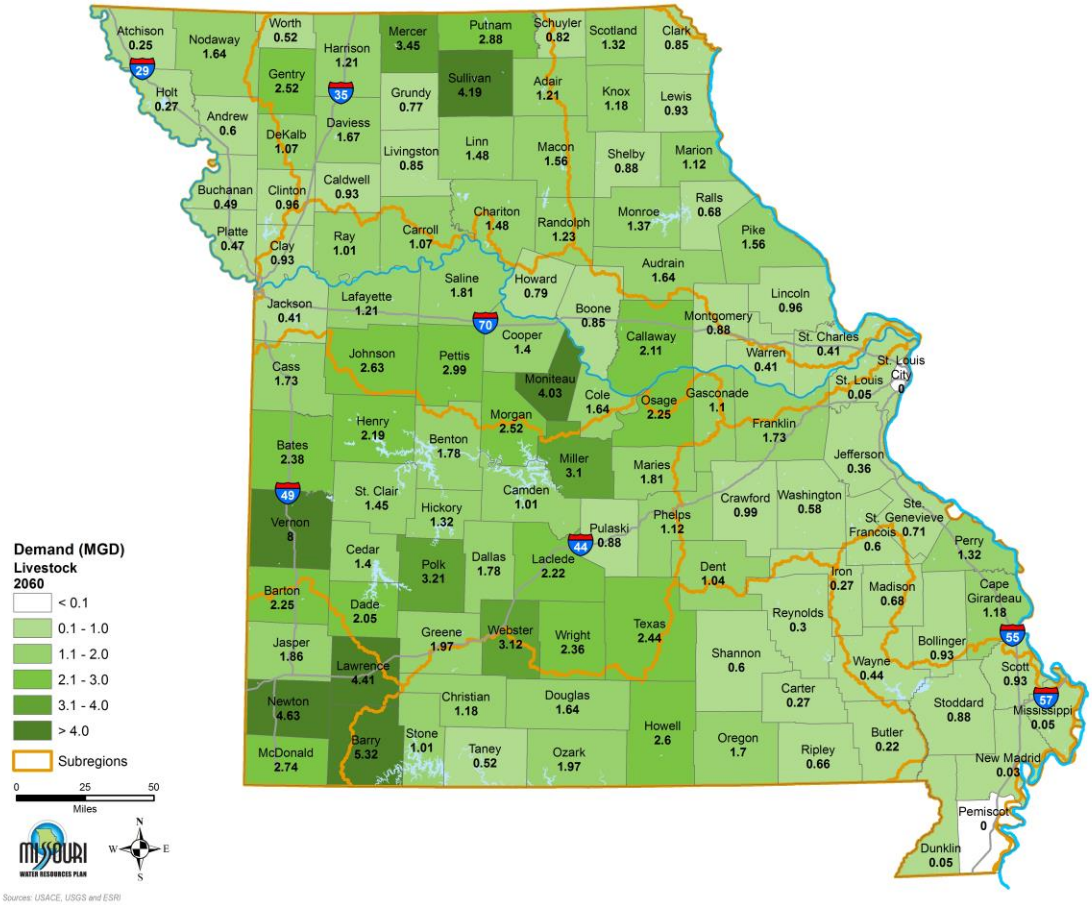


**Figure 3-32. Livestock Water Demand Forecast by County in 2060**

**Table 3-18** lists livestock water demand forecast by detailed source. Surface water subregions that contributed most to meeting livestock demand for water are the Chariton-Grand, Gasconade-Osage, and Lower Missouri. Within surface water subregions, the Gasconade-Osage, Chariton-Grand, and Lower Missouri currently contribute 60 percent of the water used for animal agriculture, and that proportion is projected to remain constant through 2060.

**Table 3-18. Forecast of Livestock Water Demand by Detailed Source**

| | | Livestock Demand (MGD) | | | | | |
|---|---|---|---|---|---|---|---|
| Source | | 2016 | 2020 | 2030 | 2040 | 2050 | 2060 |
| GROUND-WATER BY AQUIFER | Alluvial | 16.0 | 16.6 | 18.4 | 20.3 | 22.3 | 24.4 |
| | Springfield Plateau | 2.7 | 2.8 | 3.1 | 3.4 | 3.7 | 4.1 |
| | Lower Ozark | 21.0 | 21.8 | 24.1 | 26.5 | 29.1 | 31.9 |
| | GROUNDWATER TOTAL | 39.7 | 41.2 | 45.5 | 50.1 | 55.1 | 60.5 |
| SURFACE WATER BY SUBREGION | Chariton-Grand | 14.7 | 15.3 | 16.7 | 18.2 | 19.8 | 21.6 |
| | Des Moines | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| | Gasconade-Osage | 18.1 | 18.8 | 20.7 | 22.9 | 25.2 | 27.9 |
| | Lower Mississippi-St. Francis | 1.0 | 1.1 | 1.2 | 1.3 | 1.4 | 1.6 |
| | Lower Missouri | 11.1 | 11.6 | 12.8 | 14.1 | 15.6 | 17.2 |
| | Missouri-Nishnabotna | 2.8 | 3.0 | 3.3 | 3.6 | 3.9 | 4.3 |
| | Neosho-Verdigris | 4.6 | 4.8 | 5.4 | 5.9 | 6.6 | 7.2 |
| | Upper Mississippi-Kaskaskia-Meramec | 4.7 | 4.9 | 5.4 | 6.0 | 6.6 | 7.3 |
| | Upper Mississippi-Salt | 7.1 | 7.3 | 8.1 | 8.9 | 9.8 | 10.8 |
| | Upper White | 7.3 | 7.6 | 8.4 | 9.2 | 10.2 | 11.3 |
| | SURFACE WATER TOTAL | 71.5 | 74.3 | 81.9 | 90.2 | 99.3 | 109.2 |
| **STATE TOTAL** | | **111.2** | **115.5** | **127.4** | **140.3** | **154.3** | **169.7** |

In summary, Missouri's animal agriculture industry currently uses an estimated 111 MGD of water and is projected to grow by about 45 percent to nearly 170 MGD by 2060. About two-thirds of the water supplied to animal agriculture originates from surface water. The cattle sector uses three-fourths of the water supplied to animal agriculture.

## 3.8 Agriculture Irrigation

### 3.8.1 Introduction and Definitions

Cropland comprised 54 percent of the 28.2 million acres on Missouri farms in 2012 (USDA 2012). Missourians sold nearly $4.6 billion of crops produced on this land, or about half of the state's market value of agricultural products (USDA 2014a). The economic impact of these commodities includes processing them into value-added products and shows the importance crop production lends to Missouri's economy.

Producers planted more acres of soybean (5.3 million acres) than any other cash crop in 2012. Corn was grown on 3.3 million acres. Generally, corn and soybean are rotated in alternate years; thus, about 2 million acres of soybean are continuously cropped. Hay/silage accounted for 3.3 million acres. Wheat, cotton, and rice summed to 1.2 million acres (USDA 2014a). Permanent pasture, which covers more than 16 million acres in Missouri, is not included in cropland totals but is a major agricultural land use (USDA 2014a). Water is critical for crop growth, and without its abundance, crop production suffers. This analysis estimates the quantity of irrigation water used by Missouri's crop production industry by the source of supply. The estimates represent historical average climate and crop growth stages to reflect monthly water demands by crop type based on evapotranspiration, and are specific to irrigated crops. The estimates do not account for producer behavior with respect to frequency and intensity of irrigation on their farms. Because Missouri farms tend to irrigate only a small percentage of the total crop acreage, withdrawn water supports Missouri crop production on a relatively limited scale.

This analysis focused on water required to irrigate the following crops:

- Corn (grain and silage)
- Cotton
- Hay/Haylage
- Orchards
- Rice
- Sod
- Sorghum
- Soybean
- Vegetables
- Wheat

To estimate irrigation water demand by crop, current irrigated acreage by crop type was estimated for each county from Missouri Farm Service Agency (FSA) data. Annually, producers report acreage when enrolling in Missouri FSA programs, and those reports more accurately represent total and irrigated acreage. FSA data were supplemented with the 2012 USDA Census of Agriculture data. **Table 3-19** provides the current estimates of irrigated acreage for Missouri. University of Missouri Extension state and regional specialists also estimated the extent to which counties rely on groundwater or surface water for irrigation.

**Table 3-19. Current Irrigated Acreage in Missouri by Crop**

| Crop | Irrigated Acres |
|---|---|
| Corn (grain and silage) | 461,120 |
| Cotton | 277,628 |
| Hay/Haylage | 510 |
| Rice | 183,790 |
| Sorghum | 4,273 |
| Soybeans | 654,819 |
| Wheat | 98,112 |
| Orchards | 243 |
| Vegetables | 19,166 |
| Sod | 4,573 |
| Total | 1,704,234 |

To estimate the amount of water applied to the acreage, evapotranspiration and effective precipitation were modeled by crop type using Hargreaves' Method. Irrigation water requirement by crop is the difference between the amount of water the crop requires during the growing period and the effective precipitation. Potential evapotranspiration accounts for water absorbed by the crop and lost through evaporation, which is dictated by extraterrestrial radiation and temperature. Effective precipitation represents the precipitation available to a crop in a given month assuming historical average weather. By crop, regional planting and harvest dates were approximated with guidance from the *Missouri Crop Resource Guide*, Washington State University (mainly for fruit trees), and University of Missouri Extension faculty. When possible, the growing season approximation was adjusted regionally to account for variations in planting and harvest dates. Water use varies by growing season stage as the crop's requirements change during the plant growth cycle and precipitation patterns vary by month. Climate data from the High Plains Regional Climate Center were used to identify precipitation patterns. Baseline precipitation was computed as average precipitation from 1981 to 2010.

The amount of water applied to the scheme can vary depending on the irrigation system used. Micro-irrigation/drip systems are most efficient (90 percent) but flood (50 percent) and sprinkler systems (75 percent) are most common. The types of irrigation system used by producers varies. Assumptions for irrigation system type by county were based on the county values reported in the USDA National Agricultural Statistics Service survey (2014c). Finally, the source of irrigation supply was based on by-county estimates of ground and surface water supplies from University of Missouri Extension state and regional specialists.

### 3.8.2 Current Water Use Characteristics

Based on the data and approach described above, total water required to irrigate Missouri crops is estimated to be 2,070 MGD (2.3 million acre-feet) during an average weather year. The acre-foot unit represents the volume of water covering 1 acre of surface area to a depth of 1 foot. Crop irrigation varies dramatically by month as factors such as the stage of the growing season and climate patterns influence a crop's water needs and its access to rainfall. **Figure 3-33** highlights the extent to which crop irrigation water demand differs by month. In August, Missouri's crops require more than one-third of the total water needed for the year. July and June also have high irrigation demands, as nearly 30 and 20 percent, respectively, of the year's total irrigation water is needed during those months. From November to March, no irrigation is necessary.

On average, 2,070 MGD or 2.3 million acre-feet of water used for irrigating Missouri crops

In Missouri, a small number of counties irrigate substantial acreages of crops. The top five counties for irrigation water required in 2016 consumed more than three-fourths of total irrigation water needed in the state. Those top five counties were Stoddard, 470 MGD; New Madrid, 383 MGD; Butler, 326 MGD; Dunklin, 272 MGD; and Pemiscot, 203 MGD. **Figure 3-34** highlights that southeast Missouri has a relatively high concentration of counties with significant irrigation withdrawals.

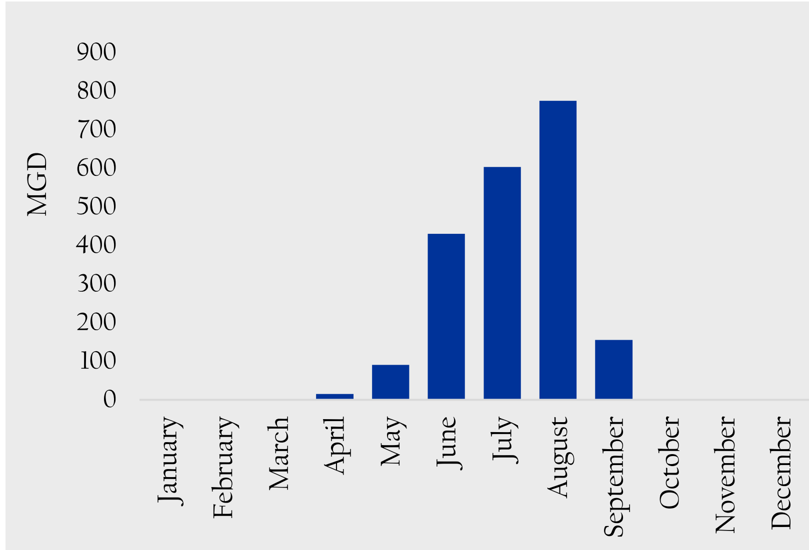


**Figure 3-33. Current Average Year Crop Irrigation Water Demand by Month**

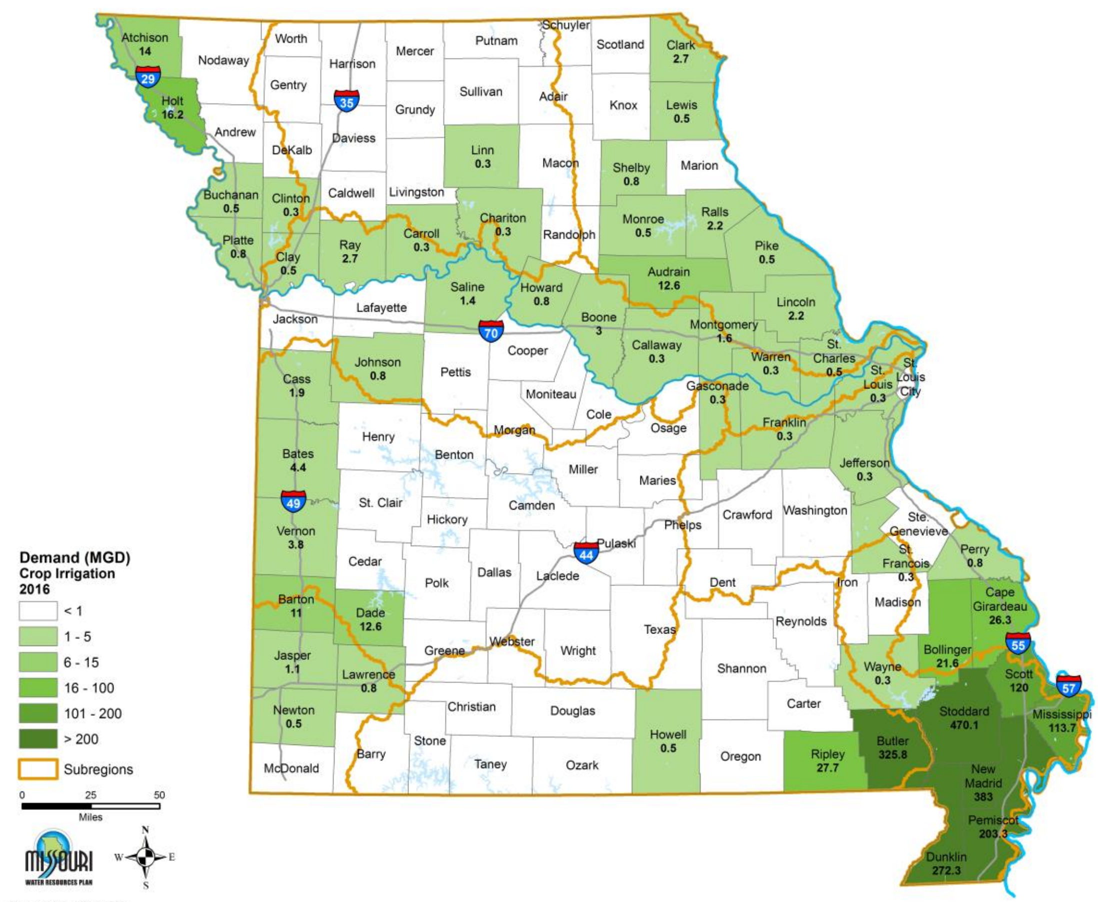


**Figure 3-34. Current Crop Irrigation Water Demand by County**

Of total irrigation water use, soybean acreage accounts for the greatest demand. As shown in **Figure 3-35,** one-third of all water required for crop irrigation originates from soybean acreage. Corn, rice, and cotton follow soybeans in their requirements for crop irrigation water. The "other" category includes corn silage, hay/haylage, sorghum, wheat, vegetables, sod, and orchard crops.

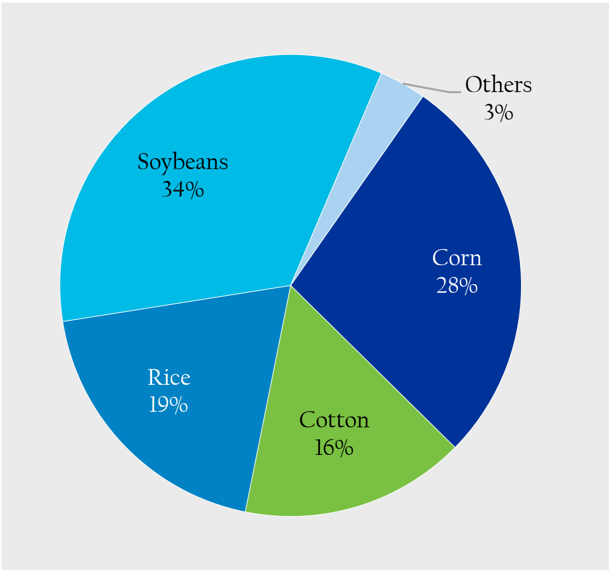


**Figure 3-35. Current Irrigation Water Demand by Crop Type**

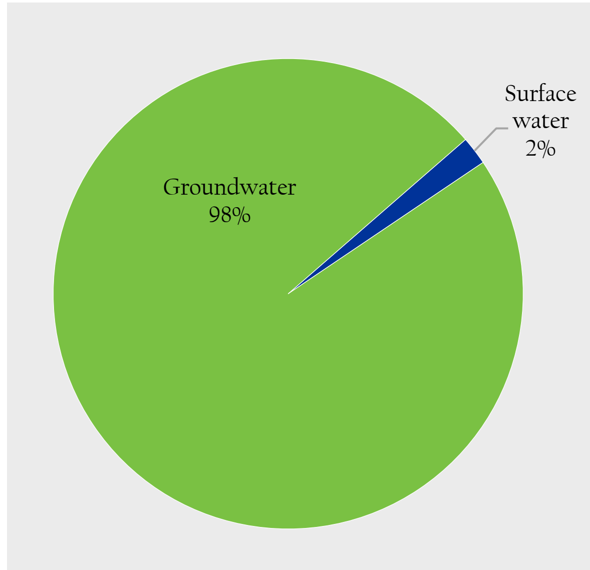


**Figure 3-36. Current Share of Crop Irrigation Water Demand by Source**

Of the water required to irrigate Missouri crops, most originates from groundwater sources. **Figure 3-36** shows that groundwater is the source for 98 percent of the water used to irrigate crops. The top five counties requiring crop irrigation water rely entirely on groundwater sources for irrigation.

### 3.8.3 Trends in Irrigation

Similar to livestock, future water needs for crop irrigation were projected to 2060 based on historical changes in irrigated crop acres and global demand projections for United States grain. To make these projections, historical irrigated acreage data from the USDA Census of Agriculture (1997, 2002, 2007, and 2012) were identified and reconciled to Missouri FSA 2012 irrigated acreage totals by mathematical computations. Based on these transformations, irrigated acreage was assumed to increase according to the trend observed between 1997 and 2012. **Figure 3-37** presents the projected change in Missouri irrigated crop acreage to 2060. Total irrigated acreage in Missouri is projected to grow about 15 percent to nearly 2 million acres by 2060.

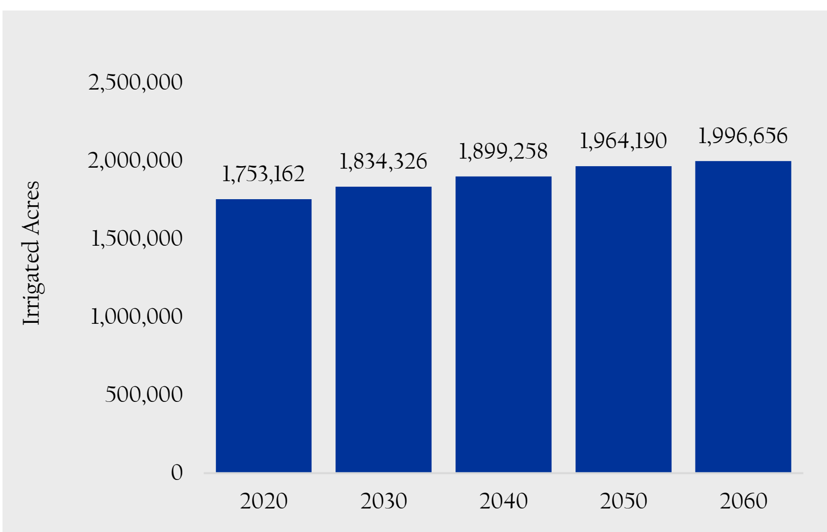


**Figure 3-37. Projected Irrigated Crop Acreage in Missouri from 2020–2060**

To determine the types of crops likely to be grown on the acreage that is irrigated, Missouri's market share of grain production was extrapolated to the global demand growth forecasts. Projections for U.S. grain and oilseed crops made by the FAPRI were used as the basis of the forecast (FAPRI 2018). Given these data, total use for corn, soybeans, and sorghum is largely expected to increase over time. Their total use is projected to be 7.5, 6.6, and 8.3 percent higher, respectively, by 2027. Slightly less wheat is projected to be used in 2027. For rice, the FAPRI projects that total use will be 8.8 percent greater by 2027. Cotton requires the fourth largest amount of irrigation water in Missouri. FAPRI forecasts total domestic and export use for U.S. cotton to increase by 7.7 percent by 2027.

### 3.8.4 Future Water Demand

Water demands for crop irrigation are projected from 2020 to 2060 by county given the assumptions described above. Future irrigation water needed to support Missouri's crop industry depends on several factors. Among those are crop choice, tolerance of new crop varieties to drought, crop water use efficiency, harvest index, total crop acreage, soil types, location, and precipitation patterns. **Figure 3-38** illustrates that water needs for crop irrigation purposes are projected to total 2,129 MGD in 2020. The projections suggest that Missouri's crop irrigation water needs will grow by nearly 14 percent to reach 2,424 MGD by 2060.

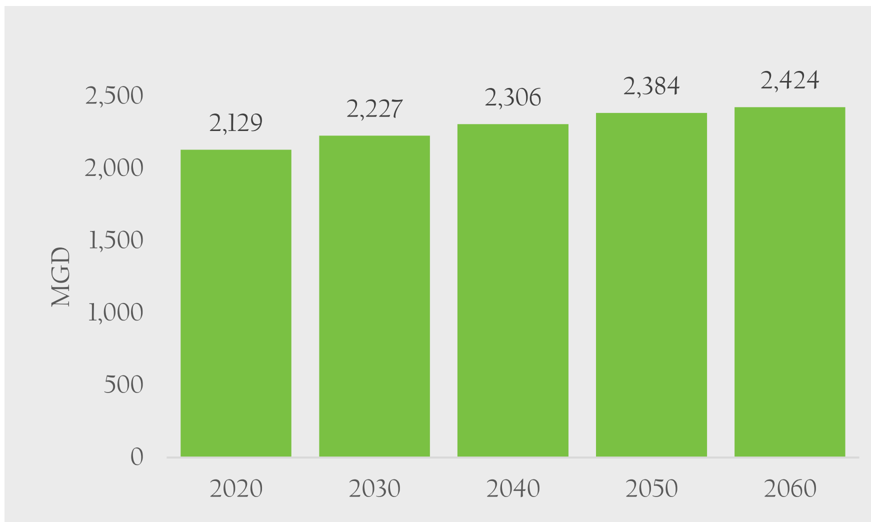


**Figure 3-38. Projected Water Demand for Missouri Crop Irrigation from 2020–2060**

As stated previously, a small number of counties are responsible for the majority of crop irrigation water use in Missouri. **Figure 3-39** presents the 2060 water demand forecast summarized by county for the Agriculture Irrigation sector. During 2060, counties projected to require the most irrigation water are Stoddard, 551 MGD; New Madrid, 449 MGD; Butler, 381 MGD; Dunklin, 319 MGD; and Pemiscot, 238 MGD. Collectively, those counties are projected to require nearly 80 percent of all irrigation water needed in the state.

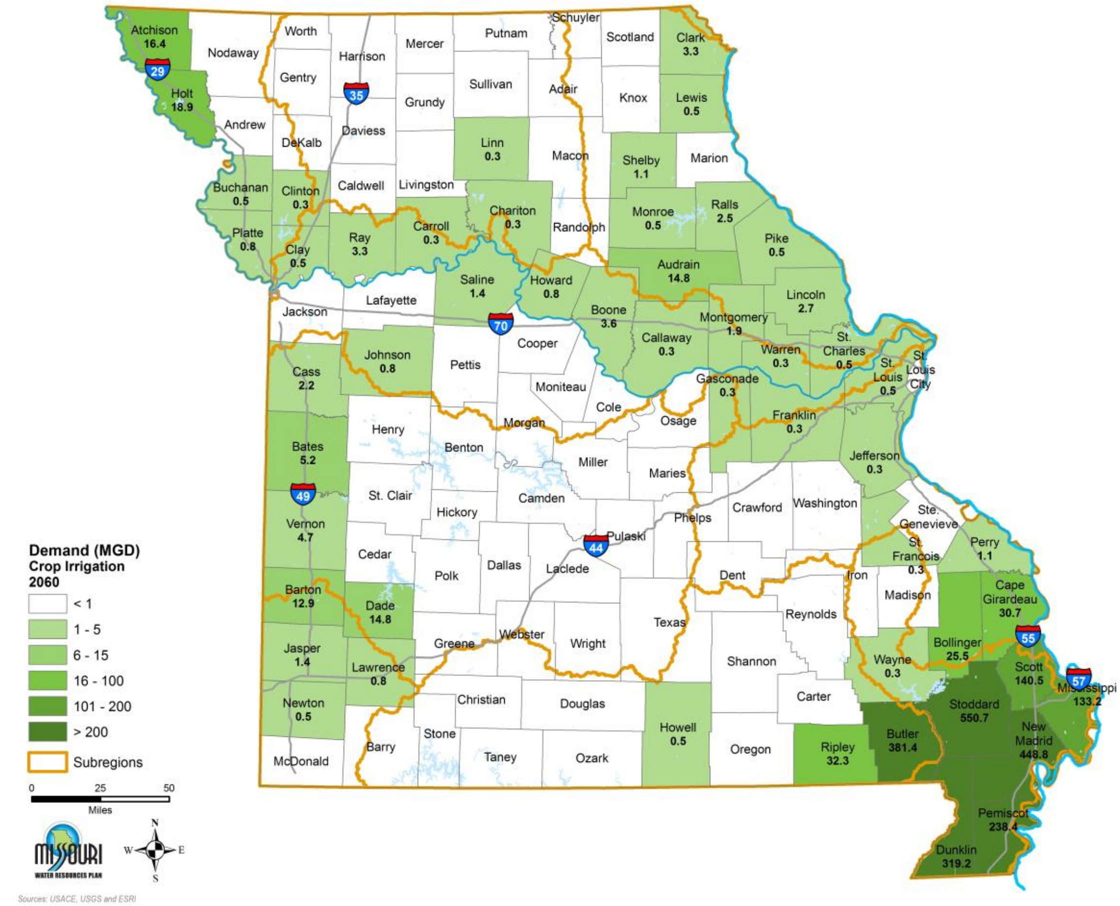


**Figure 3-39. Crop Irrigation Water Demands by County in 2060**

Demand for irrigation water is concentrated in alluvial aquifers, as shown in **Table 3-20**. A robust representation of crop irrigation water users is not available in the Major Water Users database; therefore, irrigation groundwater demands were assigned to aquifers based on the MoDNR well log database and the WIMS geodatabase, which covers wells installed since 1987.

**Table 3-20. Forecast of Crop Irrigation Water Demand by Detailed Source**

| | | Crop Irrigation Demand (MGD) | | | | | |
|---|---|---|---|---|---|---|---|
| Source | | 2016 | 2020 | 2030 | 2040 | 2050 | 2060 |
| GROUNDWATER BY AQUIFER | Alluvium | 1,939 | 1,995 | 2,087 | 2,161 | 2,234 | 2,272 |
| | Glacial Deposits | 2 | 2 | 2 | 2 | 2 | 2 |
| | Wilcox | 15 | 15 | 16 | 17 | 17 | 17 |
| | McNairy | 6 | 7 | 7 | 7 | 7 | 8 |
| | Pennsylvanian-age Bedrock | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| | Springfield Plateau | 17 | 17 | 18 | 18 | 19 | 19 |
| | Upper Ozark | 6 | 6 | 6 | 7 | 7 | 7 |
| | Lower Ozark | 43 | 45 | 47 | 49 | 50 | 51 |
| | St Francois | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| | GROUNDWATER TOTAL | 2,029 | 2,087 | 2,184 | 2,261 | 2,337 | 2,377 |
| SURFACE WATER BY SUBREGION | Chariton-Grand | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.4 |
| | Des Moines | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| | Gasconade-Osage | 4.3 | 4.5 | 4.7 | 4.8 | 5.0 | 5.1 |
| | Lower Mississippi-St. Francis | 12.3 | 12.6 | 13.2 | 13.7 | 14.1 | 14.4 |
| | Lower Missouri | 2.7 | 2.8 | 2.9 | 3.0 | 3.1 | 3.2 |
| | Missouri-Nishnabotna | 5.1 | 5.3 | 5.5 | 5.7 | 5.9 | 6.0 |
| | Neosho-Verdigris | 1.6 | 1.6 | 1.7 | 1.7 | 1.8 | 1.8 |
| | Upper Mississippi-Kaskaskia-Meramec | 5.3 | 5.5 | 5.7 | 5.9 | 6.1 | 6.2 |
| | Upper Mississippi-Salt | 5.9 | 6.1 | 6.4 | 6.6 | 6.9 | 7.0 |
| | Upper White | 2.8 | 2.9 | 3.1 | 3.2 | 3.3 | 3.3 |
| | SURFACE WATER TOTAL | 40 | 42 | 44 | 45 | 47 | 47 |
| **STATE TOTAL** | | **2,070** | **2,129** | **2,228** | **2,307** | **2,384** | **2,424** |

In summary, during an average weather year, Missouri's crops currently use an estimated 2,070 MGD of irrigation water. Based on historical trends, the volume of water needed to irrigate Missouri's crops is projected to reach 2,424 MGD by 2060. Abundant water supplies allow Missouri's agriculture to produce the food and fiber consumers require. This endeavor to tabulate current and future agricultural water demands enables stakeholders to make proactive, data-driven decisions around investment in such a valuable resource.

In 2060, Missouri's irrigation water needs are projected to be 2,424 MGD.

## 3.9 Combined Consumptive Demands

This section presents the combined consumptive demand forecast for all sectors by county and source. Consumptive demands include the following sectors:

- Major Water Systems, presented in **Section 3.3**
- Self-Supplied Nonresidential, presented in **Section 3.4**
- Self-Supplied Domestic and Minor Systems, presented in **Section 3.5**
- Thermoelectric Power Generation, presented in **Section 3.6** (consumptive portion only)
- Livestock, presented in **Section 3.7**
- Agriculture Irrigation, presented in **Section 3.8**

These combined demands represent those consumptive uses that are quantified from the available data. Demands are likely underestimated, as some nonresidential user groups are underrepresented. Additionally, these demands do not capture unexpected future withdrawals from new industries or user groups not listed above or captured by the data available and underlying assumptions inherent to the demand forecast.

Statewide, Agriculture Irrigation comprises the largest portion of consumptive water withdrawals, on average, 65 percent, as shown in **Figure 3-40**. Major Water Systems makes up 25 percent of the average annual consumptive demands. The remaining sectors combined represent 10 percent of annual withdrawals. Overall statewide consumptive demands are estimated to be 3,181 MGD, with a forecasted increase of 18 percent or 582 MGD by 2060, as shown in **Figure 3-41**. Statewide demands are estimated to total over 3,780 MGD by 2060. Agriculture Irrigation and Major Water Systems remain the largest consumers of water in 2060. Expressing demands as an average MGD is useful, but these demands have a distinct seasonal pattern that follows outdoor water use at homes, businesses, and on irrigated farmland.

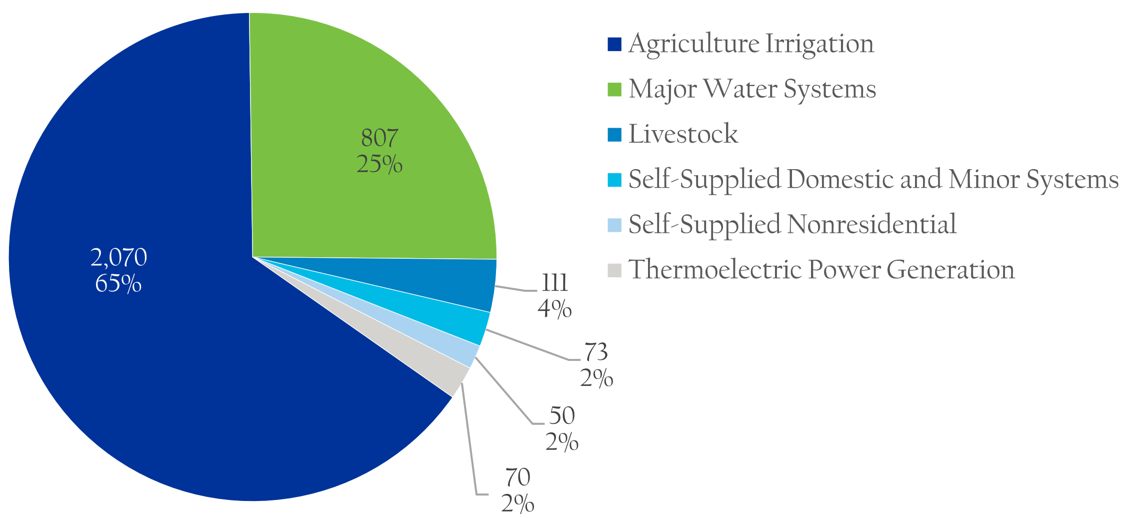


**Figure 3-40. Current Consumptive Demands by Sector (MGD)**

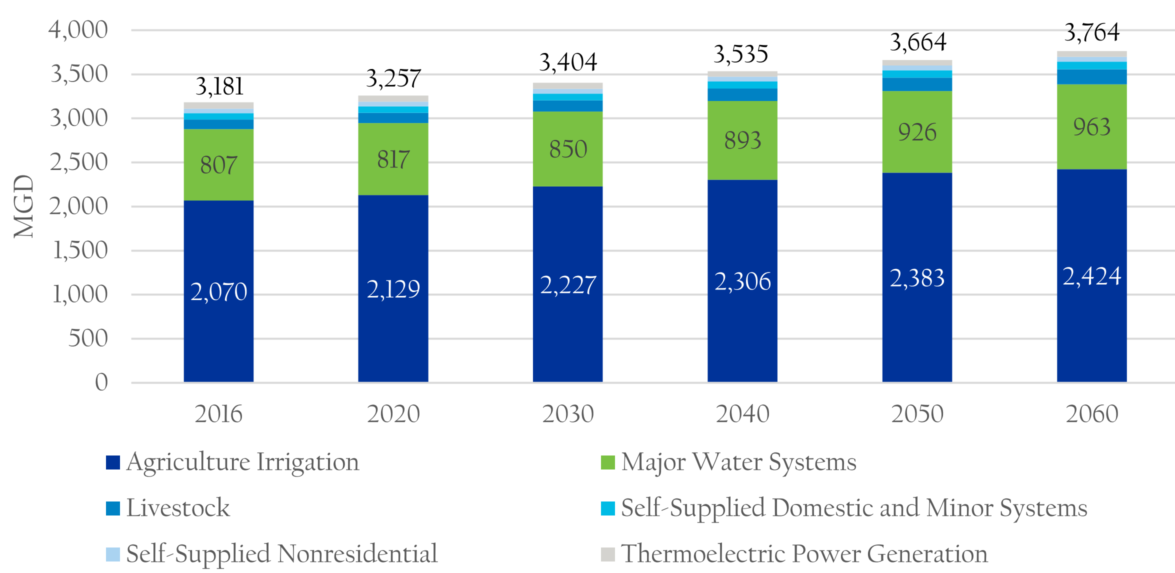


**Figure 3-41. Consumptive Demand Forecast by Sector to 2060**

**Figure 3-42** and **Figure 3-43** present the combined consumptive demands by county for 2016 and 2060, respectively. Driven heavily by agriculture irrigation, the counties estimated to currently have the greatest consumptive water demand are Butler, Dunklin, Pemiscot, New Madrid, and Stoddard counties. These same counties have the greatest growth in MGD in demand by 2060. Clusters of high consumptive demand are also found around urban areas and urban clusters. **Appendix C** provides combined consumptive demands to the planning horizon for each county.

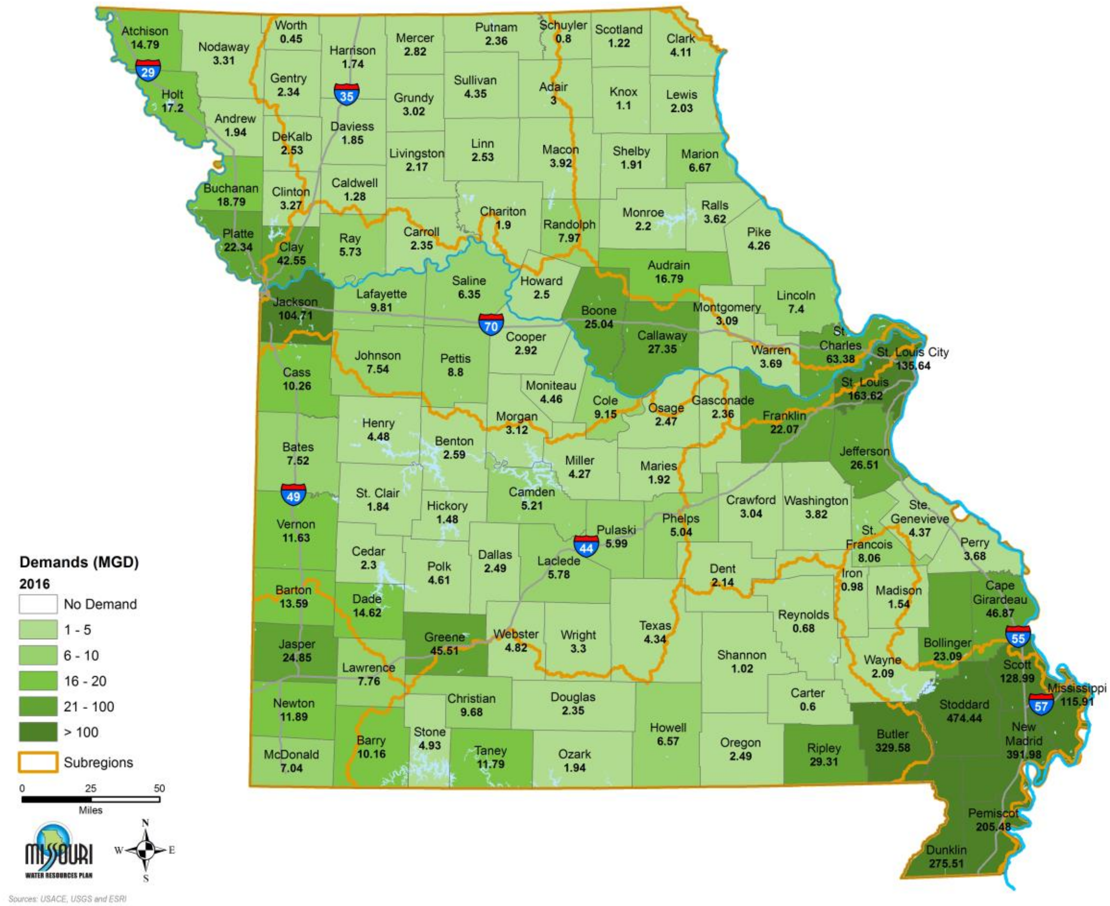


**Figure 3-42. Current Consumptive Demands Combined by County**

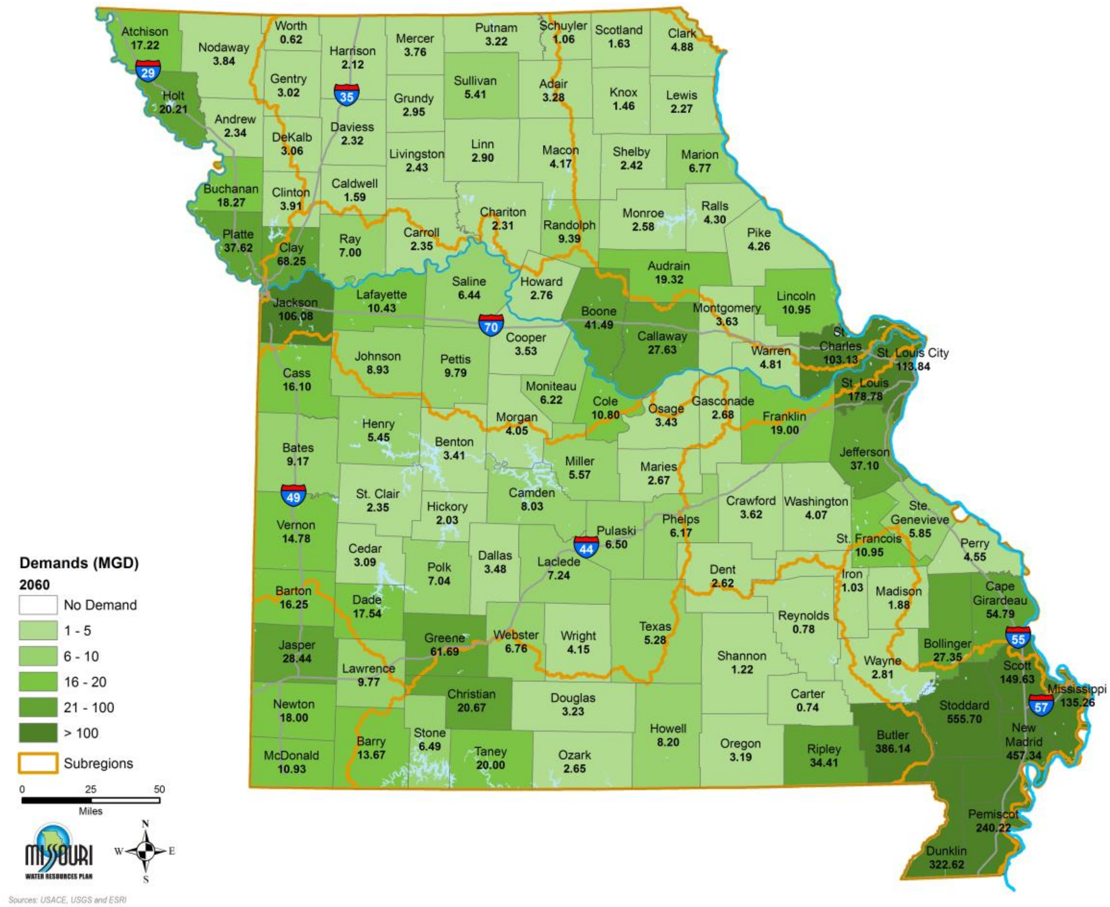


**Figure 3-43. Consumptive Demand Forecast Combined by County in 2060**

**Table 3-21** presents total consumptive demands by source for each planning period from 2016 through 2060. Seventy-eight percent of consumptive demands are supplied by groundwater with the remaining 22 percent supplied by surface water. Groundwater demands are heavily driven by agriculture irrigation and concentrated in the alluvial aquifers, which account for 67 percent of total consumptive demands. Lower Ozark Aquifer demands represent another 8 percent of total demands. The largest surface water demands are in the Lower Missouri Basin, with 44 percent of total surface water demands and 10 percent of the total consumptive demands.

**Table 3-21. Combined Consumptive Demands by Detailed Source to 2060**

| | | Total Consumptive Demands (MGD) | | | | | |
|---|---|---|---|---|---|---|---|
| Source | | 2016 | 2020 | 2030 | 2040 | 2050 | 2060 |
| GROUNDWATER BY AQUIFER | Alluvial | 2,123.2 | 2,181.7 | 2,284.3 | 2,369.4 | 2,452.2 | 2,501.5 |
| | Glacial Deposits | 9.4 | 9.5 | 9.5 | 9.9 | 10.1 | 10.4 |
| | Wilcox | 23.1 | 23.5 | 24.2 | 24.7 | 25.1 | 25.3 |
| | McNairy | 11.0 | 11.2 | 11.6 | 11.9 | 12.2 | 12.4 |
| | Pennsylvanian-age Bedrock | 1.2 | 1.3 | 1.3 | 1.4 | 1.4 | 1.5 |
| | Springfield Plateau | 21.5 | 22.3 | 23.4 | 24.4 | 25.3 | 26.2 |
| | Mississippian-age Bedrock | 1.2 | 1.2 | 1.2 | 1.3 | 1.3 | 1.4 |
| | Upper Ozark | 12.4 | 12.7 | 13.6 | 14.5 | 15.3 | 16.0 |
| | Lower Ozark | 265.6 | 274.5 | 290.5 | 309.0 | 324.5 | 341.7 |
| | St. Francois | 10.3 | 10.6 | 11.3 | 12.0 | 12.6 | 13.3 |
| | Precambrian | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| | GROUNDWATER TOTAL | 2,479 | 2,549 | 2,671 | 2,779 | 2,881 | 2,950 |
| SURFACE WATER BY SUBREGION | Chariton-Grand | 34.6 | 34.9 | 36.5 | 38.2 | 40.2 | 41.9 |
| | Des Moines | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| | Gasconade-Osage | 38.5 | 39.7 | 42.8 | 46.3 | 50.0 | 53.8 |
| | Lower Mississippi-Hatchie | 4.5 | 4.4 | 4.5 | 4.7 | 5.1 | 5.3 |
| | Lower Mississippi-St. Francis | 13.8 | 14.2 | 14.9 | 15.5 | 16.1 | 16.5 |
| | Lower Missouri | 312.5 | 314.6 | 323.5 | 329.9 | 338.5 | 349.1 |
| | Missouri-Nishnabotna | 103.3 | 105.0 | 111.0 | 118.1 | 124.8 | 131.8 |
| | Neosho-Verdigris | 19.4 | 19.9 | 21.2 | 22.6 | 23.9 | 25.3 |
| | Upper Mississippi-Kaskaskia-Meramec | 110.5 | 110.1 | 108.2 | 109.0 | 109.4 | 109.7 |
| | Upper Mississippi-Salt | 29.2 | 29.5 | 30.4 | 28.2 | 29.1 | 29.9 |
| | Upper White | 35.3 | 36.5 | 39.7 | 43.4 | 46.9 | 50.7 |
| | SURFACE WATER TOTAL | 701.7 | 708.8 | 732.7 | 756.1 | 784.1 | 814.2 |
| STATE TOTAL | | **3,181** | **3,258** | **3,404** | **3,535** | **3,665** | **3,764** |

## 3.10 Hydroelectric Power Generation

### 3.10.1 Introduction and Definitions

Hydropower refers to electric power generated by passing water through turbine systems. In 2015, hydropower accounted for approximately 2.3 percent of all electricity generation statewide (EIA 2016). With more than 20 hydroelectric plants throughout the state, hydropower is Missouri's leading renewable energy source, accounting for roughly 65 percent of renewable resource electricity generation as shown in **Figure 3-44** (EIA 2016). Unlike thermoelectric power, which USGS recognizes as an "off-stream" use, hydropower is considered an "in-stream" use and is nonconsumptive.

The capacity to produce hydroelectric energy is dependent on both available water flow and the height from which it falls. Hydropower facilities include impoundment, diversion, and pumped-storage facilities, all three of which are currently operating in Missouri.

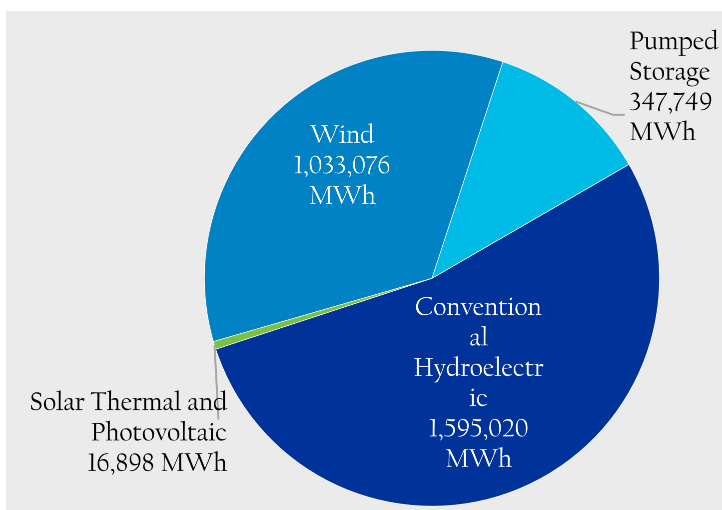


**Figure 3-44. 2015 Missouri Renewable Electricity Generation (MWh)**
*Source: EIA 2016*

Impoundment facilities store water in a reservoir on the upstream side of a dam located on a river. Water released from the reservoir enters an intake near the bottom of the dam and flows through a turbine, which is turned by the flowing water. The spinning turbine propeller activates a generator, which produces the power. The water then continues past the propeller through the tailrace into the water body below the dam.

Pumped storage is a method of keeping water in reserve for peak period power demands by pumping water that has already flowed through the turbines back up into a storage pool above the power plant during a time when customer demand for energy is low, such as the middle of the night. The water is then allowed to flow back through the turbine-generators at times when demand is high and a heavy load is placed on the power grid. The upper reservoir acts much like a battery, storing power in the form of water when demands are low and producing maximum power during daily and seasonal peak periods.

Diversion or run of the river facilities use conventional hydropower technology to produce electricity by channeling a portion of a river through a canal or penstock. Diverted river water flows through turbines that spin generators before returning water back to the river downstream. These facilities may or may not require the use of a dam.

### 3.10.2 Hydropower Facilities

In addition to over a dozen small hydropower facilities, Missouri currently has eight major hydroelectric facilities: Clarence Cannon, Harry S. Truman, Niangua, Osage (also referred to as Bagnell Dam), Ozark Beach (also referred to as Powersite Dam), Stockton, Table Rock, and Taum Sauk. Five of the eight facilities are conventional impoundments, two are diversion facilities, and one utilizes only pumped-storage technology. Plants are listed in **Table 3-22**, with details on the number of units, nameplate capacity in MW, and net generation for 2014. **Figure 3-45** provides a map of the facilities.

**Table 3-22. Major Hydroelectric Plant Facility Overview**

| Plant Name | Facility Type | Number of Generating Units | Plant Nameplate Capacities (MW) | 2014 Net Generation (MWh) | Owner/Operator |
|---|---|---|---|---|---|
| Clarence Cannon | Impoundment | 2 | 58 | 84,772 | USACE |
| Harry S. Truman | Impoundment | 6 | 161 | 98,877 | USACE |
| Niangua (Tunnel Dam) | Diversion | 2 | 3 | 686 | Sho-Me Power Electric Cooperative |
| Osage (Bagnell Dam) | Impoundment | 8 | 208 | 232,190 | Ameren Missouri |
| Ozark Beach (Powersite Dam) | Diversion | 4 | 16 | 60,693 | Empire District Electric Company |
| Stockton | Impoundment | 1 | 52 | 38,050[1] | USACE |
| Table Rock | Impoundment | 4 | 200 | 368,917 | USACE |
| Taum Sauk | Pumped Storage | 2 | 408 | -135,904[2] | Ameren Missouri |

*Source: EIA 2015a*

[1] Stockton was offline for rehabilitation in 2014; the number provided represents average annual generation from 2001–2016.

[2] The pumped storage pumping process makes the plant a net consumer of energy but has a net positive revenue from selling electricity during periods of peak demand.

The USACE-operated Clarence Cannon Dam utilizes conventional hydroelectric technology. It is located about 63 miles upstream of the Salt River's confluence with the Mississippi River. The dam impounds the North and Middle Forks of the Salt River, creating the 18,000-acre Mark Twain Lake. The facility has two hydroelectric generators with a nameplate capacity of 58 MW. The power is marketed by Southwestern Power Administration. A regulation dam, located 9.5 miles downstream from the main dam, creates a storage pool that can be used for pumped-storage hydroelectricity; however, the dam has never operated in this capacity.

The Harry S. Truman hydropower facility is a conventional hydroelectric facility operated by USACE. It is in Benton County on the Osage River, a tributary of the Missouri River. The dam impounds the 55,600-acre Truman reservoir and has six hydroelectric generators with a nameplate capacity of 161 MW. The power is marketed by Southwestern Power Administration. The project was originally designed to be a pumped-storage project, but it has never been operated in this capacity.

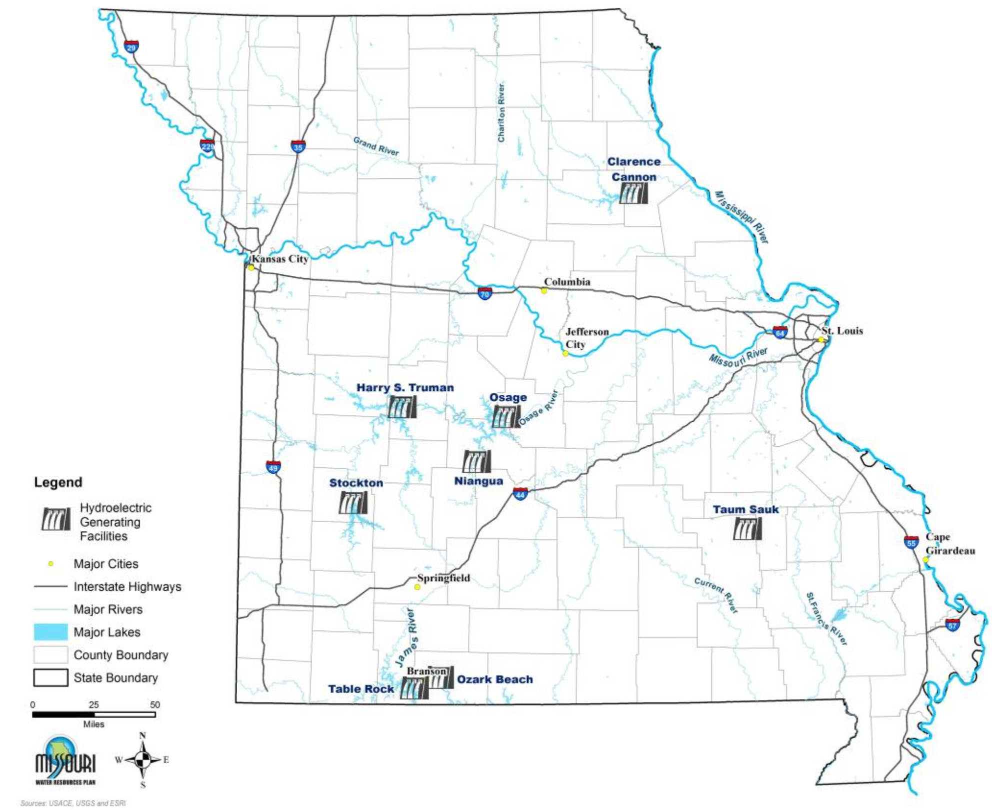


Figure 3-45. Major Hydroelectric Facility Locations in Missouri

The Niangua hydropower facility, operated by the Sho-Me Power Electric Cooperative, is a run-of-river facility. The Niangua facility, also known as Tunnel Dam, impounds the 360-acre Lake Niangua located in Camden County in central Missouri. It operates by diverting a portion of the Niangua River's flow into a tunnel drilled through a bluff and down to a powerhouse on the other side. After passing through the turbines, the water is returned to the Niangua River. The facility has two turbines with a maximum generating capacity of 3 MW.

The Osage Energy Center hydropower facility is a conventional hydroelectric facility operated by Ameren Missouri, part of St. Louis-based Ameren Corporation. The Osage facility is located inside Bagnell Dam, which impounds the Osage River, creating the 55,000-acre Lake of the Ozarks in central Missouri. The hydropower facility is normally run as a peak load facility and has eight turbines with a maximum generating capacity of 208 MW.

Ozark Beach Plant is a run-of-river hydroelectric facility operated by Empire District Electric Company. The Ozark Beach Plant in Powersite Dam is in southwest Missouri on the White River in Taney County and forms Lake Taneycomo. As is the case with the Niangua Plant, there is no hydropower pool for the facility to draw upon; the facility instead relies primarily upon releases from Table Rock Dam, 21 miles upstream. Powersite Plant has four generators with a combined generating capacity of 16 MW.

The Stockton hydropower facility is a conventional hydroelectric facility operated by USACE. Located in Cedar County in east-central Missouri, Stockton Dam impounds the Sac River, creating the 24,900-acre Stockton Lake. The Stockton hydropower facility has one generator with a nameplate capacity of 52 MW, and the power is marketed by Southwestern Power Administration.

The Table Rock hydropower facility is a conventional hydroelectric facility operated by USACE. Located in Taney County, the dam impounds approximately 80 miles of the White River, creating the 43,100-acre Table Rock Lake, of which 39,652 acres lie in Missouri. The Table Rock hydroelectric facility has four generators with a nameplate capacity of 200 MW, and the power is marketed by Southwestern Power Administration.

The Taum Sauk hydropower facility is a pumped-storage facility operated by Ameren Missouri, which is used to supply peak demands. The Taum Sauk pumped-storage hydroelectric plant is in Reynolds County, in the St. Francois Mountains, about 120 miles southwest of St. Louis. The upper reservoir sits atop Proffit Mountain, and the lower storage reservoir is situated on the East Fork of the Black River, just downstream of Johnson's Shut-Ins State Park. Water is pumped uphill through a 7,000-foot long tunnel to the upper reservoir during off-peak times and then released to generate electricity during peak times. The facility has two generating units capable of producing a combined 408 MW.

In addition to electric generation from Missouri's eight major hydroelectric facilities, the Missouri grid also receives power generated by Keokuk Hydroelectric Generation Station. Keokuk Station is located along the Mississippi River in Iowa, immediately north of the Missouri border. This facility is operated by Ameren Missouri and consists of 15 generators, with individual nameplate ratings from 7.2 to 8.8 MWs.

### 3.10.3 Current Water Use Characteristics

Unlike most other water uses, hydropower relies almost exclusively on surface water sources. Several rivers and streams in Missouri, listed in **Table 3-23,** provide water for hydropower generation, but the economic and engineering challenges of meeting the strict criteria for hydropower development are impractical in most river basins. A watershed must meet exact topographic and geologic standards before its hydropower potential may be exploited. Geologic formations at the proposed site must provide a stable platform for the planned facility and have minimal seepage. At the same time, the river valley must be narrow enough and have enough relief to provide an acceptable drop in elevation (head).

**Table 3-23. Type of Hydroelectric Plant and Water Source**

| Water Source | Plant Name | Impoundment |
|---|---|---|
| North and Middle Forks of the Salt River | Clarence Cannon | Mark Twain Lake |
| Osage River | Harry S. Truman | Truman Reservoir |
| Niangua River | Niangua (Tunnel Dam) | Lake Niangua |
| Osage River | Osage (Bagnell Dam) | Lake of the Ozarks |
| White River | Ozark Beach (Powersite Dam) | Lake Taneycomo |
| Sac River | Stockton | Stockton Lake |
| White River | Table Rock | Table Rock Lake |
| East Fork of Black River | Taum Sauk | N/A |

Consumption of water for hydropower operations is negligible due to return flows downstream; however, water utilized for hydropower operations may result in drawdowns of reservoir levels. Management of lake hydropower pool elevations differs statewide, depending on the projects' main objectives and management. In most cases, management criteria have been established to lessen impacts to other uses from hydropower operations. A few examples of flow and pool requirement and restrictions at some of Missouri's hydroelectric facilities follow.

Ameren Missouri developed a guide curve for the Osage facility that is followed 94 percent of the time with target pool elevations (Starke et al. 2012). The Osage facility can discharge up to 50,000 cubic feet per second (cfs) unless the natural flow exceeds this amount. The year-round continuous minimum flow should not drop below 900 cfs according to the guide curve.

Tunnel Dam diverts water from the Niangua River into a tunnel and returns it 6.5 miles downstream after passing through hydropower turbines. Seasonal minimal flow regulations must be met to reduce impacts to downstream water supply and water quality (Shulz 2011).

Restrictions on USACE-operated reservoirs are generally dependent on reservoir elevations as they relate to hydropower pools. Clarence Cannon, Stockton, and Harry S. Truman hydroelectric plants have restrictions on power operations due to downstream channel capacities that limit releases during periods of downstream flooding. Table Rock generation is guided by the USACE White River Basin Water Control Plan that determines releases out of Table Rock and five other White River Basin reservoirs when flooding is occurring. The Harry S. Truman hydroelectric plant has a storage allocation for hydropower from elevation 704 to 706 feet (USACE 2011). Clarence Cannon has a hydropower pool between 590 and 606 feet. Normal lake drawdown as a result of hydropower generation is limited to 2 feet per calendar week, or 4 feet per month during May through October, with the remainder of the year being limited to 2 feet per week without a monthly maximum (USACE 2015). Table Rock also has year-round drawdown limits of 1.5 feet per week and 4.5 feet in a 4-week period.

### 3.10.4 Hydroelectric Benefits

Hydroelectric generation provides low-cost energy to Missouri's electric power grid, which helps to keep energy costs down for the consumer. There is no fuel that is burned; thus, operating costs are low and not impacted by the rise and fall of fossil fuel prices. Additionally, most hydroelectric projects were built in the middle part of the 20$^{th}$ century when construction costs were low, yet electricity benefits continue to be accrued. The annual National Economic Development benefits of USACE hydroelectric generation in Missouri were estimated to be $22.73 billion in 2014 (USACE 2014). This number includes the Clarence Cannon, Harry S. Truman, Stockton, and Table Rock facilities. As the USACE facilities make a portion of the state's hydropower generation, the economic figure is not comprehensive of all hydropower generation.

### 3.10.5 Future Outlook

Hydroelectric generation at current operating facilities is likely to continue as the demand for energy persists and renewable options are prioritized. The development of new hydroelectric resources is limited by available water resources, regulatory considerations, and environmental constraints. Possible development on existing reservoirs and run of the river facilities on the Mississippi River at lock and dam sites has also been suggested (Ameren Missouri 2017).

## 3.11 Commercial Navigation

### 3.11.1 Introduction and Definitions

Simply stated, navigation is travel or transportation over water. To be navigated, a body of water, river, or stream must be deep, wide, and flow slow enough for a vessel to pass safely. There are several conditions that make a river, stream, body of water, or segment unnavigable such as ice, debris, trees, rocks, sandbars, insufficient depth, narrow channel, or rapid current. While there are many legal definitions of navigation and navigable waterways, this section aims to describe it in a more general sense by characterizing watercraft activities and key infrastructure in Missouri that support and generate commerce. Commercial navigation includes the movement of commodities on barges or other shipping vessels as well as the movement of people on paid and piloted charter vessels, toll ferries, and passenger ships. Note that navigation associated with recreation is characterized in **Section 3.13**.

Of the rivers in Missouri, only the Missouri and Mississippi rivers are utilized to transport freight. The Missouri and Mississippi rivers are classified as belonging to the national Fuel-Taxed Waterway. For rivers or river segments that belong to the Fuel-Taxed Waterway, commercial waterway operators pay a per-gallon fuel tax deposited into the Inland Waterways Trust Fund, which is used to help fund capital investments vital to sustaining and improving inland navigation infrastructure in the nation. The Missouri and Mississippi rivers play the critical role of moving commodities across, into, and out of Missouri in a safe, reliable, economical, and environmentally friendly way. These waterways provide benefits to U.S. consumers and producers of electricity, agriculture products, construction materials, petroleum products, steel, and other commodities.

The benefits of the inland waterway maritime system are well studied and documented. For shipment of dry cargo, one barge carries the equivalent of 70 semi-tractor/trailer trucks or 16 railcars. For shipping liquid cargo, one barge carries the equivalent of 144 semi-tractor/trailer trucks or 46 railcars. For perspective, one covered hopper barge carrying wheat carries enough product to produce 2.5 million loaves of bread. A loaded liquid barge carrying gasoline can supply the annual gasoline demand of approximately 2,500 people (Texas A&M Transportation Institute 2017). The efficiencies in shipping can be translated to miles per gallon of fuel savings for the same quantity of goods. As shown in **Figure 3-46**, inland barges are estimated to have an efficiency of 647 ton-miles per gallon. This is 36 percent more efficient than rail and 346 percent more efficient than highway trucking (Texas A&M Transportation Institute 2017). The reduction in fossil fuel burning to carry the same quantity of goods translates to reductions in greenhouse gas emissions and improvements in air quality.

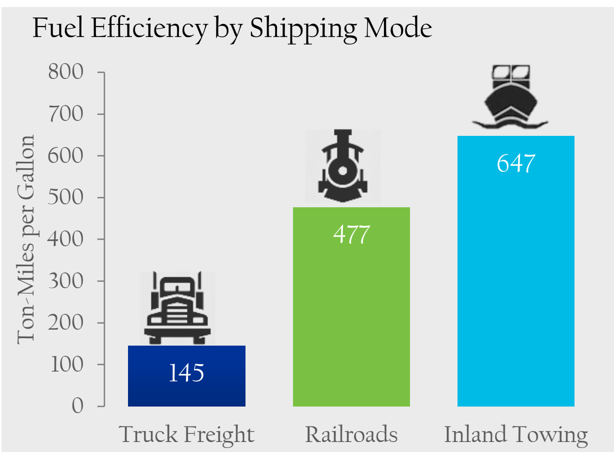


**Figure 3-46. Energy Efficiency of Inland Waterway Shipments**
*Source: Texas A&M Transportation Institute 2017*

Waterway shipping is a safe means of transporting goods and products. Vessels interact mostly with other vessels, whereas rail and semi-tractor/trailer trucks interact with passenger vehicles and trains. As a result, for every fatality on the inland maritime system, there are 22 railway and 79 highway fatalities (per million ton-miles); for every injury on the inland maritime system, there are 81 railway and 696 highway injuries (per million ton-miles) (Texas A&M Transportation Institute 2017).

The importance of Missouri's commercial navigation industry and the water and infrastructure it relies on to the economy, environment, and health and safety of the public it serves cannot be overstated. The following sections describe Missouri's water control infrastructure; port authorities, toll ferries, and passenger vessels; annual commodity tonnage shipped via Missouri's waterways; key economic indicators; and future outlook for the navigation industry.

### 3.11.2 Water Control Infrastructure

Water requirements on the Mississippi and Missouri rivers in support of commercial navigation are similar. Barges that are common to these rivers require a minimum of 9 feet of water depth to safely transit the waterways. The method of achieving this minimum depth requirement is distinctly different for the two river systems.

On the Mississippi River, upstream from St. Louis, the navigation channel depth is maintained by a series of locks and dams needed to mitigate the naturally-occurring rapids, submerged rocks and boulders, and sand bars present on that stretch of the river. Beyond the small amount of storage necessary to maintain the navigation pool level, these dams do not store water for flood control purposes but rather simply pass all the river flow. Locks and dams on the Mississippi do not eliminate the low spots caused by shoaling on the river bed and thus the river requires maintenance dredging or other structures to maintain a safe navigation channel.

There are seven locks and dams on the Missouri-portion of the upper Mississippi River as shown in **Figure 3-47**. Lock and Dam 27, also called Chain of Rocks Dam, is the most downstream lock and dam on the Mississippi River, meaning the Mississippi River is open river downstream of this lock all the way to the Gulf of Mexico. Lock and Dam 27 is located just south of the mouth of the Missouri River but north of St. Louis at Granite City, Illinois. Construction of the Mississippi River locks and dams was authorized under the 1930 Rivers and Harbors Act, with the purpose of providing safe and reliable navigation for Midwest producers and consumers. The upper locks were placed into operation around the late 1930s, and the Chain of Rocks Dam became operational in 1953. Melvin Price Dam is the most recent lock and dam to be constructed, replacing the older Lock and Dam 26 in 1990.

On the downstream segments of the Mississippi below St. Louis, the navigation channel is maintained by directing the river's flow using river-control structures such as wing dikes, bendway weirs, and chevrons, and through maintenance dredging. The river remains "open" with no lock and dam structures downstream of St. Louis as it flows out of Missouri towards the Gulf of Mexico.

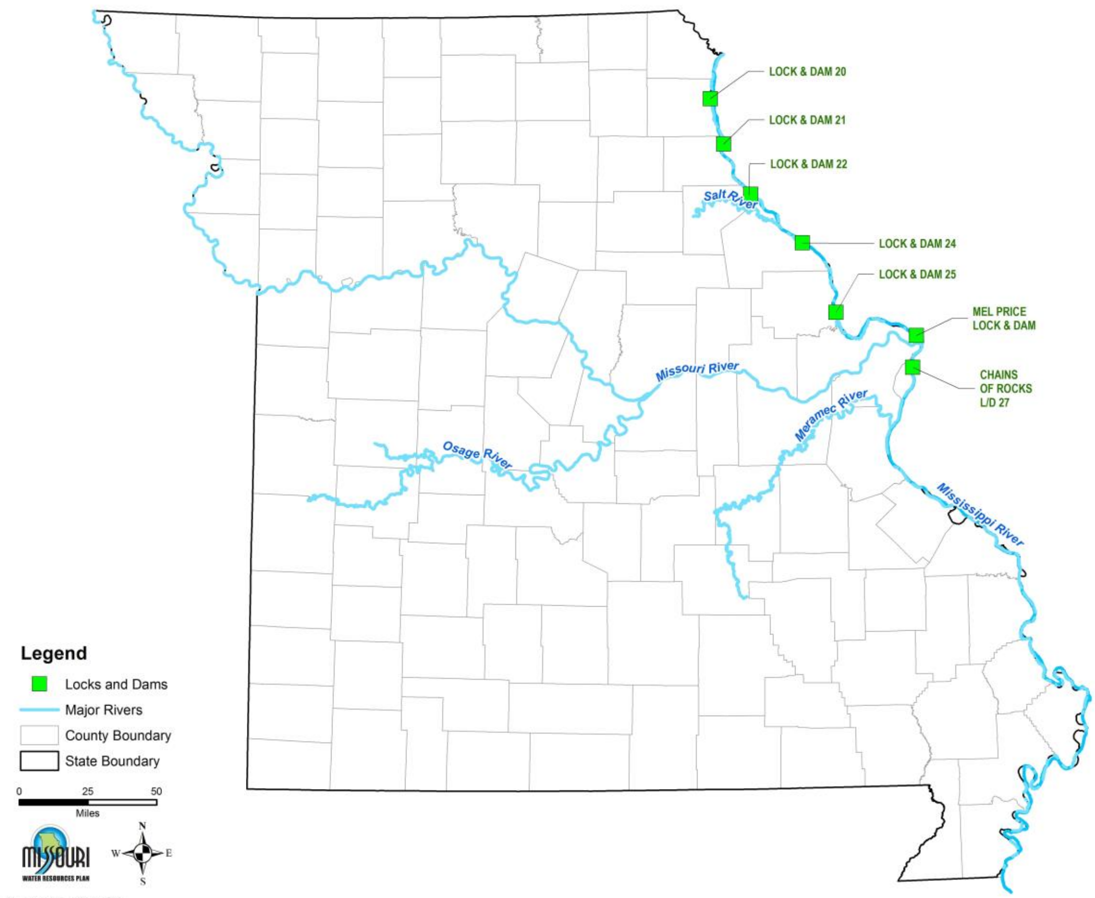


Figure 3-47. Locks and Dams in Missouri

Figure 3-48. Water Control Reservoirs on the Missouri River for Maintaining Navigation

Unlike the Mississippi River, the Missouri River navigation system depends on a large system of reservoirs to supplement flow downstream of the reservoirs. Downstream flow support is regulated by controlled outflows of water from the six mainstem reservoirs on the upper Missouri River (**Figure 3-48**). These reservoirs are located in Montana, North Dakota, South Dakota, and Nebraska.

The 1994 Flood Control Act authorizes the Missouri River Mainstem Reservoir System to be operated for the purposes of flood control, navigation, irrigation, hydropower, water supply, water quality control, recreation, and fish and wildlife (USACE 2006). The regulation of water in support of the authorized purposes is managed by USACE according to the *Missouri River Mainstem Reservoir System Master Water Control Manual*, which provides water control criteria for the management of the system for a spectrum of anticipated runoff conditions (USACE 2006). USACE's Northwestern Division's Missouri River Basin Water Management Division, located in Omaha, Nebraska, is responsible for reservoir regulation. The section of river designated for navigation runs from Sioux City, Iowa to the mouth of the river north of St. Louis. The channel is designed so that a flow of approximately 41,000 cfs at Kansas City, Missouri, provides enough water to maintain a navigation channel that is 300 feet wide and 9 feet deep to the mouth of the Missouri (USACE 2006). In times of water shortage, USACE reduces the amount of water released. A flow of approximately 35,000 cfs at Kansas City provides enough water to support to an 8 feet deep navigation channel (USACE 2006). The navigation channel is maintained by the use of river control structures such as wing dikes, revetments, and bendway weirs, which direct the river's flow into a defined channel that is designed to be self-scouring. These structures, along with reservoir releases, help to control sediment and maintain sufficient depths for navigation.

### 3.11.3 Port Authorities, Toll Ferries, and Passenger Vessels

**Figure 3-49** maps the locations of toll ferries and port authorities in Missouri. There are 12 public ports in Missouri. Three of port authorities are on the Missouri River, and the remaining nine are on the Mississippi River. These ports had a total of nearly 4 million tons of freight shipped through them in 2016. In addition to the public port authorities in Missouri, there are hundreds of private port facilities that rely on waterways and direct river access for their operations (Missouri Department of Transportation [MoDOT] 2018). These ports handle freight, such as agribusiness products, and raw materials, such as gravel and sand (MoDOT 2018). In total, there are 200 commercial docks in Missouri (USACE 2016). There are approximately 120 docks and terminals located on the lower Missouri River. Of these, about one-half are located near and downstream of Kansas City (USACE 2006).

The largest port in Missouri is the Port of Metropolitan St. Louis, which includes 70 miles of terminals along the Mississippi River on both the Missouri and Illinois sides of the river. The port is the seventh largest port by domestic tonnage in the United States and has an authorized channel depth of 9 feet. In 2015, nearly 24,000 vessels called on the port of which 69 percent were dry bulk vessels. These vessels were carrying a total of 35 million short tons, all of which is classified as domestic tonnage. Food and farm products made up 36 percent of that total, petroleum and petroleum products make up 18 percent, and coal, lignite, and coal coke make up 17 percent (U.S. Department of Transportation 2016a). The port is the northernmost lock- and ice-free port on the Mississippi River.

There are six toll ferries that operate within Missouri. Five cross the Mississippi River and provide access to Illinois and Kentucky. Akers Ferry is a remote two-car ferry that crosses the Current River within the Ozark National Scenic Riverways. These six ferries reported transporting a total of 60,508 passengers and 103,777 vehicles in 2015 (U.S. Department of Transportation 2016b).

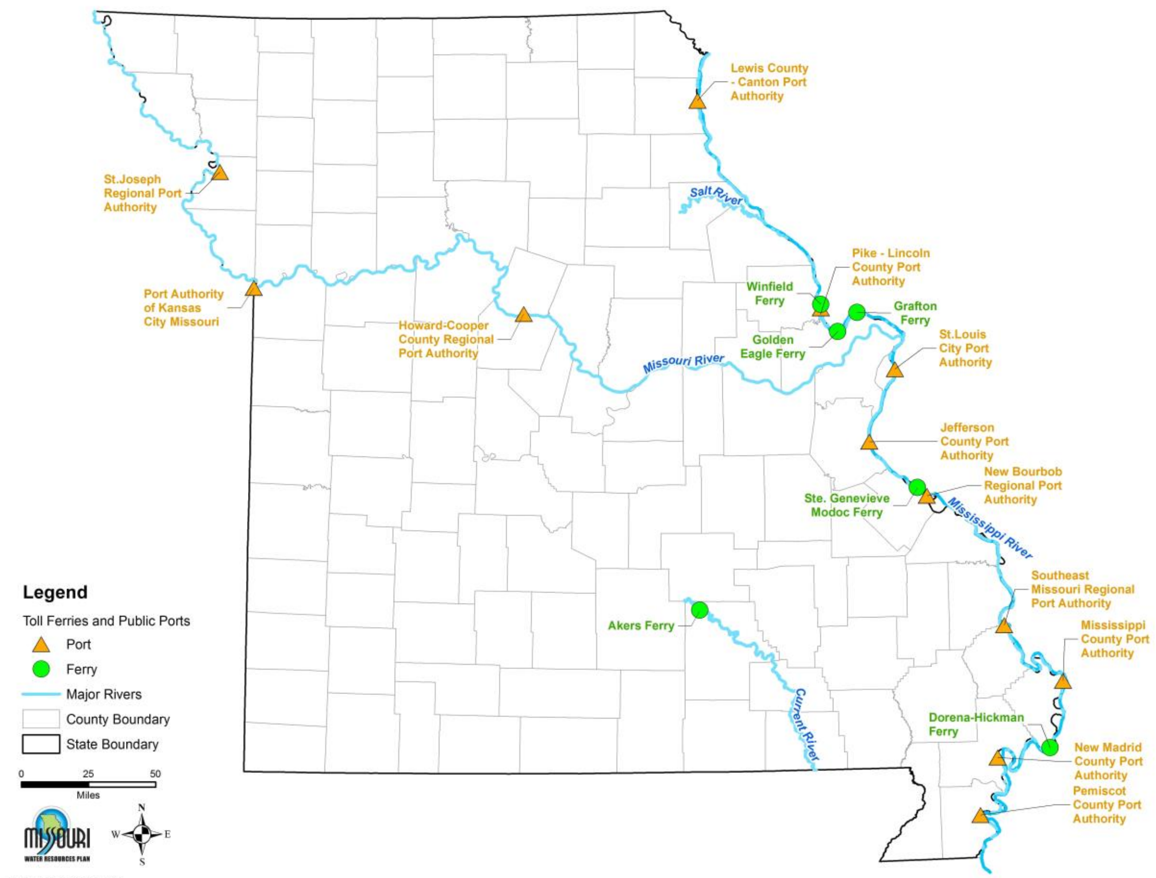


**Figure 3-49. Toll Ferries and Public Port Authorities in Missouri**

In addition to vessels that transport freight and toll ferries, Missouri has 37 certified commercial passenger vessels that operate on numerous rivers and water bodies. These include chartered fishing boats, river cruise boats, and powerboat rides. The largest vessel among this fleet is the Showboat Branson Belle on Table Rock Lake, which can carry 750 passengers.

## 3.11.4 Waterborne Commerce Tonnage and Economic Value

In 2017, 38.8 million tons of commodities that originated in or were destined for Missouri were transported on Missouri's waterways, as shown in **Figure 3-50**. Over 70 percent of those commodities originated in Missouri and were shipped to other states. Sixteen percent were shipped from other states into Missouri. The remaining 12 percent were commodities shipped within Missouri (USACE 2017).

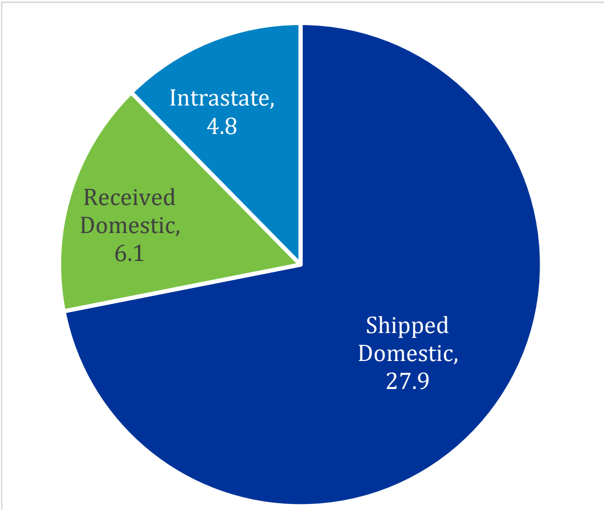


**Figure 3-50. Missouri Waterborne Commerce Tonnage in 2017 (million tons)**
*Source: USACE 2017b*

Typically, half of the tonnage moved on the Missouri River originated in or is destined for the state of Missouri. The Port of Kansas City serves as an origin or destination for between one-third and one-half of Missouri River commercial tonnage (USACE 2006). **Figure 3-51** presents tonnage by river segments for 2016. Tonnage shipped on the Missouri River is greatest between Kansas City and Jefferson City.

On the Mississippi River, tonnage is greatest on the southernmost segment of the river. In 2016, tonnage at the northernmost lock, Lock and Dam 20, was estimated to be 28.5 million tons. This equated to nearly 28,000 barges, both loaded and empty. The southernmost lock, Chain of Rocks, had a throughput estimated to be 67.3 million tons in 2016, more than double that of Lock and Dam 20. That same year, Chain of Rocks locked through 65,426 empty and loaded barges (USACE 2017).


**Figure 3-51. Missouri Waterway Tonnage in 2016**
*Source: USACE 2017*

In 2016, commodities shipped through public ports in Missouri were valued at over $12 billion. Commodities shipped into Missouri's public ports were valued at over $4.5 billion, outbound commodities were valued at over $7.2 billion, and intrastate commodities were valued at $306 million. The value of commodity flows is dominated by agricultural commodities, aggregates, and energy products (MoDOT 2018).

Ports in Missouri involved with handling tonnage directly and indirectly support nearly 290,000 jobs annually, which results in nearly $15.7 billion in labor income, over $100.6 billion in annual economic activity, and more than $2.4 billion annually in state and local tax revenue. Put into perspective, one out of every ten jobs is supported by the ports, or about 34 percent of Missouri's total economy (MoDOT 2018).

### 3.11.5 Future Outlook

The shipping of commodities along the Mississippi and Missouri rivers will continue to be of importance in Missouri. According to MoDOT (2017), port tonnage is forecasted to increase from 49.9 million tons in 2011 to 63.3 million tons for a total of $15.4 billion by 2030. Missouri's waterways are currently uncongested and have the capacity to move substantially more freight. Several active projects to support port expansion are in development along the Missouri and Mississippi rivers (Haldiman 2017, Murray 2018) with six public port authority developments already underway (MoDOT 2017). Jefferson City is planning a new Heartland Port Authority which will be an industrial and commercial multimodal transportation hub located six miles downriver of the Missouri River bridge (Allen 2018).

With the Panama Canal expansion and advances in inland containership vessel engineering, the future could see freight transported on the inland marine system that utilizes container-on-barge vessels and containership vessels specifically designed to traverse the Mississippi River and its tributaries. In 2017, American Patriot Holdings LLC (APH) completed model testing of a domestic inland containership vessel (APH 2018). APH's container vessel, which is planned for Mississippi River service, has a design range of 592 to 952 feet in overall length and capacity to carry between 1,824 and 2,960 20-foot equivalent units at a draft of 9 feet (in fresh water) (APH 2017). The Port Authority of St. Louis is working with major retail companies to encourage container-on-barge shipments (Leahy 2016).

Missouri's waterways require infrastructure and maintenance improvements that are needed to support commercial navigation in the future. A significant portion of the existing lock and dam infrastructure on the upper Mississippi River needs repair or rehabilitation, which is costly (MoDOT 2017). Other needs for this portion of the Mississippi River include developing a funding plan for Upper Mississippi River Basin infrastructure improvements that would be able to meet current and future needs, continuing full funding for the America's Marine Highway grant program, and continuing to emphasize the Upper Mississippi River's Basin's dual roles as a nationally significant navigation system and a nationally significant ecosystem (Upper Mississippi River Basin 2016).

## 3.12 Wetlands

### 3.12.1 Introduction and Definitions

There are many legal and technical definitions associated with the term "wetland." Here, wetland generically refers to all the various kinds of habitats where the land is saturated for some period of time but not necessarily permanently wet (Tiner 1997). Missouri has nine types of natural wetland communities: marshes, shrub swamps, bottomland prairies, bottomland forests, swamps, sinkhole ponds, oxbow lakes and sloughs, riparian areas, and groundwater seeps (Leahy 2010). Wetlands provide wildlife habitat, sediment retention, flood water retention, and natural water filtration. Nature's reliance on wetlands cannot be overstated. For example, there are approximately 110 bird species that regularly nest or migrate through Missouri that depend on wetlands for part of their life cycle (MDC 2015a).

Prior to settlement, Missouri had an estimated 4.8 million acres of wetlands. Nearly 87 percent of these wetlands have been converted for other purposes through agriculture expansion, urbanization, and reservoir construction (MDC 2015a). MDC, private land owners, agricultural producers, conservation organizations, and other state and federal agencies have worked together to restore and create wetlands on public and private land. Primary drivers of restoring, enhancing, and protecting Missouri's wetlands are easement and restoration programs offered through the Natural Resources Conservation Service (NRCS). The programs offered have changed in name and scope over the years, but the basic premise of the programs has remained unchanged. The current program offered through NRCS is the Wetland Reserve Enhancement Partnership (WREP). This is a voluntary program that offers landowners payment in return for property easements allowing the area to serve as a wetland. The goal of the WREP is to achieve the greatest wetland functions and values, along with optimum wildlife habitat on every acre enrolled in the program.

Missouri's wetlands are fed through rainfall and, in some areas, surface water diversions or groundwater pumping. No attempt was made to quantify the volume of rain that falls on wetlands in Missouri. However, data available through the WREP program and MoDNR's Major Water Users database were assessed to estimate the quantity of water pumped or diverted annually to support wetlands. These withdrawals are nonconsumptive water demands, meaning the water is withdrawn from the source to support the demand but is not consumed and remains available for other uses. **Figure 3-52** shows the acreage in Missouri enrolled in the WREP program by county and the state-run conservation areas and duck hunting clubs registered with MoDNR's Major Water Users. These data serve as the basis of quantifying water withdrawals to support wetlands as discussed in **Section 3.12.2**.

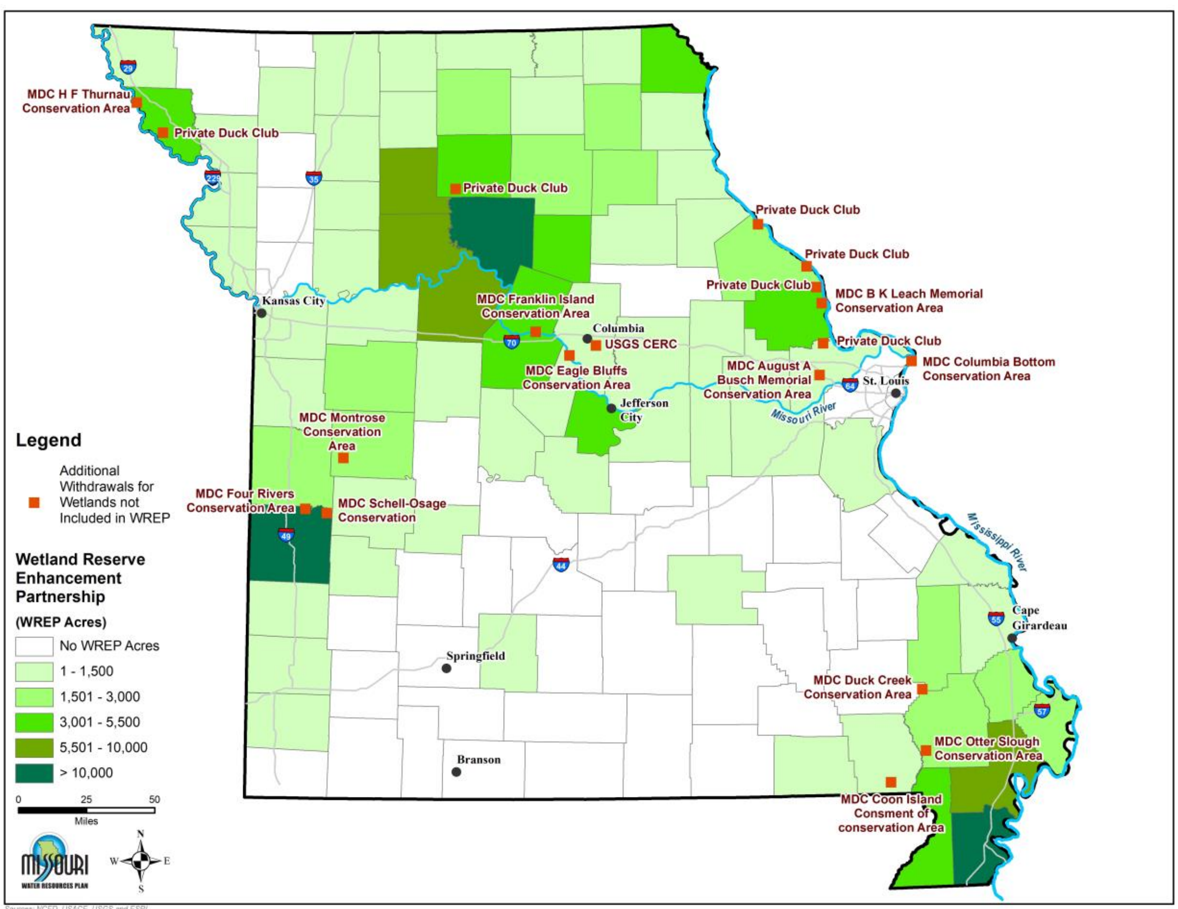


Figure 3-52. Acreage in Wetland Reserve Easements and Registered Water Withdrawals for Wetlands

### 3.12.2 Quantified Water Withdrawals

Water withdrawals for wetlands were estimated for both WREP acres and additional state-run and privately-owned wetland areas. Withdrawals for the WREP were estimated based on the NRCS reported acreage in WREP and the NRCS limit of only allowing one-third of the total acreage in the easement to be flooded. Using a GIS layer[6], total acreage set aside in the WREP in Missouri is estimated to be 145,726 acres. While not all acreage in the WREP is artificially supplied (i.e., in addition to natural rainfall), many landowners drain the wetlands annually to plant food sources for migrating waterfowl and then reflood the acreage once plant growth is established.

To assess the number of acres and the amount of water that is artificially supplied, WREP acres were mapped in GIS along with groundwater irrigation wells (available through MoDNR's Wellhead Information Management System [WIMS]) and surface water sources. WREP areas with a groundwater irrigation well within a half-mile buffer, or a surface water source within a quarter-mile buffer were identified. This analysis revealed that 35 percent of the acres have access to a groundwater well and 33 percent of the acres have access to a surface water source. Areas not located in proximity to a diversion or well totaled 32 percent of WREP acres. This totals just under 100,000 acres that are potentially artificially flooded annually.

Based on an average estimated water depth of 18 inches[7], and assuming that no more than one-third of total acreage is flooded (per program guidelines), withdrawals from groundwater and surface water sources were estimated by county. Water withdrawals to support WREP program goals are estimated to exceed 49,000 acre-feet per year (AFY), on average, or 44 MGD.

The water use reported to the Major Water Users database from MDC and private duck clubs for wildlife purposes was added to the WREP estimated withdrawals by county. **Table 3-24** lists the estimated nonconsumptive withdrawals by detailed source. In total and on average, combined annual water withdrawals to support wetlands in the state are estimated to be 104,350 AFY, or 93 MGD. **Appendix C** provides the estimated wetland withdrawals by county.

**Table 3-24. Estimated Annual Wetland Replenishment Nonconsumptive Water Withdrawals by Source**

| Source | | Total Withdrawals (AFY) | Total Withdrawals (MGD) |
|---|---|---|---|
| GROUND-WATER BY AQUIFER | Alluvial | 47,604 | 42.5 |
| | Lower Ozark | 7,034 | 6.3 |
| | Upper Ozark | 2,203 | 2.0 |
| | GROUNDWATER TOTAL | 56,841 | 50.7 |
| SURFACE WATER BY SUBREGION | Chariton-Grand | 5,998 | 5.4 |
| | Des Moines | 264 | 0.2 |
| | Gasconade-Osage | 8,175 | 7.3 |
| | Lower Mississippi-St. Francis | 129 | 0.1 |
| | Lower Missouri | 11,625 | 10.4 |
| | Missouri-Nishnabotna | 844 | 0.8 |
| | Upper Mississippi-Kaskaskia-Meramec | 7,968 | 7.1 |
| | Upper Mississippi-Salt | 12,316 | 11.0 |
| | Upper White | 191 | 0.2 |
| | SURFACE WATER TOTAL | 47,509 | 42.4 |
| **STATEWIDE TOTAL** | | **104,350** | **93.2** |

[6] Available from https://www.conservationeasement.us/downloads/
[7] Per discussions with knowledgeable NRCS staff

There are additional wetlands and waterfowl hunting areas that are flooded annually but not enrolled in the WREP, nor registered with MoDNR, and thus not included in the water withdrawal estimates shown in **Table 3-23**. MDC manages 32,000 acres of public wetlands on 15 conservation areas where managed waterfowl hunts are allowed (MDC 2015b). There are an additional 80,000 acres of public wetland habitat maintained by MDC on 169 conservation areas where walk-in waterfowl hunting is allowed (MDC 2015b).

### 3.12.3 Economic Impact

There are direct and indirect economic benefits generated by wetlands. Through their natural filtration process, wetlands improve drinking water quality and decrease the cost of drinking water treatment processes. Wetlands store floodwaters, reducing damage from flooding events. Fish and other freshwater organisms thrive in wetland environments, contributing to the state's fishing industry. Wetlands offer recreational opportunities that generate spending such as waterfowl hunting, hiking, fishing, bird watching, and photography. These activities and benefits contribute to the state and national economy; however, the exact dollar value is difficult to estimate.

Additionally, the WREP program provides direct payments to private landowners, which contributes to the state's economy. On an annual basis, there is $1.62 million in direct payments made to private landowners in Missouri through the WREP program (NRCS 2018). These payments add an additional $1.58 million to Missouri's economy in in-state sales, jobs, and taxes (NRCS 2018).

Land in the WREP and additional lands not enrolled in the program attract waterfowl and other wildlife and are used to support the waterfowl hunting industry and nature viewing. Hunters spend dollars on food and lodging, transportation, guide fees, gear and equipment, and registration and licensing fees. In 2011, the U.S. Fish and Wildlife Service (FWS) estimated that Missouri hosted 37,000 duck hunters, ranking fifth in the nation and third in the Mississippi flyway states (FWS 2015). These hunters spent 422,000 days hunting waterfowl in Missouri. Activities related to waterfowl hunting have an annual economic impact for Missouri of $149 million, support nearly 2,000 jobs, and contribute more than $13 million in state and local taxes (MDC 2015b).

Additional activities that wetlands support include bird and nature watching. In 2011, there were an estimated 1.72 million wildlife viewing participants in Missouri (MDC 2014). As with waterfowl hunters, these participants add to the local, state, and national economy.

## 3.13 Water-Based Outdoor Recreation

### 3.13.1 Introduction and Definitions

Missouri has abundant outdoor recreation resources, with hundreds of conservation areas, 87 state parks and historic sites, two major rivers, extensive water trails, the Mark Twain National Forest, and the Ozark National Scenic Riverways. These rivers, streams, ponds, and lakes provide Missourians and out-of-state visitors with opportunities to swim, canoe, motorboat, sail, fish, hunt, float, ski, dive, and participate in other outdoor activities. These activities rely on public infrastructure and proper management to ensure safe, reliable, and accessible recreation.

There are many social, economic, and environmental benefits associated with outdoor recreation. Additionally, health benefits stem from access to physical activities and the ability to connect with the natural environment. Outdoor recreation is among Missouri's largest economic sectors, fed by the recreationalist who purchases gear, equipment, and licenses and spends money on transportation, food, and lodging in local economies. The impact of outdoor recreation and the resources that support it add positive value to the local, state, and national economies.

In addition to recreational uses, commercial fisheries rely on adequate outdoor water resources to support their industry. In 2016, there were 112 commercial fishing permit holders statewide. This industry also relies heavily on the aquaculture and hatchery industry as discussed in **Section 3.14**.

There are several state and federal agencies that manage and operate the public's outdoor recreational water resources. Federal agencies include the National Park Service, which manages six national park properties; FWS, which operates 60,831 acres of wildlife refuges and the Neosho Fish Hatchery; the USDA Forest Service, which manages the rivers, streams, lakes, and natural springs within the Mark Twain National Forest; and USACE, which operates and maintains 12 reservoirs (MoDNR 2017). MDC manages access to an additional 324,855 acres of water across Missouri and numerous conservation areas.

This section maps and characterizes key water-based recreational opportunities in Missouri and provides data on the economic impact of this sector.

### 3.13.2 Designated Waters Suitable for Recreation

Based on water quality standards, the Missouri Code of State Regulations designates which waters in the state, including streams and lakes, are suitable for either whole-body contact or secondary contact recreation activities. Whole-body contact includes activities where a person is in contact with the raw surface water to the point of submergence such as swimming, water skiing, or diving. Secondary contact recreation includes activities that require limited, incidental contact with the surface water such as fishing, wading, canoeing, and boating. **Table 3-25** presents a summary of the rivers, streams, and lakes designated for whole-body and secondary contact. There are nearly 110,000 miles of rivers and streams in the state suitable for recreational use, with 99 percent of them suitable for whole-body contact. Of these, 6,282 miles are available for public use, meaning the public has direct access to the river or stream. Missouri has 318,939 surface acres of lake water available for whole-body contact, 82 percent of which the public has direct access to.

**Table 3-25. Designated Recreational Use Waters**

| Source | Designated for Secondary Contact Recreation – Public | Designated for Whole-Body Contact – Public | Designated for Whole-Body Contact – Open to the Public |
|---|---|---|---|
| Rivers/Streams (miles) | 109,496 | 108,861 | 6,282 |
| Lakes (acres) | 318,939 | 318,939 | 260,950 |

### 3.13.3 Waterbodies

#### Lakes Operated by the U.S. Army Corps of Engineers

In Missouri, there are 12 lakes operated and managed by USACE as listed in **Table 3-26** and shown in **Figure 3-53**. Two of the lakes, Bull Shoals and Norfork, have only a small percentage of their total surface area within Missouri. The largest of the lakes is the 55,600-acre Harry S. Truman Reservoir. Nine of the 12 lakes are south of the Missouri River; the majority of larger lakes (Harry S. Truman Reservoir, Stockton Lake, Pomme de Terre Lake, and Table Rock Lake) are in the Ozarks region. In 2016, the most visited lake was Table Rock Lake, with over 7 million visitors, followed by Bull Shoals, and Harry S. Truman Reservoir.

**Table 3-26. Visitation and Water-Based Activities at Missouri USACE-Managed Lakes in 2016**

| Lake | Water Surface Acres | Fishermen[1] | Boaters[1] | Swimmers[1] | Water Skiers[1] | Visitation[1] |
|---|---|---|---|---|---|---|
| Bull Shoals Lake[2] | 51,200 | 981,422 | 846,088 | 85,007 | 68,067 | 2,228,603 |
| Clearwater Lake | 1,630 | 131,182 | 14,989 | 78,785 | 12,266 | 384,623 |
| Harry S. Truman Reservoir | 55,600 | 1,036,170 | 361,852 | 121,370 | 33,452 | 1,499,545 |
| Little Blue River Lakes[3] | 1,650 | 146,047 | 191,717 | 57,124 | 25,101 | 1,004,015 |
| Long Branch Lake | 2,430 | 56,171 | 70,665 | 31,056 | 6,052 | 225,058 |
| Mark Twain Lake | 18,600 | 390,232 | 159,857 | 132,201 | 78,857 | 994,586 |
| Norfork[2] | 22,000 | 643,993 | 424,114 | 246,152 | 83,621 | 1,237,624 |
| Pomme de Terre Lake | 7,790 | 394,110 | 447,539 | 214,934 | 75,658 | 861,817 |
| Smithville Lake | 7,190 | 275,197 | 152,345 | 23,674 | 25,562 | 749,694 |
| Stockton Lake | 24,632 | 406,953 | 158,673 | 65,955 | 32,663 | 879,394 |
| Table Rock Lake | 45,662 | 1,432,232 | 4,289,248 | 748,301 | 196,732 | 7,006,232 |
| Wappapello Lake | 8,400 | 320,578 | 129,256 | 61,297 | 16,254 | 899,450 |

*Source: USACE 2018*
[1] Visits (person-trips) in 2016
[2] Small portion of lake in Missouri
[3] Longview and Blue Springs lakes

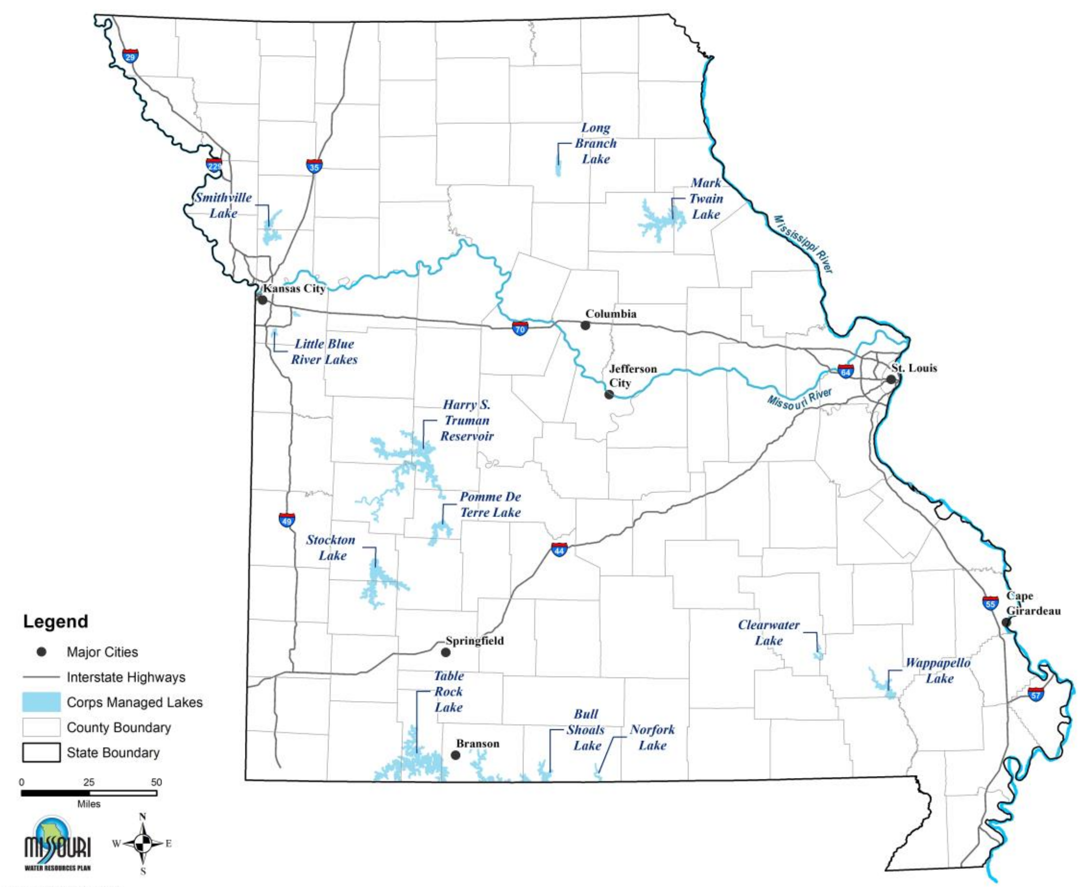


**Figure 3-53. USACE-Managed Lakes in Missouri**

## MDC-Managed Waterbodies

MDC is charged with the control, management, restoration, conservation, and regulation of the bird, fish, game, forestry, and all wildlife resources of Missouri. As such, they manage access to a number of streams, rivers, and lakes both owned by the agency and owned by other state and federal agencies and private entities. **Figure 3-54** provides a map of the waterbodies managed by MDC, many of which are USACE-operated reservoirs. MDC also manages public access to the Lake of the Ozarks, a privately-owned reservoir created on the Osage River in 1931 when Bagnell Dam was built. In total, MDC manages 324,855 acres of water across Missouri. In all, MDC manages more than 600 lakes (MoDNR 2017).

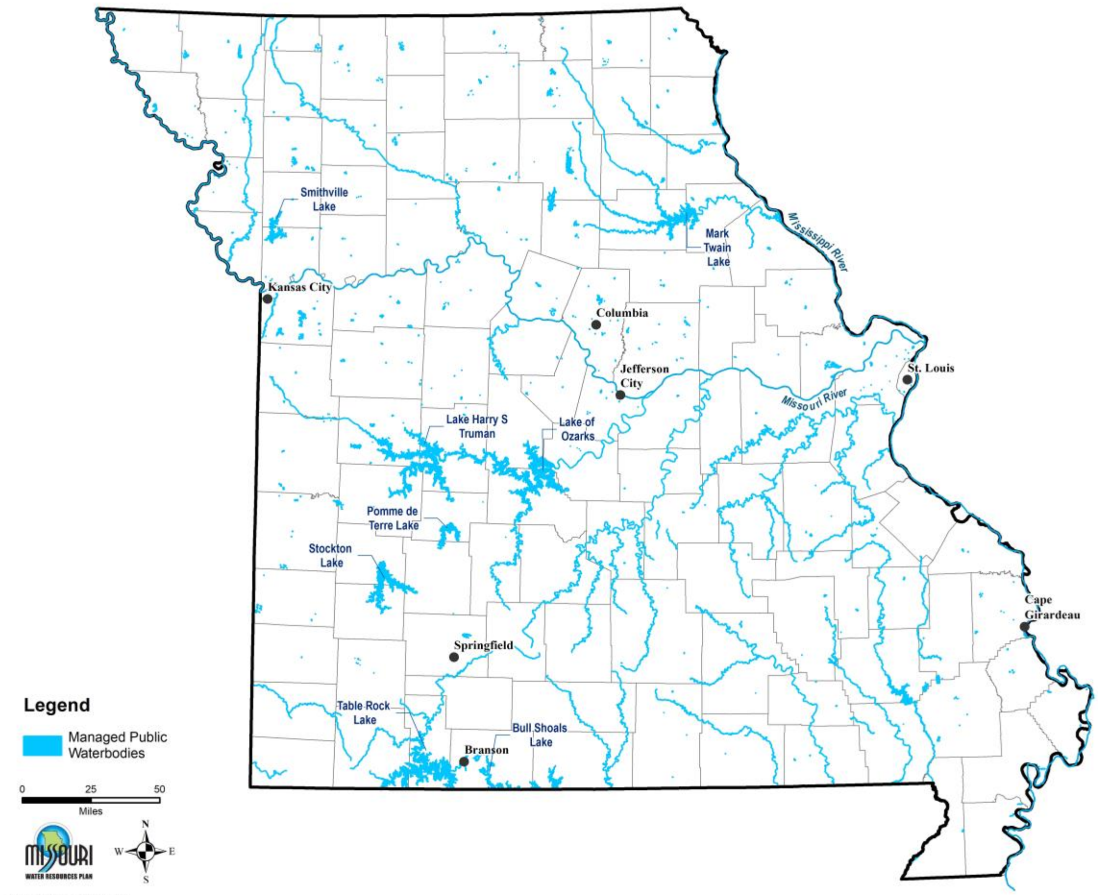


**Figure 3-54. Waterbodies Managed by MDC**

## Fishing Waters

There are many fishing streams, rivers, ponds, and lakes across Missouri. Many of these waters are managed by MDC and open to public access. These waters offer opportunities to fish for species such as black bass, catfish, rock bass, suckers, sunfish, white bass, crappie, walleye, and trout. These fish, with the exception of trout, are found natively in Missouri's waters. MDC's website lists 765 public access points that are appropriate for fishing.

Trout were first introduced into the cold water of the Ozarks by early settlers in the 1800s. Missouri's trout population is now managed by MDC, with several partners, including MoDNR, the U.S. Forest Service, the National Park Service, FWS, the James Foundation, Neosho National Fish Hatchery, USACE, and a number of city and county governments. Trout prefer cold water streams for habitat.

Currently, Missouri has 4 trout parks, 7 trout management areas, 5 special trout management areas, 8 wild trout management areas, Lake Taneycomo, and 28 urban winter trout areas in St. Louis and Kansas City. A map of trout lakes and streams across Missouri is provided in **Figure 3-55**. Lake Taneycomo is Missouri's largest cold-water habitat and receives between 675,000 and 750,000 rainbow trout and 10,000 brown trout each year from fisheries (MDC 2003). **Section 3.14** outlines the water requirements for the cold-water fish hatcheries which are directly connected to the trout parks and special areas.

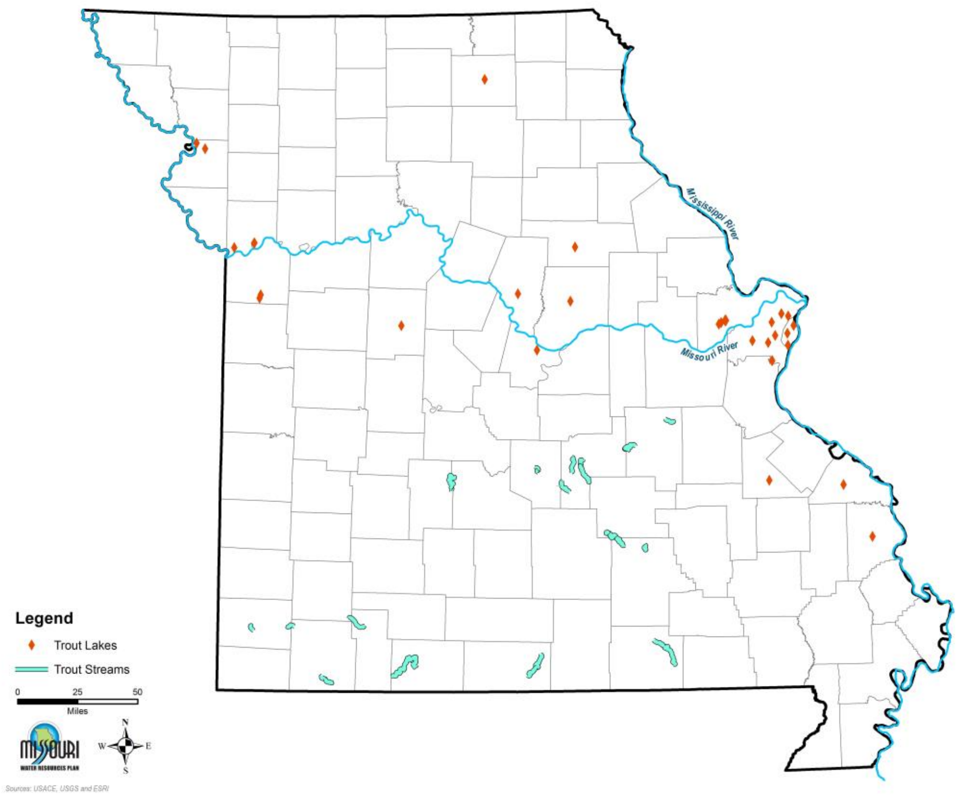


**Figure 3-55. Trout Rivers and Lakes**

## Float and Paddling Rivers

There are many rivers throughout Missouri that attract people for floating, canoeing, rafting, paddle boarding, and kayaking. Common rivers and streams utilized by recreationalists for nonmotorized boating activities are shown in **Figure 3-56** and include the Meramec River, Big Piney River, Current River, and Jacks Fork River. The Current and Jacks Fork rivers make up the Ozark National Scenic Riverways, a national park devoted to the preservation of these streams. The MDC publication *A Paddler's Guide to Missouri* (ISBN 978-1-887247-81-8) states that most rivers in Missouri are rated Class I, the easiest to navigate with occasional small rapids and minor obstacles. The paddler's guide provides an overview of the streams and rivers suitable for nonmotorized activities. Additionally, the Missouri Canoe and Floaters Association lists the following waterways as ideal for nonmotorized boating:

| | | | |
|---|---|---|---|
| Beaver Creek | Courtois Creek | Jacks Fork River | North Fork River |
| Big Creek | Current River | James River | Osage Fork Gasconade River |
| Big River | Eleven Point River | Little Niangua River | Pomme de Terre River |
| Big Piney River | Elk River | Little Piney Creek | Sac River |
| Big Sugar Creek | Finley Creek | Little Sugar Creek | St. Francis River |
| Black River | Gasconade River | Meramec River | |
| Bourbeuse River | Huzzah Creek | Missouri River | |
| Byrant Creek | Indian Creek | Niangua River | |

There are several rivers and lakes in Missouri designated as water trails, popular among canoe and kayak paddlers. These include portions of the Missouri River, James River, Mississippi River, and Niangua and Big Niangua rivers, and Monsanto Lake, Finger Lakes, Lake of the Ozarks, and Stockton Lake.

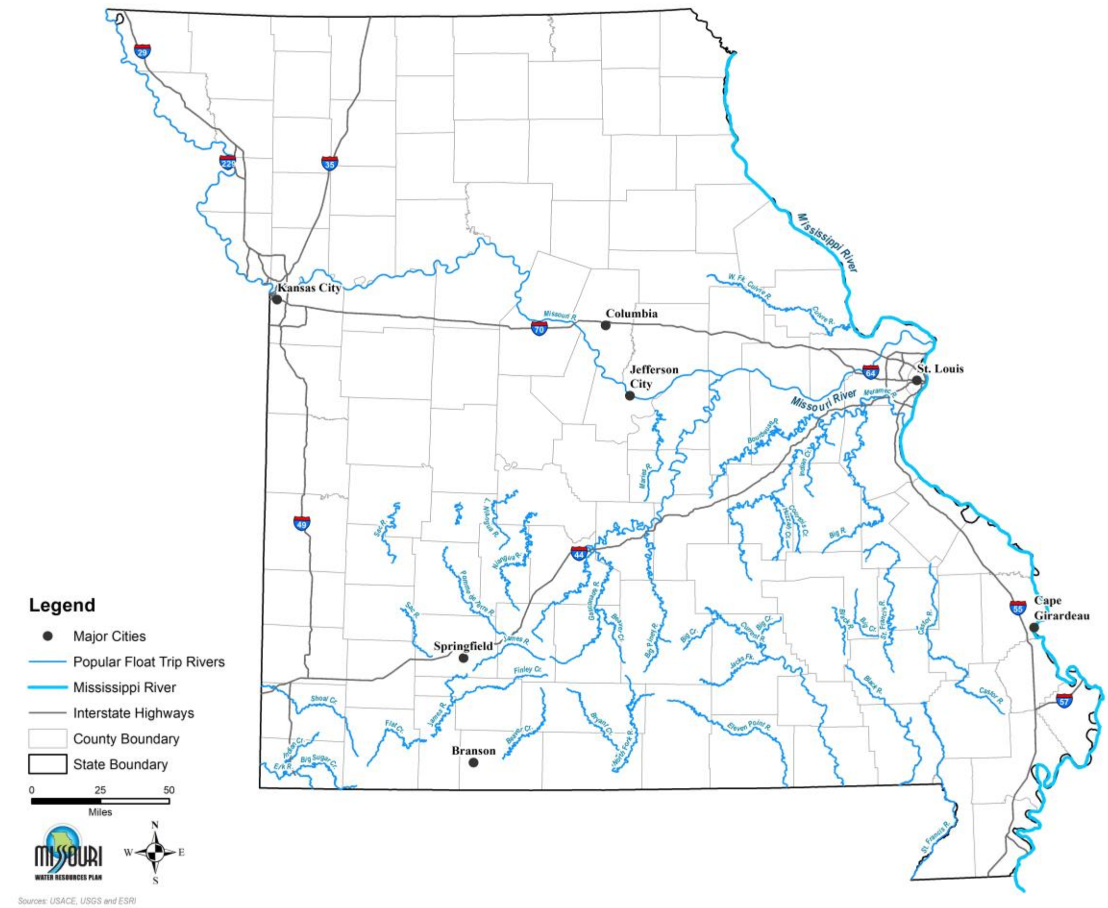


**Figure 3-56. Popular Float Trip Rivers in Missouri**
*Source: Missouri Canoe and Floaters Association 2018b*

## 3.13.4 Water Access Points

Most larger waterbodies in Missouri offer access to some form of boating, either motorized, nonmotorized, or both. Access points managed by MDC are shown in **Figure 3-57**. In total, MDC manages 586 water access points across Missouri. In 2015, Missouri had 293,660 registered boats (U.S. Department of Homeland Security 2015). Additionally, there are many private access points along the rivers, streams, and lakes in Missouri.

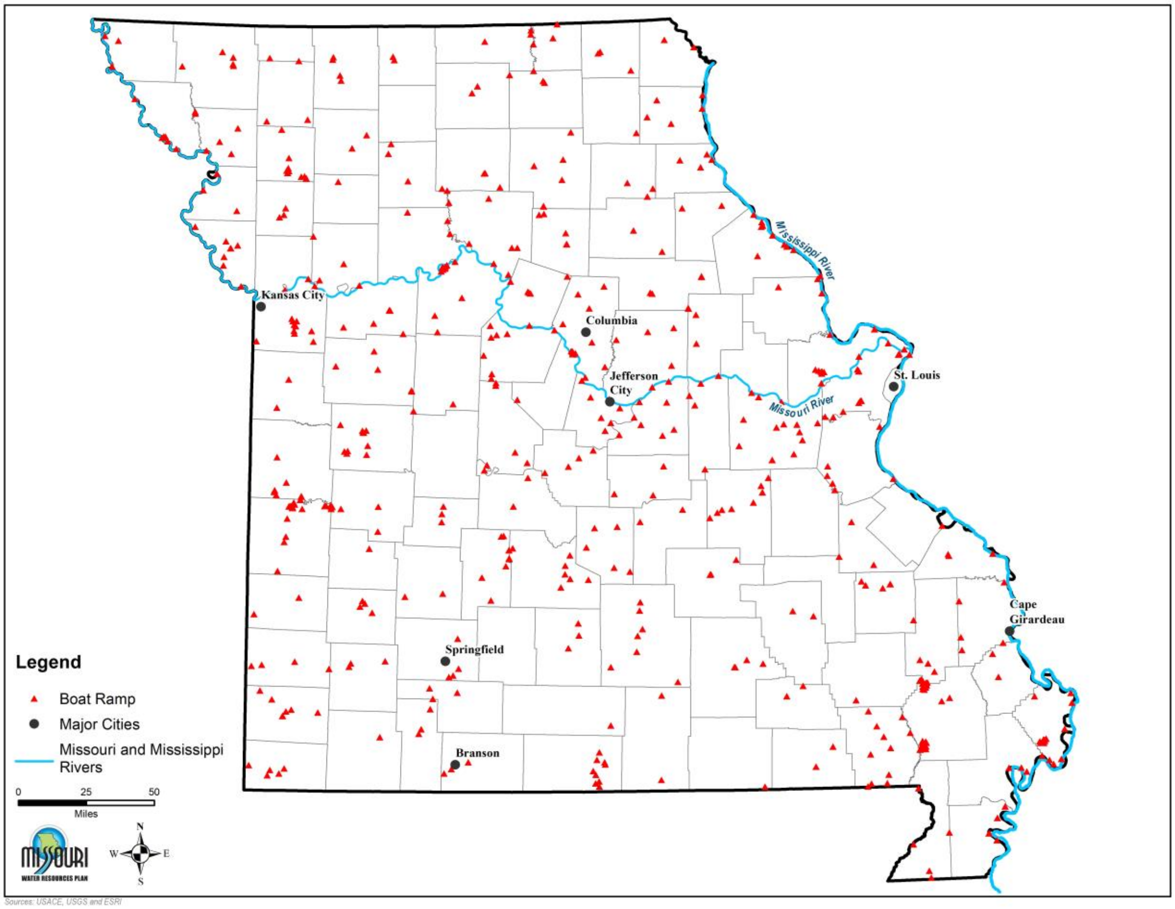


Figure 3-57. Water Access Points Managed by MDC

### 3.13.5 Economic Impacts

Participating in outdoor recreation typically involves expenditures such as travel, food, supplies, and specialized equipment. Spending occurs by visitors from out-of-state locations and Missouri residents. As such, outdoor recreation is among Missouri's largest economic sectors.

The Outdoor Industry Association's *2017 Outdoor Economy Report* shows that Missouri averages $14.9 billion in spending annually on outdoor recreational activities, which creates $889 million in state and local taxes (2017). The outdoor recreation industry also creates an estimated 133,000 jobs in Missouri, equaling $4.6 billion in wages and salaries per year. Anglers spent $685 million on fishing activities in Missouri in 2011 (Congressional Sportsmen's Foundation [CSF] 2013). This contributed to nearly 11,000 jobs, $211 million in federal taxes, and $181 million in local and state taxes (CSF 2013). In 2017, fishing license sales totaled $12.85 million, which qualified the state for nearly $7.83 million in federal funding available to support the management and restoration of fish habitat (CSF 2017). The Lake Taneycomo trout fishery is estimated to add approximately $13.3 million per year to the local economy (MDC 2003). The Missouri Canoe and Floaters Association states that there are 112 private outfitter companies that provide goods and services to the Missouri outdoor recreation industry (2018a). Adequate quantities and quality of water are essential for each of these industries.

When people visit USACE lakes, the money spent by these visitors adds to the local and national economy by supporting jobs and generating revenue and income. In 2016, USACE estimated the economic value of its reservoir infrastructure in Missouri as shown in **Table 3-27**. In a single year, the 14.5 million visitors to

USACE reservoirs located in Missouri spent an estimated $684 million within 30 miles of the reservoir during their visit (USACE 2018). The visitor spending supported nearly 6,000 tourism and recreation jobs within 30 miles of the reservoirs and generated $153 million in labor income (USACE 2018). In total, these USACE reservoirs were estimated to add $202 million to the economies surrounding the lakes (USACE 2018).

**Table 3-27. Economic Impact of USACE Reservoirs**

| Reservoir/Lake | Visitor Spending within 30 miles (1,000$) | Sales within 30 miles (1,000$) | Jobs within 30 miles | Labor Income within 30 miles (1,000$) | Value added within 30 miles (1,000$) |
|---|---|---|---|---|---|
| Bull Shoals Lake[1] | $82,041 | $42,707 | 706 | $17,416 | $22,484 |
| Clearwater Lake | $9,379 | $5,461 | 94 | $2,114 | $2,656 |
| Harry S. Truman Reservoir | $48,180 | $26,887 | 443 | $11,023 | $13,910 |
| Little Blue River Lakes | $29,076 | $17,986 | 274 | $7,486 | $9,704 |
| Long Branch Lake | $7,959 | $4,464 | 70 | $1,781 | $2,279 |
| Mark Twain Lake | $28,566 | $16,524 | 270 | $6,411 | $8,190 |
| Norfork Lake[1] | $44,264 | $24,758 | 387 | $8,991 | $12,307 |
| Pomme de Terre Lake | $37,921 | $20,246 | 325 | $8,246 | $10,559 |
| Smithville Lake | $23,923 | $14,737 | 229 | $6,201 | $7,997 |
| Stockton Lake | $26,186 | $16,065 | 252 | $6,474 | $8,324 |
| Table Rock Lake | $321,147 | $176,718 | 2,643 | $71,183 | $96,552 |
| Wappapello Lake | $25,311 | $14,235 | 241 | $5,600 | $7,053 |
| **TOTAL** | **$683,953** | **$380,788** | **5,934** | **$152,926** | **$202,015** |

*Source: USACE 2018*
Note: Data are for 2016 fiscal year and are in constant 2016 dollars.
[1] Small portion of lake in Missouri

## 3.14 Aquaculture and Fish Hatcheries

### 3.14.1 Introduction and Definitions

Aquaculture is the farming and cultivating of cold- and warm-water organisms such as fish or crustaceans for food, restoration, conservation, or sport fishing. Missouri's aquaculture industry relies on abundant, clean water for raising these organisms. Aquaculture production occurs under controlled feeding, sanitation, and harvesting procedures primarily in ponds, flow-through raceways, cages, net pens, and closed recirculation tanks. Pond production accounts for 74 percent of private aquaculture production in Missouri, followed by raceways at 16 percent (**Figure 3-58**) (USDA 2014b).

In Missouri, aquaculture originated with the State Fish Commission and the federal government. The State Fish Commission built its first hatchery at Brown Spring near St. Joseph. FWS established the Neosho National Fish Hatchery in 1888, the oldest operating federal fish hatchery in the United States. Today, MDC operates nine fish hatcheries throughout the state. Five of the fisheries are cold-water hatcheries that produce more than 1.6 million brown and rainbow trout annually. These include Shepherd of the Hills, Bennett Spring, Roaring River, Montauk, and Maramec Spring hatcheries (MDC 2018). At Shepherd of the Hills, cold water comes from the bottom of Table Rock Lake and is released through the dam to the hatchery and the adjacent Lake Taneycomo. There

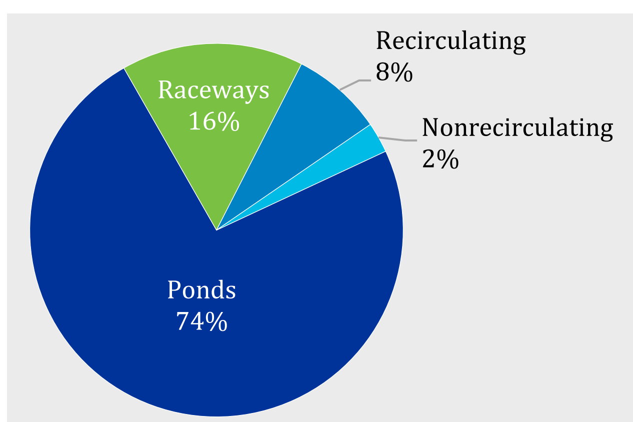


**Figure 3-58. Private Aquaculture Production by Type in Missouri**

are four hatcheries (Blind Pony Hatchery, Chesapeake Fish Hatchery, Hunnewell Lake Conservation Area, and the Lost Valley Fish Hatchery) that produce warm-water fish such as black bass, catfish, crappie, and sunfish. The Blind Pony Hatchery produces the endangered pallid sturgeon, which is used to restore populations in the Missouri and Mississippi rivers.

The aquaculture industry has expanded beyond state- and federal-operated hatcheries. Missouri has approximately 35 privately owned aquaculture farms, with 1,809 acres used for aquaculture production (USDA 2014b). These businesses raise carp, catfish, yellow perch, tilapia, trout, bass, and prawns. The Missouri Aquaculture Directory, produced by the Missouri Department of Agriculture, lists 70 aquaculture-related businesses that support the aquaculture industry (Missouri Department of Agriculture 2017).

### 3.14.2 Economic Importance

The 35 privately owned aquaculture producers in the state reported $7.4 million in annual sales (USDA 2014b). Additional revenue is generated by aquaculture support businesses. The draw of anglers to rivers, streams, and lakes produces additional economic activity. According to a report issued by the CSF, 1.28 million hunters and anglers spent $1.67 billion on hunting and fishing activities in Missouri in 2011 (CSF 2015). As mentioned previously, anglers spent $685 million on fishing activities in Missouri, which contributed to nearly 11,000 jobs, $211 million in federal taxes, and $181 million in local and state taxes (CSF 2015). Additionally, MDC's five cold-water hatcheries generate $104 million in retail sales and have an impact of $187 million on the economy (MDC 2018).

### 3.14.3 Quantified Water Withdrawals

The water that supports statewide aquaculture is withdrawn from the source, either surface or groundwater, but is not consumed. USGS provides comprehensive reporting of aquaculture water withdrawals for Missouri. In 2010, aquaculture withdrawals were estimated to be 181 MGD, with 94 percent supplied by surface water sources (Maupin et al. 2014). As shown in **Figure 3-59**, the largest withdrawals occurred in Douglas County (21 percent), Dent County (17 percent), and Taney County (14 percent). Data for county withdrawals are provided in **Appendix C**.

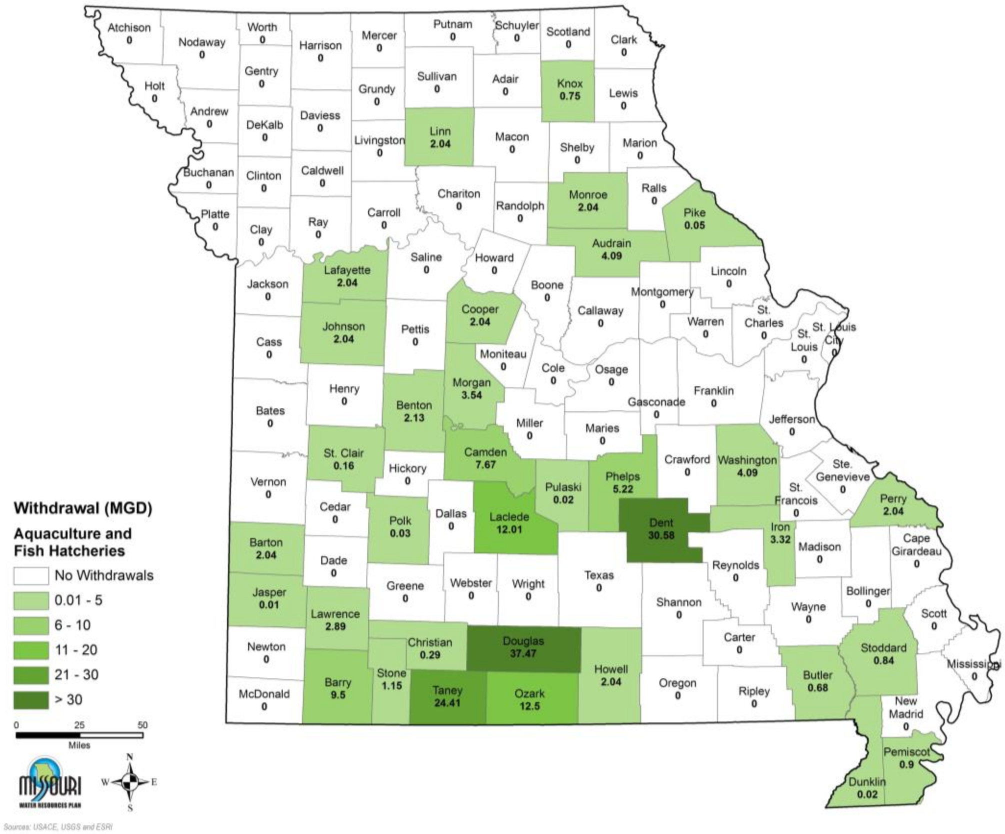


**Figure 3-59. Aquaculture and Fish Hatcheries Water Withdrawals**
*Source: Maupin et al. 2014*

MDC's trout production facilities require a steady supply of cold water. Available water supply and water supply required are shown in **Table 3-28**. In the past, trout populations have been impacted by protracted wet or dry cycles, which can dramatically alter the discharge and temperature of cold-water streams; physical habitat within streams; and the survival, feeding, growth, and reproduction of trout (MDC 2003).

**Table 3-28. MDC Trout Production Facility Water Needs**

| Facility | Water Supply Available (cfs) | Water Supply Needed (cfs) |
|---|---|---|
| Bennett Spring | 150 | 31 |
| Maramec Spring | 144 | 11 |
| Montauk | 82 | 31 |
| Roaring River | 32 | 19 |
| Shepherd of the Hills[1] | 22 | 22 |

*Source: MDC 2003*

[1] Shepherd of the Hills water is supplied from Table Rock Lake and also utilizes a pond containing 1.43 acre-feet of water.

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# Section 4 Missouri's Water Supply

## 4.1 Introduction

Missouri has an abundant supply of water, both in the ground and on the surface. Precipitation falling within the state, which has averaged about 43 in/yr over the last 30 years, provides over 15 trillion gallons of runoff water to rivers, lakes, and streams. More than twice that amount of water—38 trillion gallons per year—enters the state from the Missouri River and Mississippi River, draining land from neighboring states and beyond. Precipitation infiltrating the ground replenishes aquifers that provide an estimated 500 trillion gallons of potable groundwater storage within the state (Miller and Vandike 1997).

While the state has plentiful resources of surface water and groundwater, making that water available for beneficial use can be a challenge. For example, much of the groundwater originating from bedrock aquifers in northern and west central Missouri is highly mineralized and unsuitable for most uses without treatment. In these areas, municipalities and other major water users primarily rely on surface water from streams or reservoirs or groundwater from unconsolidated aquifers, and their proximity to these resources becomes an important factor influencing the affordability of water. Timing is also important in determining the availability of water, since peak demands often coincide with the driest times of the year. Multiyear droughts can lower aquifers and drain reservoirs that typically provide ample supply. Even when available, the quality of the water may not be suitable for all intended uses without treatment.

### Overview of Section 4 Missouri's Water Supply

This section of the Missouri WRP quantifies Missouri's available supply of surface water and groundwater and compares the available supply to current and projected future demands.

This section is organized as follows:

- Section 4.2 Water Budgets – summarizes calculated surface and groundwater budgets.
- Section 4.3 Limitations of the Analyses – provides the context for the analyses and summarizes how they should be used.
- Section 4.4 Water Availability Results by Subregion – compares available supply to current and projected future demands by subregion.
- Section 4.5 Missouri River – highlights the importance of the Missouri River for water supply, navigation, and other uses, and discusses ongoing challenges.
- Section 4.6 Water Availability Results for Select Subbasins – compares available supply to current and projected future demands by subbasin.
- Section 4.7 County-Level Assessment of Groundwater Sustainability – provides a county-level assessment of groundwater availability.
- Section 4.8 Ozark Plateaus Aquifer System Groundwater Flow Model Assessment – discusses the use of the USGS Ozark Aquifer System Groundwater model to evaluate projected 2060 groundwater demands.
- Section 4.9 Summary – provides a summary of water availability by subregion.

These issues highlight the need for an accurate characterization of the quantity, quality, location, and timing of water supplies that are available for use now and in the future. Once the total available supply is known, areas where water supplies may be stressed or where potential water shortages or gaps exist can be identified by comparing the total available supply to projected demands. The identification of water stress and water supply gaps is a core component of comprehensive water planning and a critical step leading to the development of effective water management policies and actions. In the context of this plan, water stress occurs when demands are close to exceeding the available supply of usable water. A water supply gap refers to a shortage of water due to demands exceeding supply for a duration of time.

**Water stress** occurs when demands are close to exceeding available supply.

**Water supply gap** refers to a shortage of water due to demands exceeding supply for a duration of time.

The hierarchical system of drainage basins discussed in **Section 2** provides a means to assess water availability at various scales. Specifically, drainage basins are discussed in this report in terms of subregions, which correspond to USGS HUC 4 drainage areas, and smaller subbasins, which correspond to USGS HUC 8 drainage areas. Missouri contains nine subregions, and these are shown in **Figure 4-1**. Water availability in rivers, streams, and reservoirs was totaled for each of the state's nine subregions. Similarly, groundwater was totaled by subregion, although this approach has limitations since aquifers may transmit water between drainage basins, which are surface features.

Much of the focus of the Missouri WRP, including the water availability assessment, is on Missouri's nine major subregions as shown in **Figure 4-1** and described in **Section 4**. However, in two subregions where potential water stress was identified, water availability was also investigated at a more local, subbasin-scale at the smaller HUC 8 level, as shown in **Figure 4-1**. In this plan, subregions are sometimes referred to by their HUC 4 designation, and their smaller component subbasins by their HUC 8 designation.

Data from the following sources were used to assess water availability and develop the water budgets discussed below:

- Surface water and groundwater demands are from the analysis described in **Section 3**.
- To estimate surface water availability, data from the USGS stream gage network in Missouri via the USGS National Water Information System (NWIS) web interface (USGS 2018).
- To estimate groundwater availability, potable groundwater storage estimates were taken from the *Missouri State Water Plan Series Volume II: Groundwater Resources of Missouri* (Miller and Vandike 1997), and recharge was estimated using reported values from the *Estimated mean annual natural ground-water recharge in the conterminous United States* (Wollock 2003).
- To assess reservoir storage, allocations to water supply on USACE reservoirs were obtained from USACE (Henggeler 2018, Krebs 2018, Neher 2018) and the volume of water and 2011 demands placed on non-USACE water supply reservoirs were obtained from the *Missouri Water Supply Study* (Edwards et al. 2011).

## 4.2 Water Budgets

A water budget is used to quantify and understand the movement of water through the hydrologic cycle. In support of regional and statewide water plans, water budgets inform water planning, management, and policymaking by:

- Improving understanding of the availability, movement, and use of water
- Allowing for a concise means of comparing basins with each other in terms of water availability and water consumption
- Identifying basins that have a relatively high level of water consumption, and may experience water stress or shortages at current and projected future levels of demand
- Comparing the natural versus manmade components of the hydrologic cycle

- Identifying where certain water management decisions will result in the most impact by understanding which basins have water surpluses and which have potential shortfalls, considering all current and projected future consumptive and nonconsumptive uses
- Providing a basis to assess sustainability of the resource
- Highlighting areas where water is available, but infrastructure is the limiting factor in meeting demands

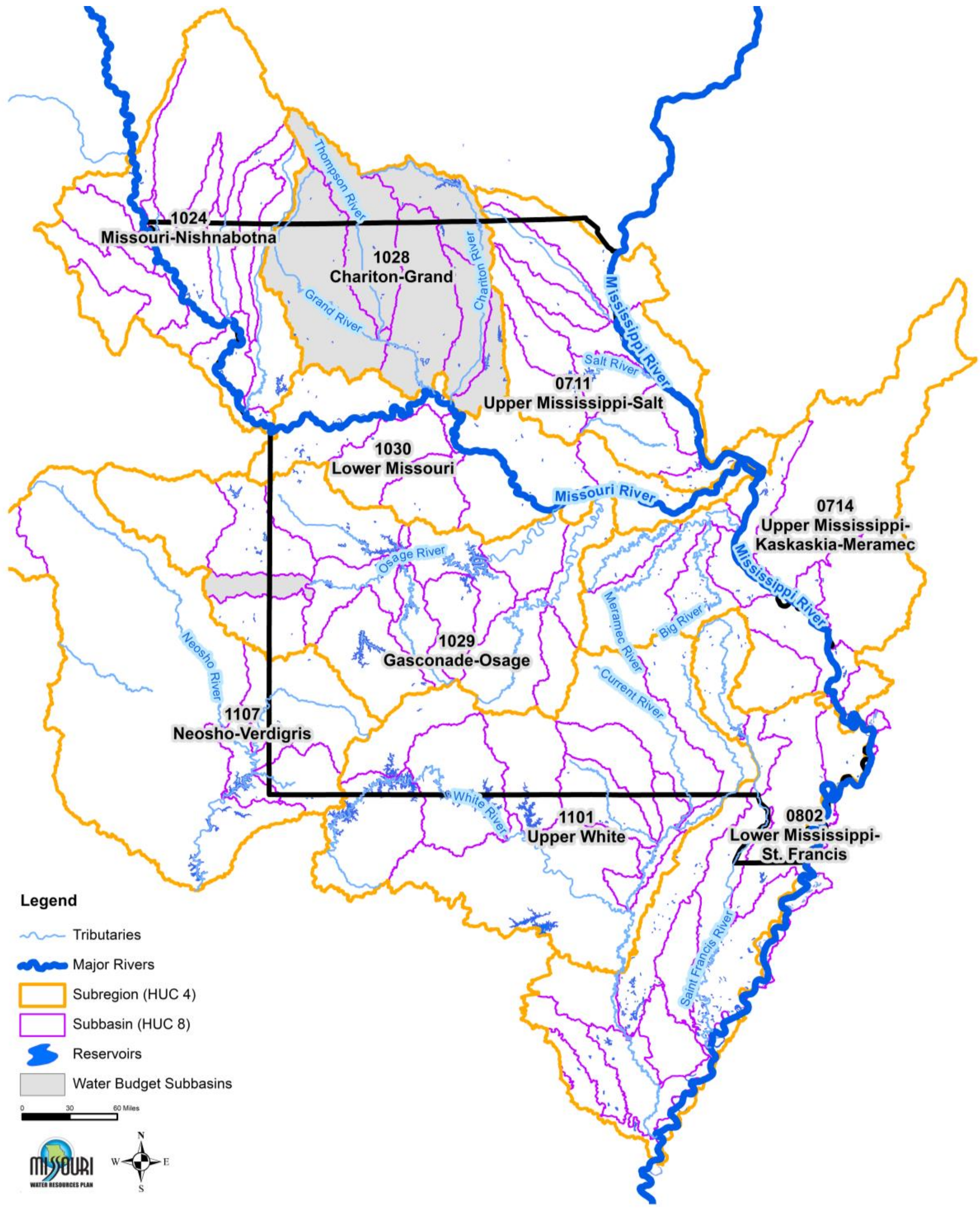


**Figure 4-1. Missouri's Nine Major Subregions (HUC 4)**

The water budgets account for the mostly natural movement of water within the hydrologic cycle and the movement of water resulting from human activities. For this plan, separate water budgets have been developed focusing on surface water and groundwater, although both are interdependent. The water budgets were also used to generate results of various scenarios that evaluate future conditions. These scenario results are discussed in **Section 9**.

The detailed methodology used in developing the water budgets is presented in **Appendix D**. Supplementing this section are nine subregion summaries in **Appendix E** and seven subbasin summaries in **Appendix F**. The subbasin summaries cover all six subbasins within the Chariton-Grand subregion and the Little Osage subbasin in the Gasconade-Osage subregion, where the potential for surface water stress was identified. The summaries document the results of the availability assessment in tabular and graphical format. Demands are totaled and compared to available supply to identify areas of potential stress and/or gaps. Storage, both in reservoirs and aquifers, is totaled and summarized. At the beginning of **Appendix E**, a user's guide is also provided to help readers understand and interpret the information contained in each summary.

### 4.2.1 Surface Water Budgets

The mostly natural elements of the surface water budgets include:

- **Precipitation**: the total rain and snowfall that occurs in the watershed.
- **Streamflow**: includes the portion of precipitation that flows over the land surface and into streams, as well as groundwater that discharges to streams, or base flow. Streamflow is influenced by both withdrawals, such as those for drinking water, and discharges, such as those from municipal wastewater treatment plants.
- **Evapotranspiration**: the portion of water that either evaporates into water vapor and returns to the atmosphere or is taken up by the roots of plants and returned to the atmosphere via water loss through stems and leaves.

The components of the surface water budget that are a result of human activities include:

- **Surface Water Withdrawals**: the portion of water that is withdrawn from a stream, river, lake, or reservoir and used for drinking water, irrigation, energy production, industrial use, or other human activity. In the water budgets, withdrawals have been separated into consumptive and nonconsumptive categories, as described in **Section 3**.
- **Surface Water Returns**: the portion of water discharged to a surface water body after being withdrawn for use from a surface or groundwater source. Common examples include treated wastewater effluent and thermoelectric generation cooling water returns.

To provide a better understanding of where Missouri's surface water resources originate, streamflow is identified in the water budgets as originating from within or outside Missouri. This is important since streamflow originating outside the state may be subject to regulation and withdrawals imposed by others before it reaches Missouri. Out-of-state surface water sources include both surface water generated within portions of a subregion located in other states and major river inflows. These major river inflows are primarily the Missouri and Mississippi rivers.

Although alluvial groundwater aquifers have hydrologic connections to overlying streams and rivers, withdrawals from these shallow aquifers are included in the groundwater budgets. In Missouri, alluvial aquifers are prominent components of groundwater supply north of the Missouri River, where the high salinity of groundwater in most nonalluvial aquifers prohibits its use. Alluvial aquifers also provide groundwater supply in the regions surrounding the Missouri and Mississippi rivers.

Complicating the development of surface water budgets is the fact that streamflow records already include the influence of withdrawals and returns on flow. When developing water budgets, naturalized (also called unimpaired) streamflow is useful because it represents surface water availability for a natural state, where recorded human withdrawals, depletions, and returns are removed from the streamflow record. Naturalized streamflow is estimated by adding upstream withdrawals to and subtracting upstream returns from the flow measured at the stream gage.

This approach was used to create the water budgets instead of simply utilizing unaltered streamflow records, as these records intrinsically include historic withdrawals and returns. This approach would create a mathematical problem, as in the process of creating water budgets, the historic and projected future demands described in **Section 3** would be placed on the streamflow record in addition to intrinsic withdrawals and returns. This double-counting of withdrawals and returns is avoided in the water budgets by using naturalized streamflow records.

For all subregions, naturalized streamflow was calculated using historical gage data and estimates of withdrawals and returns. Streamflow entering each subregion from outside the state was not naturalized since Missouri generally has no influence over out-of-state withdrawals and returns. This does not imply that out-of-state withdrawals and returns on available water supply in Missouri are unimportant, and the impacts of these on water supply are discussed for future scenarios in **Section 9**.

The components of surface water budgets are shown in **Figure 4-2**.

The **drought of record year** is identified by the lowest annual flow over the entire period of record for a stream gage; therefore, the drought of record may be different for different streams.

Surface water budgets were developed for both average years and dry years. Average year budgets use streamflow averaged over the 31-year period from 1985 through 2016. Demands are based on 2016 current and 2060 projected demands that occur during a year with average precipitation. The dry year budgets use streamflow during the driest year of the same 31-year period, in each subregion. The driest year for each subregion varies from one subregion to the next. Since water demands, especially for irrigation, typically increase during a dry year, adjustments were made to the current and projected average demands to more closely reflect dry year demands. The drought of record year, defined here as the lowest annual flow year over the entire period of record for a stream gage, was also evaluated. Monthly streamflow during the drought of record year was compared to monthly demands.

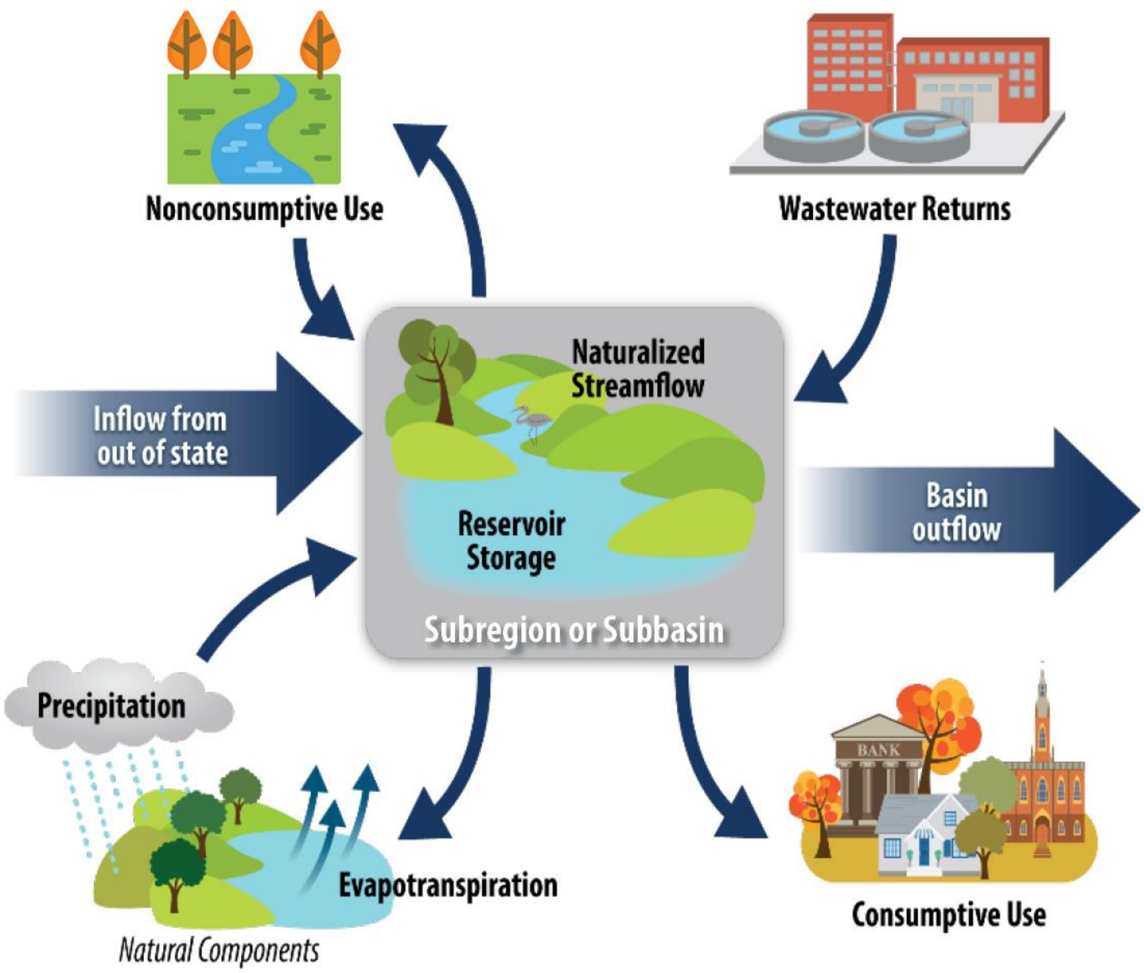


**Figure 4-2. Surface Water Budget Schematic**

The results of the annual average surface water budgets for all nine subregions are presented in **Tables 4-1a** through **4-1c**. The values are presented in MGD. **Table 4-1a** includes precipitation, evapotranspiration, and streamflow. **Tables 4-1b** and **4-c** show 2016 current and projected 2060 surface water withdrawals and returns, respectively. The amount of streamflow flowing out of each subregion is listed as basin outflow.

**Tables 4-2a** and **4-2b** present the surface water budgets in in/yr, reflecting current demands. The conversion to in/yr was done by dividing the total amount of water for the year by the area of the subregion within Missouri. In this manner, each subregion can be easily and directly compared with all other subregions, regardless of size, and the magnitude of each component of the water budget to all other components can be more easily compared.

### Table 4-1a. Average Annual Surface Water Budgets – Natural Components and Streamflow (MGD)

| HUC 4 | Name | Natural Components | | Streamflow | | |
|---|---|---|---|---|---|---|
| | | Precipitation | Evapo-transpiration | Streamflow (entering from outside the HUC 4) | Streamflow (generated in the HUC 4) | Total Streamflow |
| 0711 | Upper Mississippi-Salt | 14,828 | 8,756 | 79,077 | 4,433 | 83,510 |
| 0714 | Upper Mississippi-Kaskaskia-Meramec | 15,095 | 9,112 | 149,601 | 4,421 | 154,022 |
| 0802 | Lower Mississippi-St. Francis | 10,869 | 5,761 | 155,286 | 1,773 | 157,059 |
| 1024 | Missouri-Nishnabotna | 6,343 | 3,945 | 31,910 | 1,699 | 33,609 |
| 1028 | Chariton-Grand | 15,242 | 9,020 | 1,296 | 4,070 | 5,366 |
| 1029 | Gasconade-Osage | 30,262 | 18,486 | 2,824 | 9,390 | 12,214 |
| 1030 | Lower Missouri | 20,540 | 12,055 | 58,274 | 6,007 | 64,281 |
| 1101 | Upper White | 23,634 | 14,195 | 1,849 | 9,032 | 10,881 |
| 1107 | Neosho-Verdigris | 6,369 | 3,881 | 0 | 1,854 | 1,854 |

### Table 4-1b. Average Annual Surface Water Budgets – Current (2016) Withdrawals and Returns (MGD)

| HUC 4 | Name | Current Withdrawals and Returns | | | | Outflow |
|---|---|---|---|---|---|---|
| | | Nonconsumptive Withdrawals | Nonconsumptive Returns | Consumptive Withdrawals | Wastewater and Thermoelectric Returns | Subregion Outflow* |
| 0711 | Upper Mississippi-Salt | 8 | 8 | 476 | 477 | 83,513 |
| 0714 | Upper Mississippi-Kaskaskia-Meramec | 29 | 29 | 1,181 | 1,173 | 154,015 |
| 0802 | Lower Mississippi-St. Francis | 3 | 3 | 14 | 14 | 157,059 |
| 1024 | Missouri-Nishnabotna | 1 | 1 | 1,010 | 948 | 33,549 |
| 1028 | Chariton-Grand | 7 | 7 | 793 | 768 | 5,342 |
| 1029 | Gasconade-Osage | 34 | 34 | 181 | 166 | 12,203 |
| 1030 | Lower Missouri | 14 | 14 | 2,322 | 218 | 62,179 |
| 1101 | Upper White | 92 | 92 | 55 | 64 | 10,892 |
| 1107 | Neosho-Verdigris | 5 | 5 | 21 | 25 | 1,860 |

### Table 4-1c. Average Annual Surface Water Budgets – Projected (2060) Withdrawals and Returns (MGD)

| HUC 4 | Name | Projected 2060 Withdrawals and Returns | | | | Outflow |
|---|---|---|---|---|---|---|
| | | Nonconsumptive Withdrawals | Nonconsumptive Returns | Consumptive Withdrawals | Wastewater and Thermoelectric Returns | Subregion Outflow* |
| 0711 | Upper Mississippi-Salt | 8 | 8 | 33 | 33 | 83,513 |
| 0714 | Upper Mississippi-Kaskaskia-Meramec | 29 | 29 | 1,112 | 1,092 | 154,005 |
| 0802 | Lower Mississippi-St. Francis | 3 | 3 | 17 | 14 | 157,056 |
| 1024 | Missouri-Nishnabotna | 1 | 1 | 1,195 | 1,109 | 33,525 |
| 1028 | Chariton-Grand | 7 | 7 | 932 | 900 | 5,335 |
| 1029 | Gasconade-Osage | 34 | 34 | 221 | 190 | 12,187 |
| 1030 | Lower Missouri | 14 | 14 | 1,787 | 1,758 | 64,255 |
| 1101 | Upper White | 92 | 92 | 74 | 67 | 10,876 |
| 1107 | Neosho-Verdigris | 5 | 5 | 28 | 25 | 1,854 |

* Where subregion outflows are higher than the total streamflow listed in Table 4-1a, this is the result of using recorded wastewater treatment facility effluent flows to estimate returns to surface water, whereas demands were estimated using data from MoDNR's Major Water Users database. Returns do not balance with demands because of the use of different data sources.

**Table 4-2a. Average Annual Surface Water Budgets – Natural Components and Streamflow (in/yr)**

| HUC 4 | Name | Natural Components | | Streamflow | | |
|---|---|---|---|---|---|---|
| | | Precipitation | Evapo-transpiration | Streamflow (entering from outside the HUC 4) | Streamflow (generated in HUC 4) | Total Streamflow |
| 0711 | Upper Mississippi-Salt | 40 | 24 | 214 | 12 | 226 |
| 0714 | Upper Mississippi-Kaskaskia-Meramec | 45 | 27 | 450 | 13 | 463 |
| 0802 | Lower Mississippi-St. Francis | 48 | 26 | 692 | 8 | 700 |
| 1024 | Missouri-Nishnabotna | 36 | 23 | 182 | 10 | 192 |
| 1028 | Chariton-Grand | 39 | 23 | 3 | 10 | 14 |
| 1029 | Gasconade-Osage | 44 | 27 | 4 | 14 | 18 |
| 1030 | Lower Missouri | 42 | 25 | 120 | 12 | 133 |
| 1101 | Upper White | 47 | 28 | 4 | 18 | 22 |
| 1107 | Neosho-Verdigris | 46 | 28 | 0 | 13 | 13 |

**Table 4-2b. Average Annual Surface Water Budgets – Current (2016) Withdrawals and Returns (in/yr)**

| HUC 4 | Name | Current Withdrawals and Returns | | | | Outflow |
|---|---|---|---|---|---|---|
| | | Nonconsumptive Withdrawals | Nonconsumptive Returns | Consumptive Withdrawals | Wastewater and Thermoelectric Returns | Subregion Outflow |
| 0711 | Upper Mississippi-Salt | 0.02 | 0.02 | 1.29 | 1.29 | 226 |
| 0714 | Upper Mississippi-Kaskaskia-Meramec | 0.09 | 0.09 | 3.55 | 3.53 | 463 |
| 0802 | Lower Mississippi-St. Francis | 0.01 | 0.01 | 0.06 | 0.06 | 700 |
| 1024 | Missouri-Nishnabotna | 0.004 | 0.004 | 5.77 | 5.41 | 192 |
| 1028 | Chariton-Grand | 0.02 | 0.02 | 2.00 | 1.94 | 14 |
| 1029 | Gasconade-Osage | 0.05 | 0.05 | 0.27 | 0.24 | 18 |
| 1030 | Lower Missouri | 0.03 | 0.03 | 4.79 | 0.45 | 128 |
| 1101 | Upper White | 0.18 | 0.18 | 0.11 | 0.13 | 22 |
| 1107 | Neosho-Verdigris | 0.04 | 0.04 | 0.15 | 0.18 | 13 |

The surface water budgets show that, on an average annual basis:

- The nine subregions receive between 36 and 48 in/yr of precipitation. Between 53 and 62 percent of precipitation is lost to evaporation and transpiration. The remaining amount becomes runoff contributing to streamflow or recharges Missouri's aquifers, and is used to meet Missouri's water supply needs.
- Streamflow that is generated from precipitation falling in each subregion ranges from 8 in/yr in the Lower Mississippi-St. Francis to 18 in/yr in the Upper White. On average across the state, about 12 in/yr, or just under one-third of precipitation, becomes streamflow.
- A very large amount of streamflow—much more than is generated within Missouri—originates from out of state and flows through the five subregions that include the Missouri and Mississippi rivers. While this water represents a seemingly large supply, its availability is generally limited to nearby users that can economically withdraw, treat, and distribute it.
- Total withdrawals, both consumptive and nonconsumptive, are only a small fraction of total streamflow in all subregions. The amount of water that is consumptively used and thus not returned to rivers, lakes, and streams, is even smaller. Note, however, that not all nonconsumptive uses are withdrawals.

Although demands are projected to increase in each subregion through 2060, they remain a small fraction of total streamflow. **Table 4-3** further demonstrates this by showing projected 2060 surface water demands as a percent of total streamflow, which includes flow from out of state and flow generated from within the subregion. **Table 4-3** also shows projected 2060 surface water demands as a percent of total streamflow (including flow from out of state), and as a percent of streamflow that originates from within the subregion. Projected demands are less than 5 percent of flow generated within each subregion, except in the Chariton-Grand where withdrawals represent over 23% of total streamflow. Note that this analysis does not show infrastructure gaps that result from geographical barriers between water sources and water users.

**Table 4-3. Projected 2060 Surface Water Demands as Percent of Streamflow**

| HUC 4 | Name | Total Streamflow (MGD) | Streamflow Generated in HUC 4 (MGD) | Total 2060 Withdrawals[1] as a Percent of Total Streamflow | Total 2060 Withdrawals[2] as a Percent of Streamflow Generated Only in HUC 4 |
|---|---|---|---|---|---|
| 0711 | Upper Mississippi-Salt | 83,509 | 4,433 | 0.0% | 0.8% |
| 0714 | Upper Mississippi-Kaskaskia-Meramec | 154,021 | 4,421 | 0.7% | 1.6% |
| 0802 | Lower Mississippi-St. Francis | 157,059 | 1,773 | 0.0% | 1.1% |
| 1024 | Missouri-Nishnabotna | 33,610 | 1,699 | 3.6% | 1.9% |
| 1028 | Chariton-Grand | 5,366 | 4,070 | 17.5% | 23.1% |
| 1029 | Gasconade-Osage | 12,214 | 9,390 | 2.1% | 2.7% |
| 1030 | Lower Missouri | 64,281 | 6,007 | 2.8% | 2.9% |
| 1101 | Upper White | 10,881 | 9,032 | 1.5% | 1.8% |
| 1107 | Neosho-Verdigris | 1,854 | 1,854 | 1.8% | 1.8% |

[1] *Includes major river and nonmajor river withdrawals*
[2] *Withdrawals not on a major river originating out of state*

**Stress** to groundwater resources may occur when withdrawals exceed recharge. Following a period of stress, **supply gaps** may occur if storage is depleted to the point where wells experience reduced or no yield.

Dry year surface water budgets are discussed in **Section 4.4**, which present detailed water availability results for all nine subregions.

### 4.2.2 Groundwater Budgets

Groundwater budgets for each subregion were developed to compare recharge and aquifer storage to withdrawals. Stress to groundwater resources may occur when withdrawals exceed recharge. Following a period of stress, supply gaps may occur if storage is depleted to the point where wells experience reduced or no yield. To be consistent with the assessment of surface water availability, groundwater budgets were developed for each subregion and select subbasins; however, it is recognized that this approach has some limitations since most major aquifers do not typically follow drainage basin boundaries.

**Figure 4-3** depicts the elements of the groundwater budget. They include:

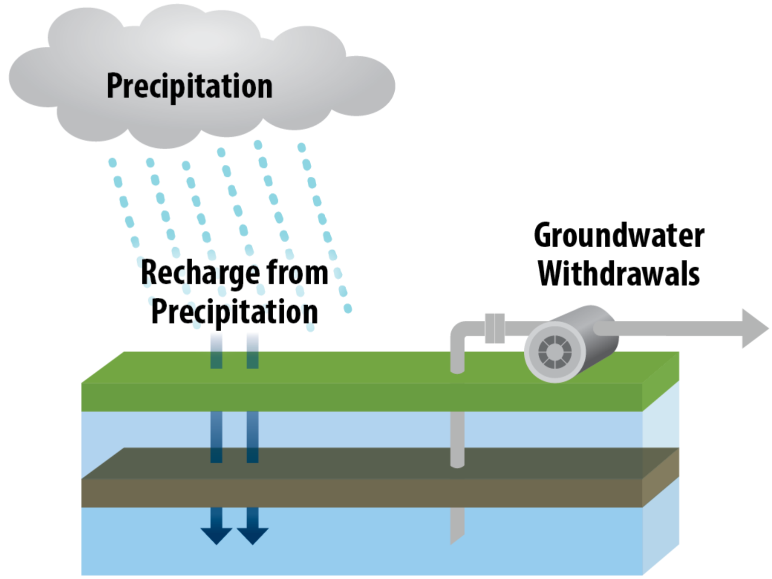


Figure 4-3. Groundwater Budget Schematic

- **Recharge from Precipitation:** the amount of recharge to the water table. Recharge across the state has been previously estimated by USGS (Wollock 2003). The estimates were derived using base flow indexes developed from a mean annual runoff contour map for the period of 1951 to 1980. Recharge estimates for each subbasin (HUC 8) are shown in **Figure 4-4**. Recharge generally increases from the northwest to the southeast, following the same long-term pattern of increasing precipitation. Recharge to an aquifer can also come from an adjacent or overlying aquifer, or from a nearby river, and may be an important component of the water budget in parts of the state. These types of recharge are difficult to quantify. No estimates of recharge from sources other than precipitation were developed.
- **Groundwater Withdrawals:** the portion of water that is withdrawn from a well and used for drinking water, irrigation, energy production, industrial use, or other human activity. In the water budgets, withdrawals have been separated into consumptive and nonconsumptive categories, as described in **Section 3**.
- **Potable Groundwater Storage:** the amount of groundwater stored in each major aquifer that is usable or drainable. The estimates were developed in support of a previous Missouri State Water Plan (Miller and Vandike 1997).

Returns to groundwater through on-site wastewater systems (e.g., septic tanks, spray fields, other nonsurface water discharges) were not estimated. These are typically a very small component of the overall groundwater budget and developing reliable estimates of the amount of water that recharges the aquifers from these systems is difficult.

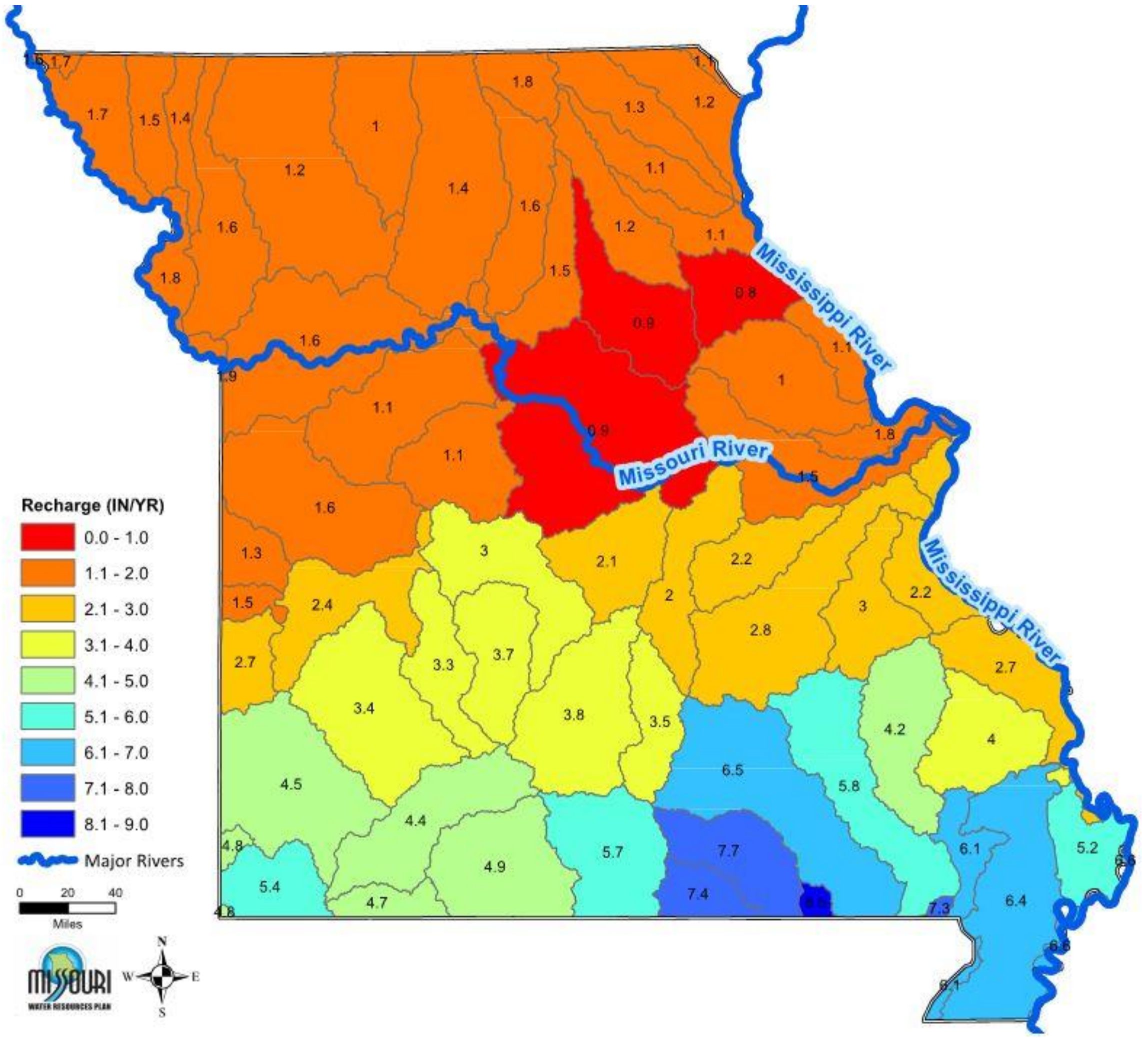


**Figure 4-4. Groundwater Recharge (in/yr) by Subbasin (HUC 8)**
*Source: (Wollock 2003)*

The groundwater budgets do not attempt to estimate the lateral movement of water from one aquifer to another, the amount of recharge to deeper aquifers, or the amount of recharge from losing stream reaches or alluvial areas where shallow pumping may be inducing recharge from a river.

**Table 4-4** presents average annual groundwater budgets with projected 2060 groundwater withdrawals. As a screening tool to identify potential stress, total withdrawals by subregion are divided by recharge. Withdrawals as a percent of recharge are shown in the last column of the table. In most subregions, projected groundwater withdrawals are less than 20 percent of average annual recharge; however, in some subregions that include the Missouri and Mississippi rivers, withdrawals range from 29 percent (Lower Missouri) to 150 percent (Lower Mississippi-St. Francis) of recharge from precipitation. Significant pumping from alluvial aquifers occurs in these subregions along the two major rivers, and much of the water pumped from alluvial aquifers is expected to come from the rivers, rather than recharge from precipitation. Also, in the Lower Mississippi-St. Francis, a significant amount of groundwater flows laterally into the alluvial aquifers from the Ozark Aquifer. As such, the high percentages generally do not indicate potential stress. A more localized comparison of withdrawals to total recharge is necessary to identify stress and potential gaps.

**Table 4-4. Groundwater Budgets by Subregion**

| HUC 4 | Basin Name | Total Potable Groundwater Storage (billion gals) | Recharge to Water Table from Precipitation (MGD) | Projected 2060 Groundwater Withdrawals (MGD) | 2060 Withdrawals as a Percent of Average Annual Recharge (%) |
|---|---|---|---|---|---|
| 0711 | Upper Mississippi-Salt | 26,896 | 406 | 71 | 17% |
| 0714 | Upper Mississippi-Kaskaskia-Meramec | 42,985 | 964 | 126 | 13% |
| 0802 | Lower Mississippi-St. Francis | 67,277 | 1,257 | 1,889 | 150% |
| 1024 | Missouri-Nishnabotna | 3,627 | 280 | 146 | 52% |
| 1028 | Chariton-Grand | 6,490 | 514 | 14 | 3% |
| 1029 | Gasconade-Osage | 140,732 | 1,905 | 96 | 5% |
| 1030 | Lower Missouri | 68,263 | 581 | 167 | 29% |
| 1101 | Upper White | 108,451 | 2,977 | 435 | 15% |
| 1107 | Neosho-Verdigris | 30,974 | 650 | 68 | 10% |

The large amount of total potable groundwater storage in each subregion suggests that even in dry years when recharge may be significantly lower there is an ample supply of groundwater stored in the aquifers to mitigate drought. While this is generally the case across much of the state, local areas that rely heavily on groundwater may still be susceptible to short or prolonged droughts and experience reduced well yields or dry wells because of local conditions. To evaluate groundwater sustainability at a more local level, two additional assessments were completed:

1. County-level comparisons were made between estimated average annual recharge, 2016 withdrawals, and projected 2060 withdrawals. These results are presented in **Section 4.7**.
2. The USGS Ozark Aquifer System groundwater model was used to evaluate the potential impacts of projected 2060 withdrawals within the Ozark Aquifer System. These results are presented in **Section 4.8**.

## 4.3 Limitations of the Analyses

There are several limitations inherent in the approach used to assess water availability on a statewide basis. First, it is recognized that localized stress or water shortages may not be evident at the subregion level or even the subbasin level. At a more local level, the magnitude, duration, and probability of stress or shortages may be greater than those identified in the analyses because groundwater demands and supply are aggregated at the subregional level. For example, some groundwater users may see impacts such as reduced yield or dry wells, depending on the depth of the well and pump setting, magnitude of withdrawals from nearby users, and other factors, even though the availability analyses at the subregion or subbasin level suggests there is ample water.

Secondly, historical hydrologic data, namely streamflow and estimated groundwater recharge, which are both driven by precipitation and climate conditions, are used as the basis for the water availability assessments. Historical hydrology is used, since future climate conditions cannot be predicted with certainty; however, there is no assurance that future climate conditions will closely resemble those of the past. For example, droughts could be more extreme (less precipitation) and have a longer duration than those for which hydrologic data are available. To mitigate against this, a range of future climate conditions and their impact on hydrology are evaluated. Through scenario planning this plan expands on the baseline water budgets by assessing this and other possible future scenarios that may influence both supply availability and water demands. This is described in **Section 9**.

Finally, projected proportions of surface water to groundwater use in each region are based on current proportions. The actual future proportions may differ.

All these limitations must be understood when considering the water availability results presented below by subregion and subbasin.

## 4.4 Water Availability Results by Subregion

The water availability assessment focuses on the nine major subregions in the state. The subregion summaries presented in **Appendix E** document the results of the availability assessment in tabular and graphical format.

The subregion summaries present the following information:

- A basin map showing the location of major rivers and USGS stream gages
- A surface water budget for average annual conditions
- A summary of current and 2060 surface water demands by sector
- Graphical comparisons of surface water demand to both average and median streamflow for an average year, dry year, and the drought of record year
- Flow-duration curves using the entire period-of-record flows in each subregion, to assess the frequency of potential surface water shortages using current and projected demands
- An assessment of reservoir storage using a mass-balance calculation to determine the months of storage above the reservoir's intake elevation available under dry year inflows and no inflow
- A summary of current and 2060 demands by sector and major aquifer
- A groundwater budget that includes estimates of potable groundwater storage and 2060 demands by aquifer, and total recharge to the water table from precipitation

The following section summarizes the major results of the water availability analyses by subregion.

### 4.4.1 Upper Mississippi-Salt Subregion

The Upper Mississippi-Salt subregion (HUC 0711) is in the northeastern corner of Missouri and covers 7,764 square miles within the state (USGS and U.S. Department of Agriculture Natural Resources Conservation Service [NRCS] 2018). Major tributaries to the Mississippi River within the subregion include the Salt River, the Fabius River, and the Cuivre River. Surface water flowing into the subregion from out of state via the Mississippi River averages 79,077 MGD and is approximately 18 times greater than the 4,433 MGD of surface water generated within the Missouri portion of the subregion. This out of state contribution from the Mississippi River is also nearly 1.9 times the amount of surface water that is generated within the entire state of Missouri in an average year (42,679 MGD).

The subregion includes most of the Northeastern Missouri groundwater province and includes the Mississippi River and Missouri River alluvium. The Northeastern Missouri province contains glacial drift deposits that are underlain by Pennsylvanian and older bedrock; however, the glacial drift deposits are unimportant as an aquifer due to limited yield and the Pennsylvanian contains highly mineralized water throughout most of the subregion. South of the freshwater-saline transition zone, the Cambrian-Ordovician Aquifer is an important source of groundwater (Miller and Vandike 1997).

## Water Use by Sector and Source

Thermoelectric power accounts for 94 percent of surface water withdrawals (**Figure 4-5**). Not including surface water withdrawals for thermoelectric power, which are higher than all other surface water withdrawals by an order of magnitude at 447.7 MGD, the subregion relies more heavily on groundwater resources (54.7 MGD or 60 percent of total withdrawals) than surface water (36.1 MGD or 40 percent of total withdrawals). The alluvial aquifer along the Mississippi River is the primary source for the major water system and agriculture sectors. The Cambrian-Ordovician Aquifer is also an important source for most sectors in the very southern portion of the subregion.

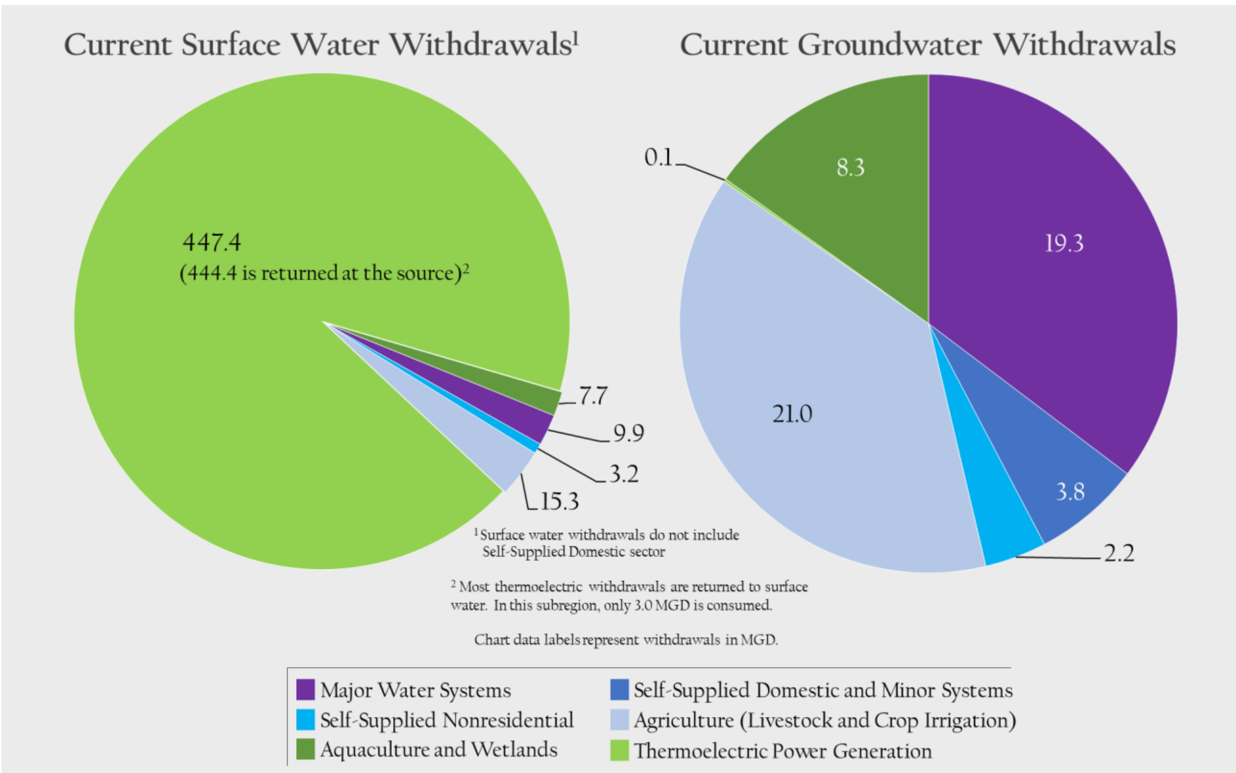


**Figure 4-5. Upper Mississippi-Salt Surface and Groundwater Withdrawals by Sector**

Surface water withdrawals, not including thermoelectric power use, are projected to increase by 13 percent to 40.9 MGD in 2060 and groundwater withdrawals are projected to increase by 30 percent to 70.9 MGD in the same timeframe.

The Sioux Energy Center located on the Mississippi River in St. Charles County is scheduled to be retired in 2033 (Ameren Missouri 2017); therefore, projected 2060 surface water withdrawals for the thermoelectric power sector are zero. Additionally, there is one hydropower dam operated by USACE at Clarence Cannon Dam as described in **Section 3.10.2**. The operation of, and water demand for, this facility is complex and dependent on multiple factors including reservoir pool operation, downstream flood condition, and requirements of the reservoir's other authorized uses. This results in a complex series of operational rules that are not summarized in this report. This facility's importance as a source of renewable energy is anticipated to continue to increase, and planning to provide for its water demands will therefore be an ongoing priority.

## Monthly Streamflow Analysis

Although flow in the Mississippi River greatly exceeds total surface water withdrawals in the subregion, even during dry years and the drought of record year, surface water users in the western part of the subregion must rely on tributaries to the Mississippi. **Figure 4-6** compares current surface water withdrawals not from the Mississippi River to median dry year and drought of record year streamflow for the subregion. Dry year streamflow is based on median monthly flows for the driest year between 1980 and 2016. Drought of record year streamflow is based on the historically dry years of 1954 or 1956, whichever year had the lowest gaged flow. The summer-month withdrawals for the major water system and agriculture sectors are adjusted to reflect increases that would be expected during a dry year. The comparisons show that withdrawals approach or exceed median dry year flows in 3 months (July, August, and October) of the dry year and in 3 months (January, November, and December) of the drought of record year. These results suggest a potential for a surface water gap in areas of the subregion that do not have access to the Mississippi River as a supply, and emphasizes the importance of reservoir storage, interconnections with other systems, conjunctive use of groundwater, or other means to bridge potential supply gaps. These potential gaps are also apparent in the flow-duration curve included in the subregion summary in **Appendix E**. The curve suggests that streamflow generated within the subregion will be below average annual withdrawals approximately 1 to 2 percent of the time and below maximum monthly withdrawals up to 8 percent of the time.

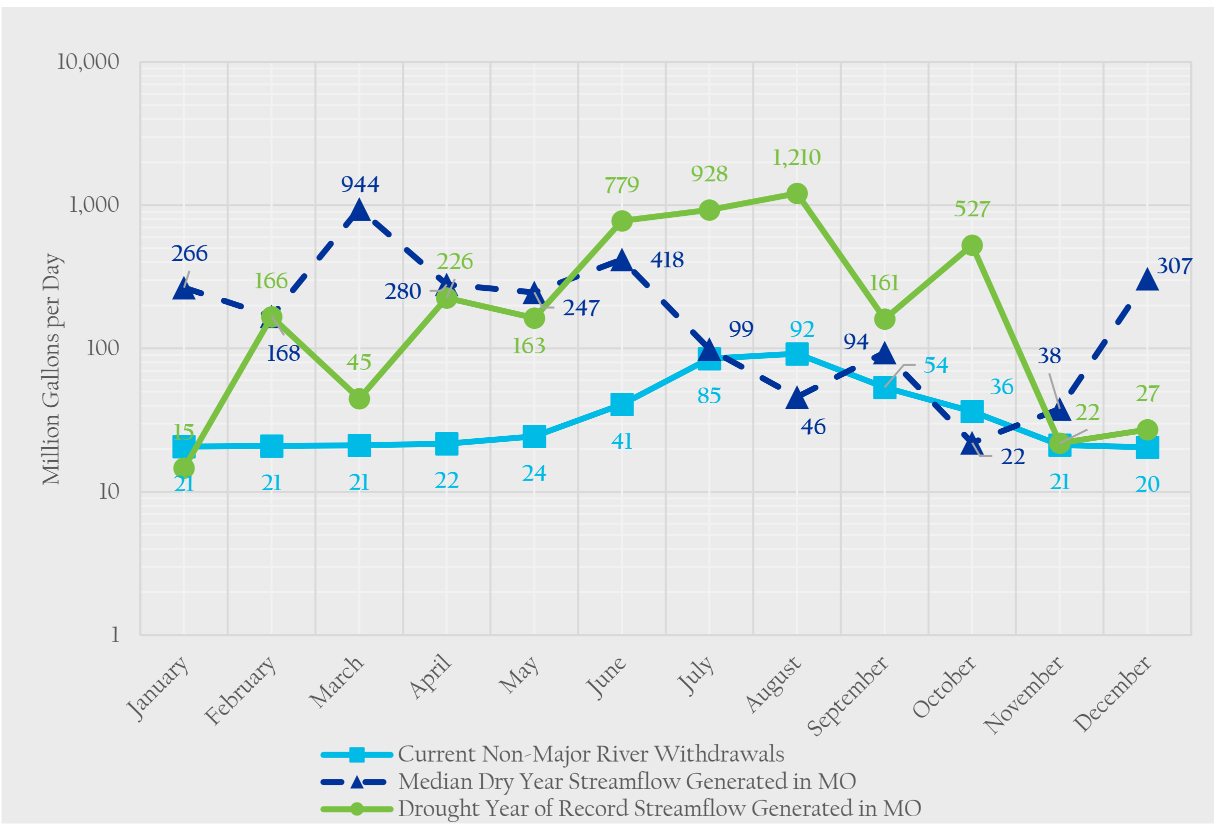


**Figure 4-6. Upper Mississippi-Salt Comparison of Streamflow and Dry Year Withdrawals**

*Note: This compares in-state generated streamflow to total surface water withdrawals, not including Mississippi River withdrawals.*

## Reservoir Analysis

The Upper Mississippi-Salt subregion includes eight water supply reservoirs with a total water supply storage of 28,013 acre-feet or 9,128 mgal. Mark Twain Lake is the largest of the eight and has a water supply storage allocation of 20,000 acre-feet (6,517 mgal) (USACE 2016). The reservoirs help mitigate against the potential surface water supply gap identified in the monthly streamflow analysis. For this and all other subregions with reservoirs that provide drinking water supply a mass balance calculation was completed to coarsely evaluate reservoir storage using average demands from 2011 (Edwards et al. 2011), average free water surface evaporation (NOAA 1982), and dry year inflow based on the lowest streamflow year between 1980 and 2016. For this analysis, no reservoir outflow was assumed. Using this mass balance approach, of the eight water supply reservoirs in the subregion, four reservoirs would still be capable of meeting demands, assuming dry year inflows and 2011 average demands. The other four reservoirs have between 16 and 53 months of storage under the same conditions. With no net inflow, the reservoirs individually have between 4 and 41 months of storage and an average of 18 months of storage. Refer to **Appendix D** for additional explanation of the assumptions and methodology used in the reservoir evaluation.

## Groundwater Budget

**Figure 4-7** depicts the groundwater budget for the Upper Mississippi-Salt subregion using a generalized representation of the major aquifers. Estimated potable groundwater storage and projected 2060 groundwater demands are shown by major aquifer. Most of the potable groundwater storage—over 23 of the subregion's 26 trillion gallons—occurs in the southeast, within the Cambrian-Ordovician Aquifer. North of Lincoln, Montgomery, and Callaway counties lies the freshwater-saline water transition zone (**Figure 4-8**). To the north of this transition zone, the availability of potable groundwater diminishes, except where alluvial aquifers exist along the Mississippi River and major tributaries. Projected 2060 groundwater withdrawals of 71 MGD are 17 percent of average annual recharge. At the subregion level, the comparison of groundwater withdrawals to recharge and potable storage indicates that groundwater availability is sufficient to meet current and projected needs without imposing stress or resulting in major supply gaps. South of the freshwater-saline transition zone, the quantity of potable groundwater stored in the aquifers is generally sufficient to meet groundwater demands even during prolonged droughts.

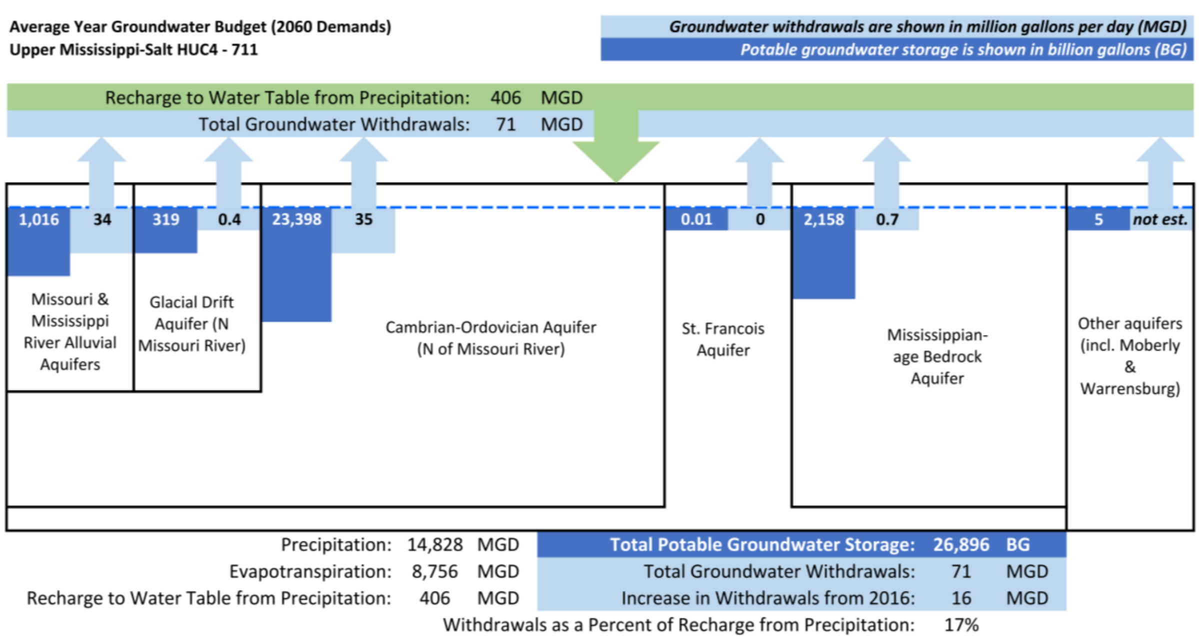


**Figure 4-7. Upper Mississippi-Salt Groundwater Budget**

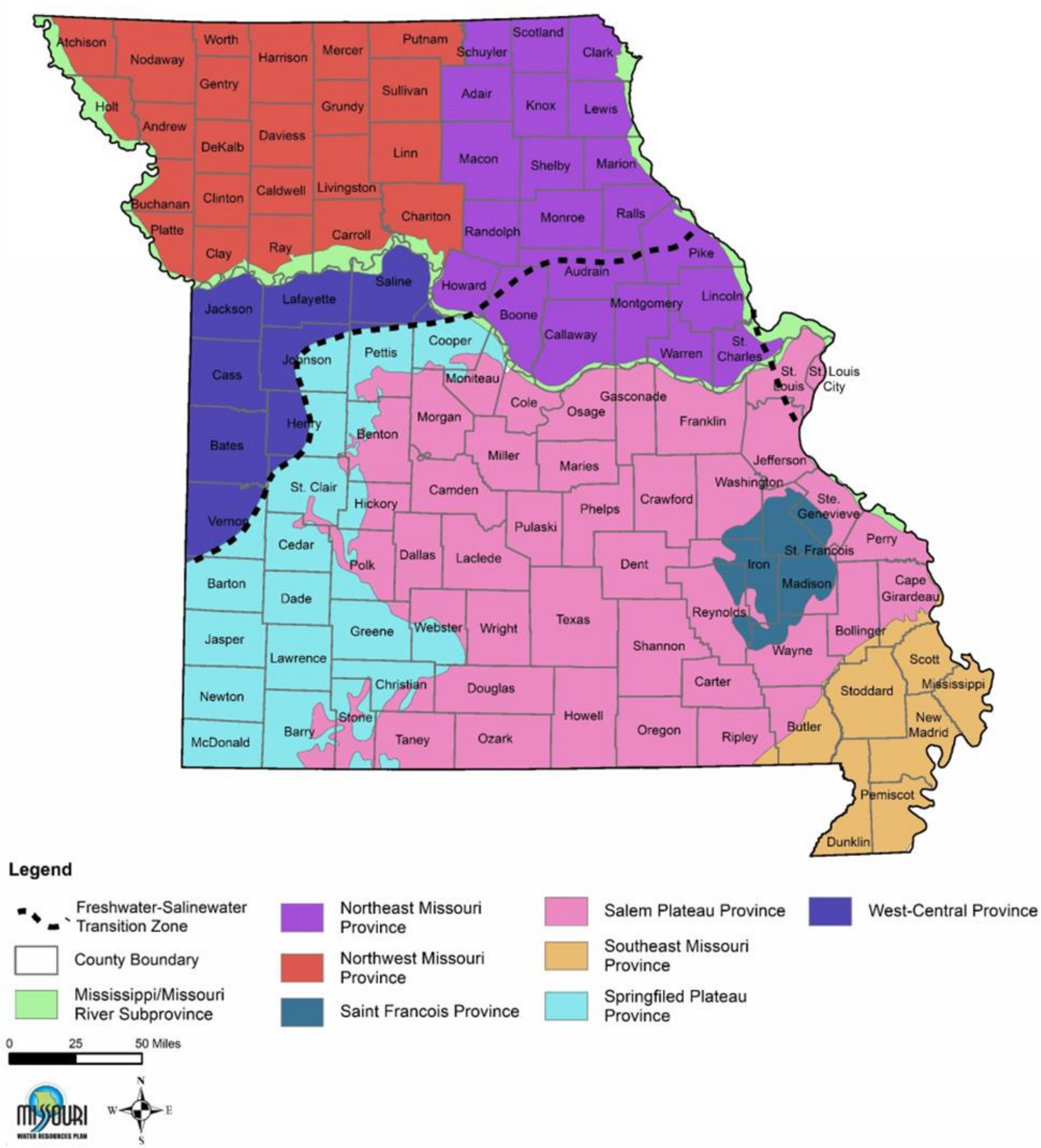


**Figure 4-8. Freshwater-saline Water Transition Zone and Major Groundwater Provinces**

## 4.4.2 Upper Mississippi-Kaskaskia-Meramec Subregion

The Upper Mississippi-Kaskaskia-Meramec subregion (HUC 0714) is in eastern Missouri, the Mississippi River forming the border with Illinois, and covers 6,986 square miles within the state (USGS and NRCS 2018). The Bourbeuse, Meramec, and Big rivers drain north and east, emptying into the Mississippi River. Surface water flowing into the subregion—most of it in the Missouri and Mississippi rivers—averages 149,601 MGD and is approximately 34 times greater than the 4,421 MGD of surface water generated within the Missouri portion of the subregion.

The subregion falls primarily within the Salem Plateau groundwater province and includes portions of the St. Francois Mountain area and Mississippi River Alluvial Aquifer. Major aquifer systems include the Ozark, St. Francois, and Mississippi River Alluvial aquifers.

## Water Use by Sector and Source

Thermoelectric power is by far the largest water use sector in the subregion, accounting for 79 percent of surface water withdrawals (**Figure 4-9**). Not including withdrawals for thermoelectric power, which are primarily surface water withdrawals currently estimated at 951.4 MGD, the subregion relies more heavily on surface water resources (257.7 MGD or 71 percent of total withdrawals) compared to groundwater (103.0 MGD or 29 percent of total withdrawals). The Mississippi River is the primary source for the major water systems sector. The alluvial aquifer along the Mississippi River is a secondary source for major water systems and a primary source for the agriculture sector, based on current withdrawals. The Ozark Aquifer is also an important source for most sectors.

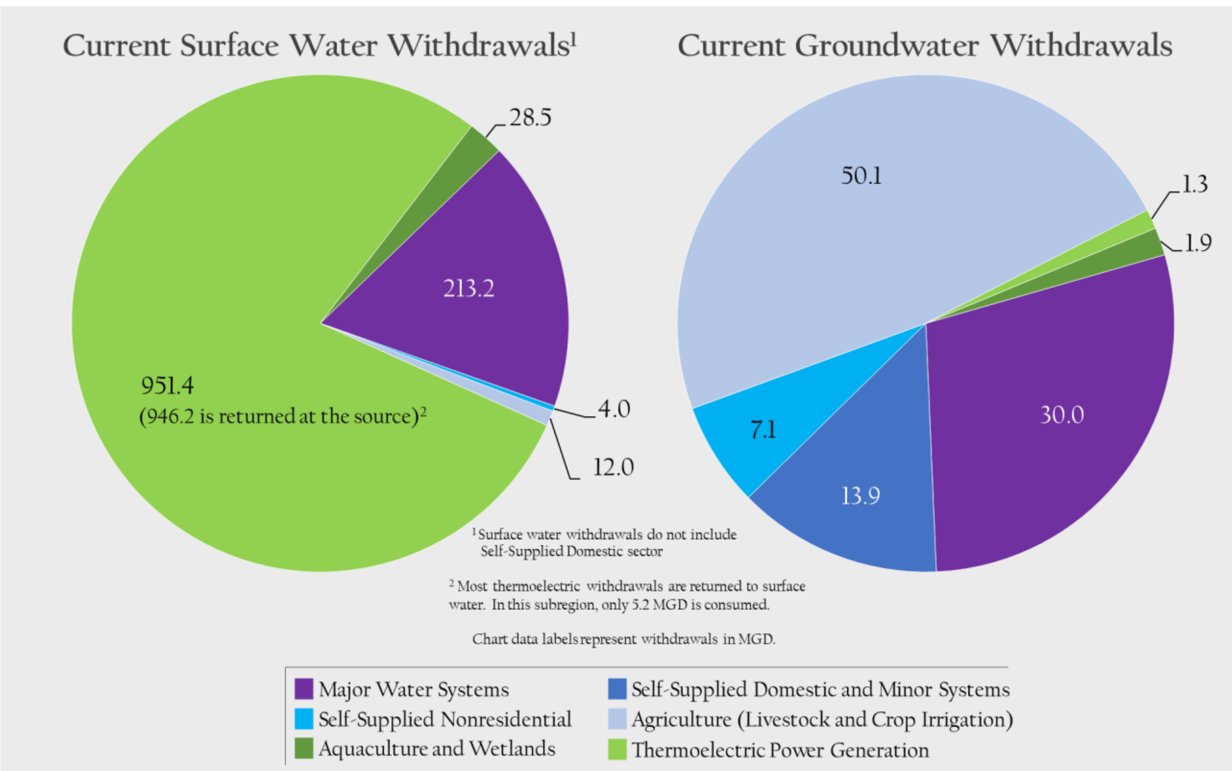


**Figure 4-9. Upper Mississippi-Kaskaskia-Meramec Surface and Groundwater Withdrawals by Sector**

Total surface water withdrawals are projected to decrease by 6 percent by 2060, due to a projected decrease in thermoelectric energy demand. Not including the thermoelectric sector, surface water withdrawals are projected to increase by 5 percent to 270.4 MGD. Total groundwater withdrawals are projected to increase by 20 percent to 125.4 MGD by 2060.

## Monthly Streamflow Analysis

Flow in the Mississippi River greatly exceeds total surface water withdrawals in the subregion. Surface water users in the western part of the subregion withdraw from tributaries to the Mississippi River. **Figure 4-10** compares current surface water withdrawals not from the Mississippi River to median dry year and drought of record year streamflow for the subregion. Dry year streamflow is based on median monthly flows for the driest year between 1980 and 2016. Drought of record year streamflow is based on streamflow from 1954 or

1956 whichever year had the lowest gaged flow. The summer-month withdrawals for the major water users and agriculture sectors are adjusted to reflect increases that would be expected during a dry year. The comparisons show that current withdrawals range between 111 and 119 MGD at their peak but remain well below the median dry year and drought of record year monthly flows. Even with the 5 percent projected increase in 2060 demands (excluding thermoelectric), the monthly flow comparison does not suggest future surface water stress in this subregion even under drought of record conditions.

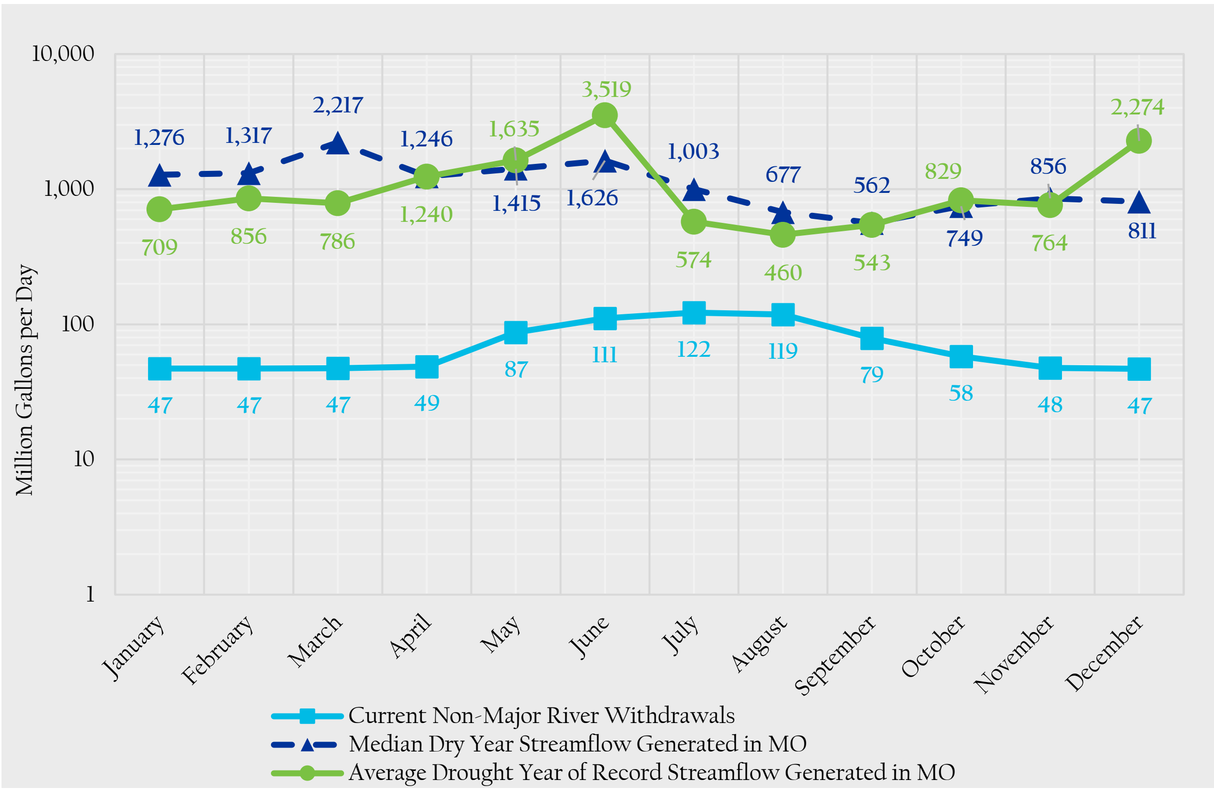


**Figure 4-10. Upper Mississippi-Kaskaskia-Meramec Comparison of Streamflow and Dry Year Withdrawals**

*Note: This compares in-state generated streamflow to total surface water withdrawals not including Mississippi River withdrawals.*

## Reservoir Analysis

No lakes or reservoirs are used for public water supply in this basin. This reflects the ample availability of water in the Mississippi River, its major tributaries, and the subregion's easily accessible and generally high-quality groundwater resources.

## Groundwater Budget

**Figure 4-11** depicts the groundwater budget for the Upper Mississippi-Kaskaskia-Meramec subregion using a generalized representation of the major aquifers. Estimated potable groundwater storage and projected 2060 groundwater demands are shown by major aquifer. Most of the potable groundwater storage—almost 34 of the subregion's 43 trillion gallons—occurs in the Ozark Aquifer. Projected 2060 groundwater withdrawals of 126 MGD are 17 percent of average annual recharge from precipitation. Nearly half of the groundwater withdrawals come from the Mississippi River Alluvial Aquifer, which is likely to receive recharge from the Mississippi River and parts of the Ozark Aquifer. At the subregion level, the comparison of groundwater withdrawals to recharge and potable storage indicates that groundwater availability is sufficient to meet current and projected needs without imposing stress or resulting in supply gaps. Potable groundwater stored in the aquifers is sufficient to meet groundwater demands even during prolonged droughts.

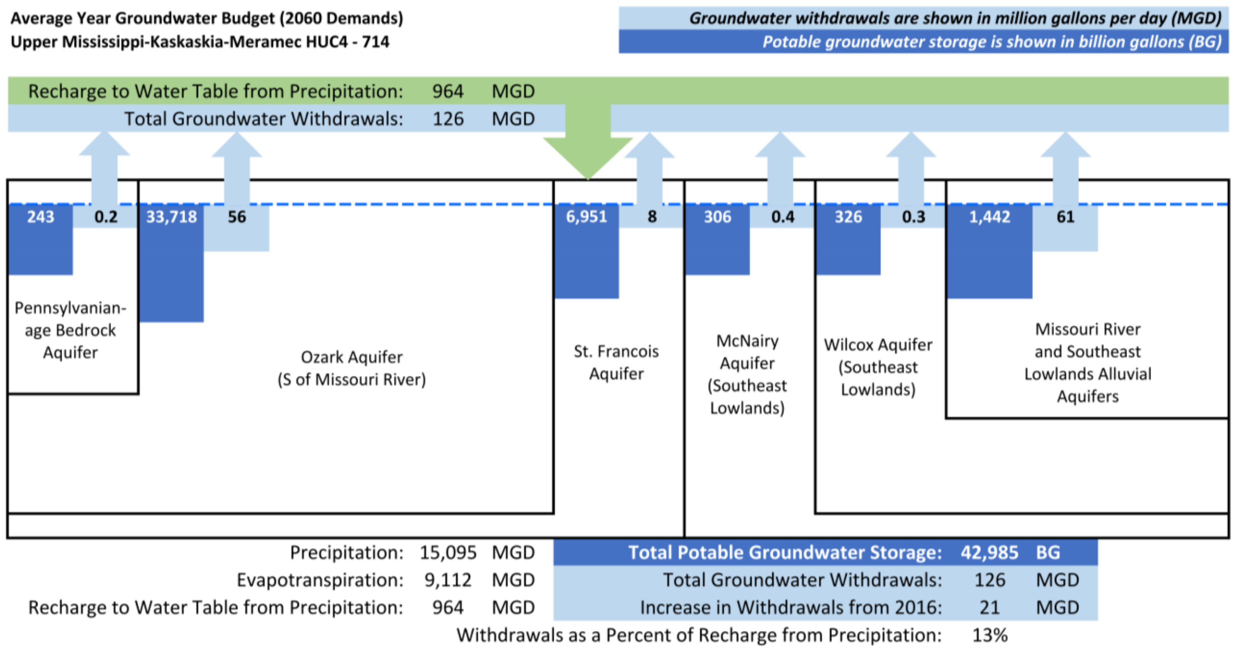


**Figure 4-11. Upper Mississippi-Kaskaskia-Meramec Groundwater Budget**

## 4.4.3 Lower Mississippi-St. Francis Subregion

The Lower Mississippi-St. Francis subregion (HUC 0802) is in the southeast corner of Missouri, in what is commonly referred to as the Bootheel. The subregion covers 4,717 square miles within the state of Missouri (USGS and NRCS 2018). The St. Francis River and the Mississippi River are the major surface water resources in this subregion.

The subregion falls primarily within the Southeast Missouri groundwater province. The headwaters of the St. Francis River stretch into the Salem Plateau groundwater province and St. Francois Mountain area. The major aquifer systems include the Southeast Lowlands Alluvial, Wilcox, McNairy, Ozark and St. Francois aquifers.

### Water Use by Sector and Source

Agriculture accounts for 82 percent of surface water withdrawals and 97 percent of groundwater withdrawals in the region (**Figure 4-12**). The subregion relies heavily on the vast amount of groundwater that resides within the northern portion of the Mississippi Embayment Aquifer System. Current groundwater withdrawals from this subregion, 1,620 MGD, are approximately 70 percent greater than the combined groundwater withdrawals from all other subregions of the state. The major water systems, self-supplied domestic, self-supplied nonresidential, and aquaculture and wetlands sectors also rely much more on groundwater than surface water.

Groundwater withdrawals are projected to increase by 17 percent to 269.1 MGD by 2060 driven by increased demand from the agriculture sector. Surface water withdrawals are projected to increase by 18 percent to 19.8 MGD but will remain two orders of magnitude lower than groundwater withdrawals.

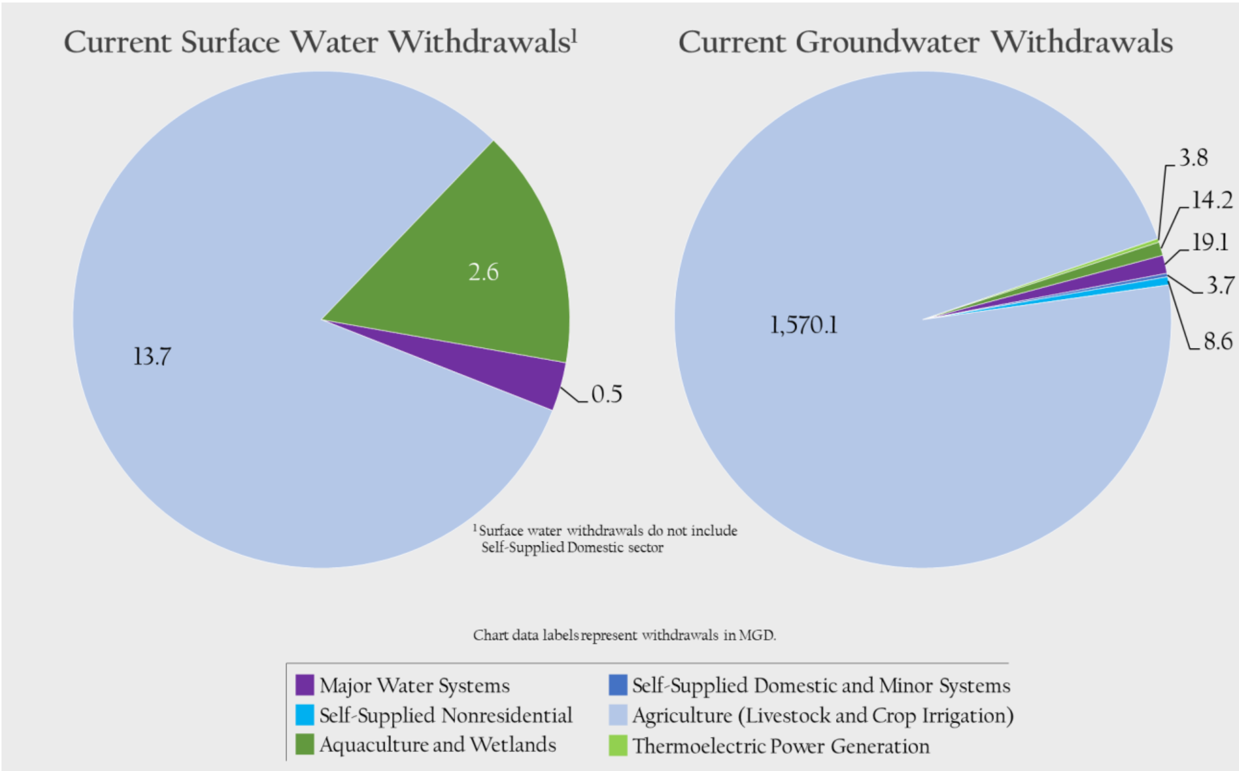


**Figure 4-12. Lower Mississippi-St. Francis Surface and Groundwater Withdrawals by Sector**

## Monthly Streamflow Analysis

Flow in the Mississippi River greatly exceeds total surface water withdrawals in the subregion. Surface water users in the northwestern part of the subregion rely on the St. Francis River and several small reservoirs. **Figure 4-13** compares current surface water withdrawals not from the Mississippi River to median dry year and drought of record year streamflow for the subregion. Dry year streamflow is based on median monthly flows for the driest year between 1980 and 2016. Drought of record year streamflow is based on the historically dry years 1954 or 1956, whichever year had the lowest gaged flow. The summer-month withdrawals for the major water users and agriculture sectors are adjusted to reflect increases that would be expected during a dry year. The comparisons show that current withdrawals range between 71 and 91 MGD at their peak but remain well below the median dry year and drought of record year monthly flows. Even with the 20 percent projected increase in 2060 demands the monthly flow comparison does not provide strong evidence to suggest future surface water stress or supply gaps in this subregion; however, the potential for localized stress cannot be ruled out.

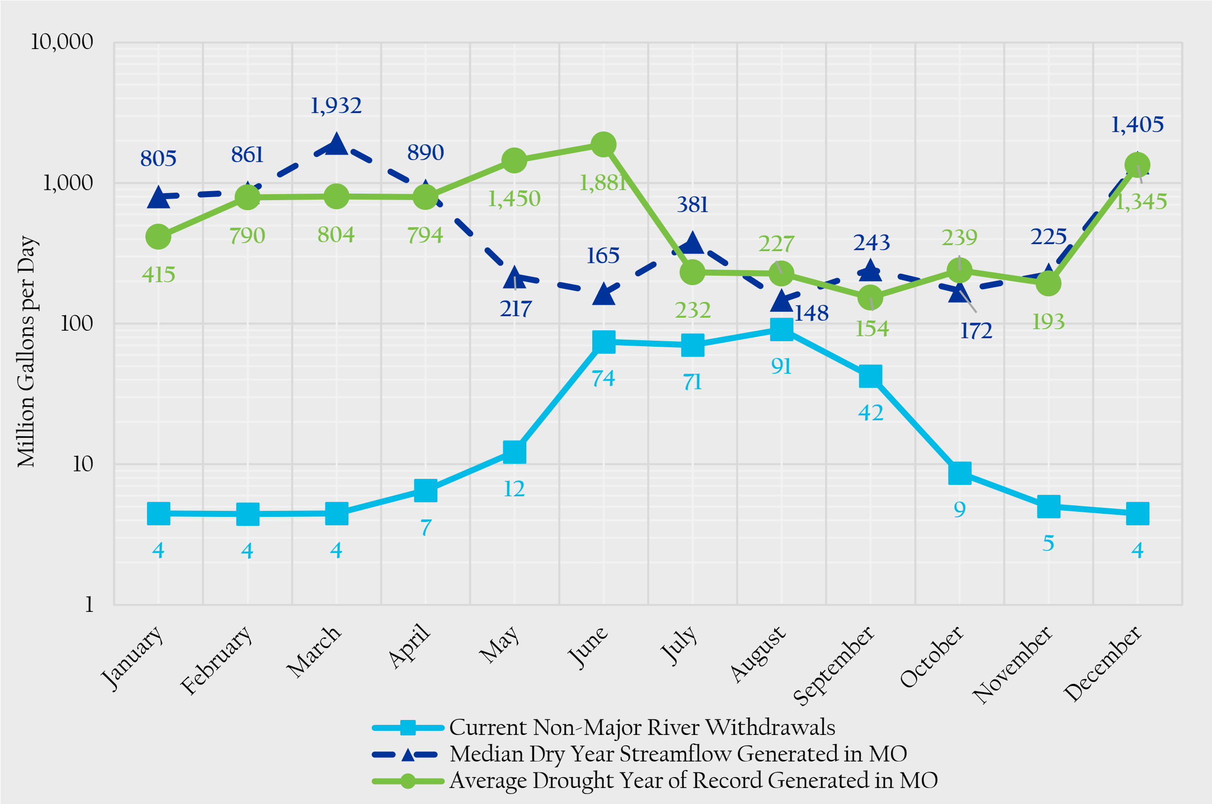


**Figure 4-13. Lower Mississippi-St. Francis Comparison of Streamflow and Dry Year Withdrawals**
*Note: This compares in-state generated streamflow to total surface water withdrawals not including Mississippi River withdrawals.*

## Reservoir Analysis

The Lower Mississippi-St. Francis subregion includes two water supply reservoirs with a total storage of 507 acre-feet or 165 mgal. The Shepherd Mountain Reservoir, located downstream of the private Snowhollow Reservoir, provides Ironton's water supply (Edwards et al 2011). The City of Ironton has an agreement with the owners of Snowhollow Reservoir to release water to Shepherd Mountain Lake during periods of drought. The reservoirs are both located at the headwaters of the basin and have relatively small drainage areas. Assuming average demands from 2011, average free water surface evaporation, and dry year inflow based on the lowest streamflow year between 1980 and 2016, both reservoirs would be able to meet demands. With no net inflow, Shepherd Mountain Lake has enough storage for 7 months of average demands and Snowhollow Lake has enough storage for 36 months of average demands. Analyses conducted by Edwards et al (2011) suggested that Ironton's demand would be met during the most critical drought periods of the 1950s and 1960s.

## Groundwater Budget

**Figure 4-14** depicts the groundwater budget for the Lower Mississippi-St. Francis subregion using a generalized representation of the major aquifers. Estimated potable, in-state groundwater storage and projected 2060 groundwater demands are shown by major aquifer. Over half the potable groundwater storage—39 of the subregion's 67 trillion gallons—occurs in the Wilcox and McNairy aquifers; however, the more easily accessed Southeast Lowlands Alluvial Aquifer accounts for 97 percent of the projected 2060 groundwater withdrawals. Current withdrawals of 1,620 MGD are 129 percent of average annual recharge from precipitation. While this suggests that groundwater levels should be on the decline, long-term observation wells in the subregion have shown no such trend. Recharge sources other than precipitation, namely the Mississippi River to the east and Ozark Aquifer to the northwest, are likely contributing significant amounts of flow into the Southeast Lowlands Alluvial Aquifer. As a result, groundwater availability is enough to meet current and projected needs without imposing stress or resulting in supply gaps. Additionally, potable groundwater stored in the aquifers is enough to meet groundwater demands even during prolonged droughts, when recharge from precipitation is much lower. Even at projected 2060 withdrawals of almost 1.9 billion gallons per day, the Southeast Lowlands Alluvial, McNairy and Wilcox aquifers have a combined storage of 56 trillion gallons and would provide over 80 years of supply without accounting for recharge from any source.

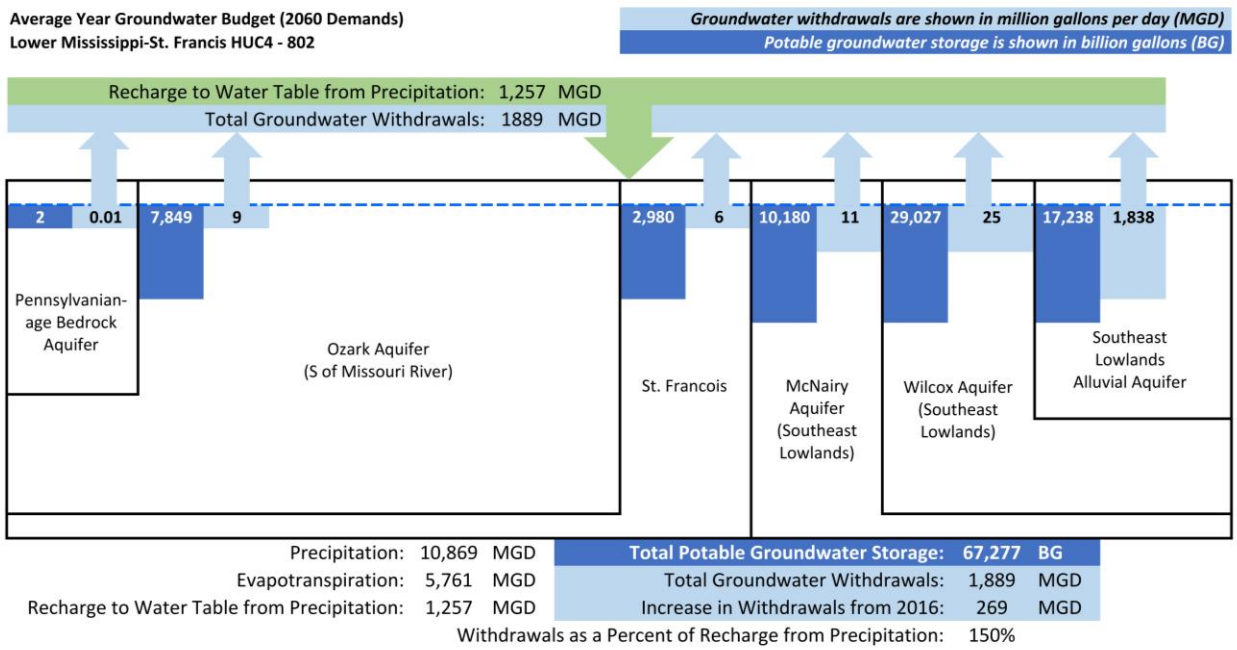


**Figure 4-14. Lower Mississippi-St. Francis Groundwater Budget**

### 4.4.4 Missouri-Nishnabotna Subregion

The Missouri-Nishnabotna subregion (HUC 1024) is in the northwest corner of Missouri and covers 3,682 square miles within the state (USGS and NRCS 2018). Major rivers within the subregion are the Platte River, Nishnabotna River, and Nodaway River, all of which flow generally to the south and into the Missouri River. Surface water flowing into the subregion from out of state via the Missouri River averages 31,910 MGD and is approximately 19 times greater than the 1,699 MGD of surface water generated within the Missouri portion of the subregion.

The subregion is within the Northwestern Missouri groundwater province and includes the Missouri River alluvium. Usable groundwater in the Northwestern Missouri province occurs mostly in buried sand and gravel channels within glacial drift deposits, which are generally thicker and have more potential as a supply source than in northeastern Missouri. Conversely, the bedrock units of the Northwestern province are less likely to produce potable groundwater as they are in parts of the northeast (Miller and Vandike 1997). Bedrock groundwater in the subregion tends to have higher mineralization and salinity levels and potable groundwater supplies are generally limited to alluvial areas and glacial drift deposits.

## Water Use by Sector and Source

Thermoelectric power is the largest water use sector in the subregion, accounting for 90 percent of surface water withdrawals (**Figure 4-15**). Not including thermoelectric power, the subregion relies almost equally on groundwater resources (103.2 MGD or 51 percent of total withdrawals) and surface water (98.4 MGD or 49 percent of total withdrawals). The alluvial aquifer along the Missouri River is the primary source for all sectors using groundwater. The Missouri River is the primary surface water source, accounting for approximately 80 percent of surface water withdrawals.

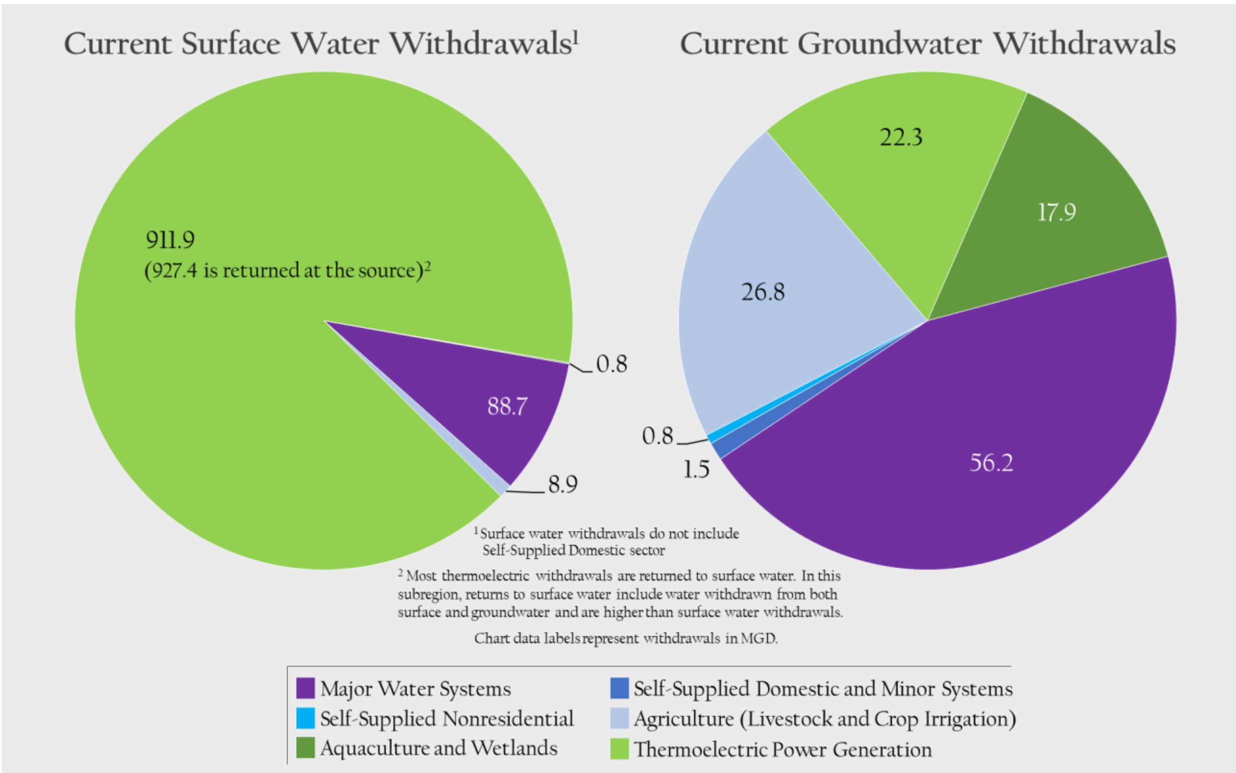


**Figure 4-15. Missouri-Nishnabotna Surface and Groundwater Withdrawals by Sector**

Total surface water withdrawals (including withdrawals for thermoelectric power generation) are projected to increase by 15 percent to 1,196 MGD in 2060. Nonthermoelectric surface water withdrawals are projected to increase by 28 percent to 126.1 MGD, primarily driven by increased major water system demands. Total groundwater withdrawals are projected to increase by 14 percent to 146 MGD.

## Monthly Streamflow Analysis

Although flow in the Missouri River greatly exceeds total surface water withdrawals in the subregion, especially during dry years and the drought of record year, surface water users in the eastern part of the subregion must rely on tributaries to the Missouri. **Figure 4-16** compares current surface water withdrawals not from the Missouri River to median dry year streamflow and the drought of record year streamflow for the subregion. Dry year streamflow is based on median monthly flows for the driest year between 1980 and 2016. Drought of record year streamflow is based on the historically dry years of 1954 and 1956, whichever year had the lowest gaged flow. The summer-month withdrawals for the major water users and agriculture sectors are adjusted to reflect increases that would be expected during a dry year. The comparisons show that withdrawals approach or exceed median dry year flows in 3 months (July, August, and September) of the dry year and in 5 months (January, September, October, November, and December) of the drought of record year. These results suggest the potential for a surface water gap in areas of the subregion that do not have access to the Missouri River for supply and emphasize the importance of reservoir storage, interconnections with other systems, conjunctive use of groundwater, or other means to bridge these potential supply gaps. This potential gap is also apparent in the flow-duration curve included in the subregion summary in **Appendix E**. The curve suggests that streamflow generated within the subregion will be below average annual withdrawals approximately 10 percent of the time; however, the projected dry year maximum monthly withdrawals in 2060 of 96 MGD would exceed streamflow about 11 percent of the time.

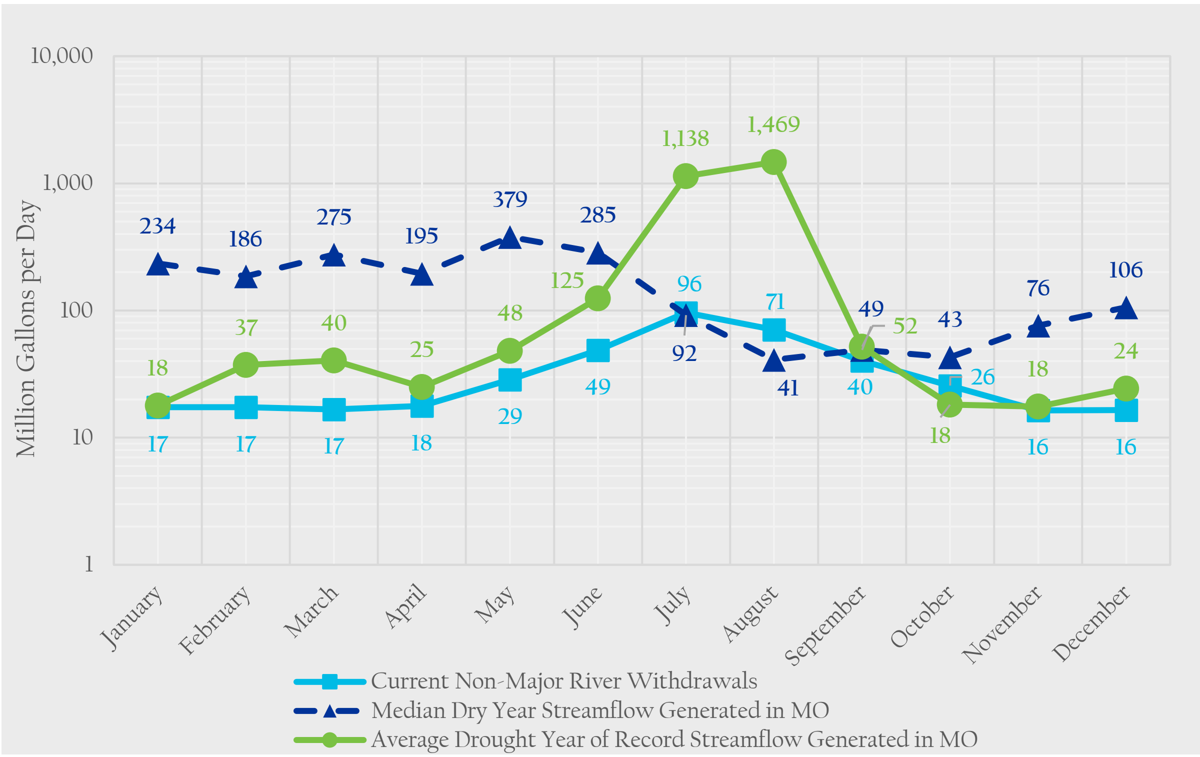


**Figure 4-16. Missouri-Nishnabotna Comparison of Streamflow and Dry Year Withdrawals**
*Note: This compares in-state generated streamflow to total surface water withdrawals not including Missouri River withdrawals.*

## Reservoir Analysis

The Missouri-Nishnabotna subregion includes three water supply reservoirs with a total storage of 112,772 acre-feet or 36,747 mgal: Smithville Lake, City Lake serving Dearborn, and Mozingo Lake serving Maryville. Smithville Lake is by far the largest of the three and has a water supply storage allocation of 95,200 acre-feet (31,021 mgal). It is located at the far southern end of the subregion, just north of Kansas City. As such, it is generally inaccessible to many of the water users to the north without significant investment in infrastructure. Assuming average demands from 2011, average free water surface evaporation, and dry year inflow based on the lowest streamflow year between 1980 and 2016, the reservoirs have enough storage to meet demands for 22 (City Lake), 56 (Mozingo Lake), and 97 (Smithville Lake) months. With no net inflow, the reservoirs individually have enough storage to meet demands for 9 (City Lake), 40 (Smithville), and 41 (Mozingo) months.

The Northwest Missouri Regional Water Supply Transmission System Study (CDM Federal Programs Corporation [CDM Smith] et al. 2010) included an evaluation of supply availability and infrastructure needs for the region. It found that some water systems that rely on surface water, especially those which rely on small reservoirs, as their primary source of drinking water supply are more susceptible to impacts from extreme drought.

Two additional reservoirs, Maryville and Savannah, are within this subregion, but no information was available to analyze them and therefore the months of storage available were not determined.

### Groundwater Budget

**Figure 4-17** depicts the groundwater budget for the Missouri-Nishnabotna subregion using a generalized representation of the major aquifers. Estimated potable groundwater storage and projected 2060 groundwater demands are shown by major aquifer. Potable groundwater is stored in the Missouri River Alluvial and Glacial Drift aquifers, where present. The Glacial Drift Aquifer includes buried channels from preglacial alluvial deposits. Projected 2060 groundwater withdrawals of 146 MGD are 52 percent of average annual recharge from precipitation. The Missouri River is an even greater source of recharge to the Missouri River Alluvial Aquifer than precipitation.

Although the water budget suggests that potable groundwater storage is sufficient to meet water supply needs, much of the stored water is not easily accessible to users east of the Missouri River and away from the thickest glacial drift deposits. As is the case across much of northern Missouri, location determines whether groundwater can economically and reliably be used as a water supply source.

**Northwest Missouri Regional Water Supply Transmission System Study**

The Northwest Missouri Regional Water Supply Transmission System Study evaluated water supply issues for 12 counties in northwestern Missouri. The study was commissioned in 2009 by the Great Northwest Wholesale Water Commission, which is currently comprised of the cities Cameron, Maysville, and Stewartsville. The commission is a public water entity with the goal of implementing a regional project that provides a reliable water supply to its members in northwest Missouri. It has the authority to construct and own infrastructure, issue debt on behalf of its members, receive grant proceeds and other public assistance, and purchase and sell water from retail water systems.

The study found that with decreasing populations in parts of the region, the tax base falls short of covering imminent water infrastructure improvement costs. Additionally, water systems that rely on surface water as their primary source of drinking water supply are more susceptible to impacts from extreme drought.

The study estimated future water demands and developed preliminary cost estimates for regionalization of water systems. Estimated potential wholesale water rates were developed to better evaluate the benefits of joining a regional public water utility. It was found that the benefits of regionalization largely depend on a system's susceptibility to drought and its distance from the Missouri River. The study concluded that regionalization would be more beneficial to those communities and water systems that are far from the Missouri River and are faced with greater water source reliability issues during drought. Certain water systems in Caldwell, Clinton, Gentry, and Nodaway counties that rely on surface water as their primary source of drinking water will require a supplemental source of water to meet average daily demands during extreme drought conditions. Such systems could substantially improve the availability, reliability, and quality of drinking water supplied to its customers if they were to join the commission.

*Source: CDM Smith et al. 2010*

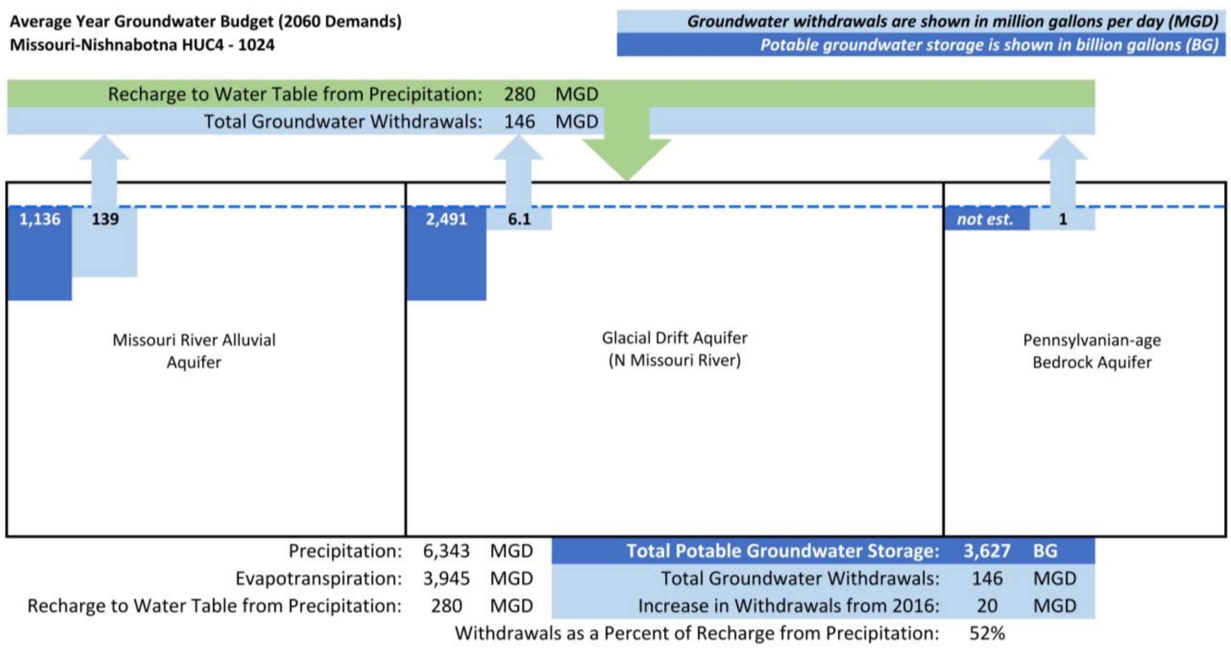


**Figure 4-17. Missouri-Nishnabotna Groundwater Budget**

## 4.4.5 Chariton-Grand Subregion

The Chariton-Grand subregion (HUC 1028) is in north central Missouri and covers 8,306 square miles within the state (USGS and NRCS 2018). Major rivers within the subregion include the Grand River, the Thompson River, and the Chariton River, all of which generally flow south and into the Missouri River.

The subregion is within the Northwestern Missouri groundwater province and includes small portions of the Missouri River alluvium, where it drains to the Lower Missouri subregion. Usable groundwater in the Northwestern Missouri province occurs mostly within fingers of glacial drift deposits (**Figure 4-18**). Bedrock groundwater in the subregion tends to be highly mineralized and potable groundwater supplies are generally limited to alluvial areas and glacial drift deposits.

### Water Use by Sector and Source

Thermoelectric power is the largest water use sector in the subregion, accounting for 96 percent of surface water withdrawals (**Figure 4-19**). Not including thermoelectric power, the subregion relies primarily on surface water resources (36.5 MGD or 74 percent of total withdrawals). The major water systems and agriculture sectors use approximately the same amount of surface water. Groundwater withdrawals (12.8 MGD or 26 percent of total withdrawals) occur mostly in the Missouri River Alluvial and Glacial Drift aquifers. Groundwater withdrawals are the highest for the aquaculture and wetlands sector, a nonconsumptive use. Of the consumptive use sectors, major water systems and agriculture consume nearly the same amount of water.

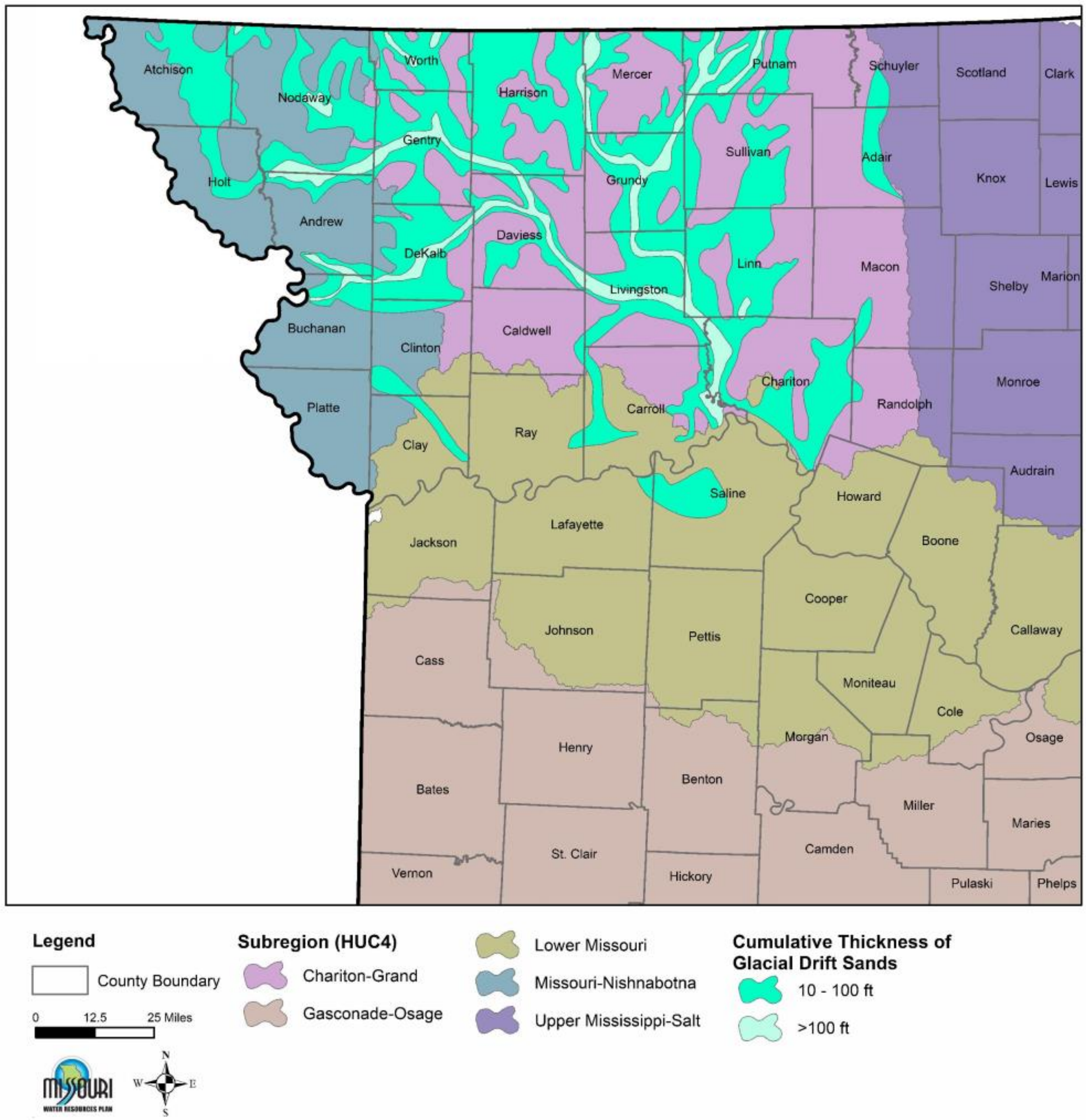


Figure 4-18. Location and Thickness of Glacial Drift Sands in Northwestern Missouri

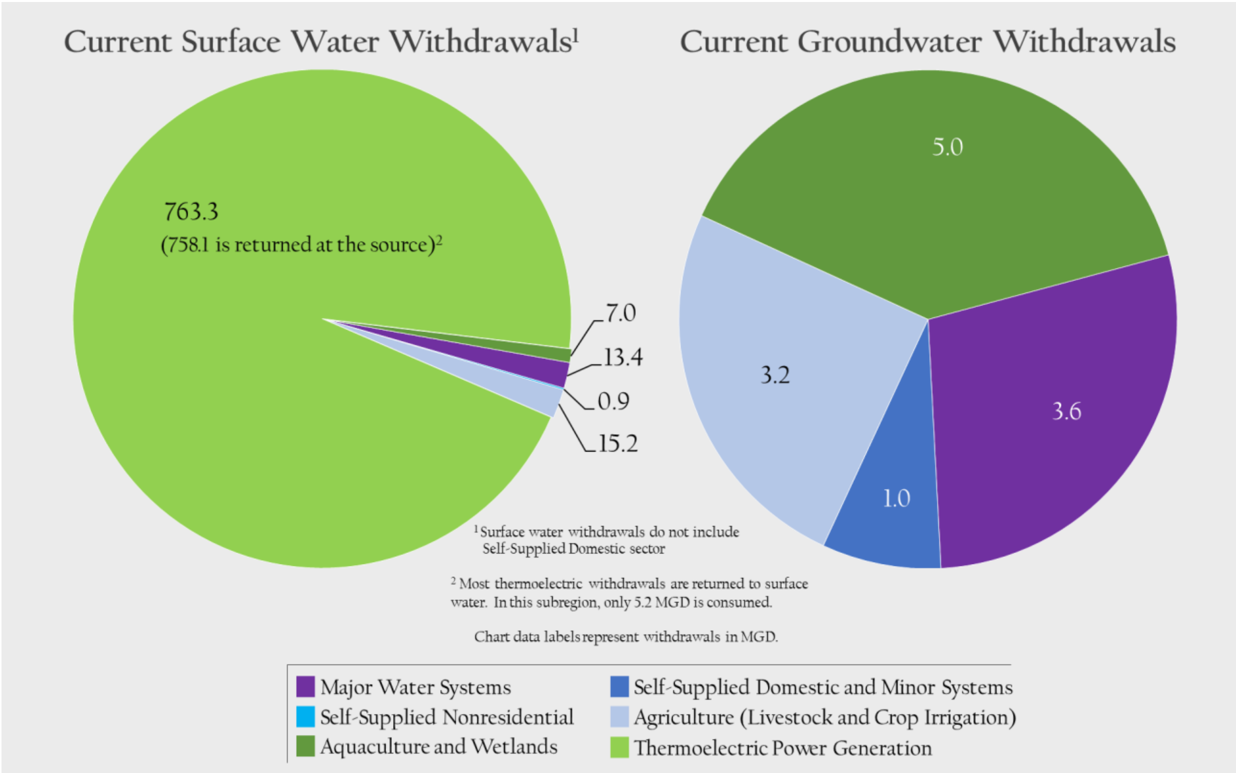


**Figure 4-19. Chariton-Grand Surface and Groundwater Withdrawals by Sector**

Surface water withdrawals (including withdrawals for thermoelectric power generation) are projected to increase by 17 percent to 939 MGD in 2060. Nonthermoelectric surface water withdrawals are projected to increase by 18 percent to 42.9 MGD, primarily driven by increased agricultural demands. Groundwater withdrawals are projected to increase by 7 percent to just under 14 MGD.

### Monthly Streamflow Analysis

**Figure 4-20** compares current surface water withdrawals to median dry year and drought of record year streamflow for the Missouri portion of the subregion. Streamflow that originates in Iowa, which accounts for 24 percent of the subregion's area, has been excluded to focus the supply analysis on water originating within Missouri. This assumption does not imply that out-of-state surface water is unimportant to the state's water supply. This is further illustrated as part of the scenario planning process described in **Section 9**.

Dry year streamflow is based on median monthly flows for the driest year between 1980 and 2016. Drought of record year streamflow is based on streamflow from 1954 or 1956, whichever year had the lowest gaged flow. The summer-month withdrawals for the major water users and agriculture sectors are adjusted to reflect increases that would be expected during a dry year. The comparisons show that withdrawals do not approach or exceed median dry year flows in any month. The month with the smallest difference between streamflow and withdrawals is October, when streamflow is 99 MGD and withdrawals are 64 MGD. Total current withdrawals would have exceeded streamflow during the drought of record year in 1 month (October). These results suggest the potential for a surface water gap in areas of the subregion that do not have reservoir storage or access to groundwater of suitable quality as a supplemental or backup source of supply.

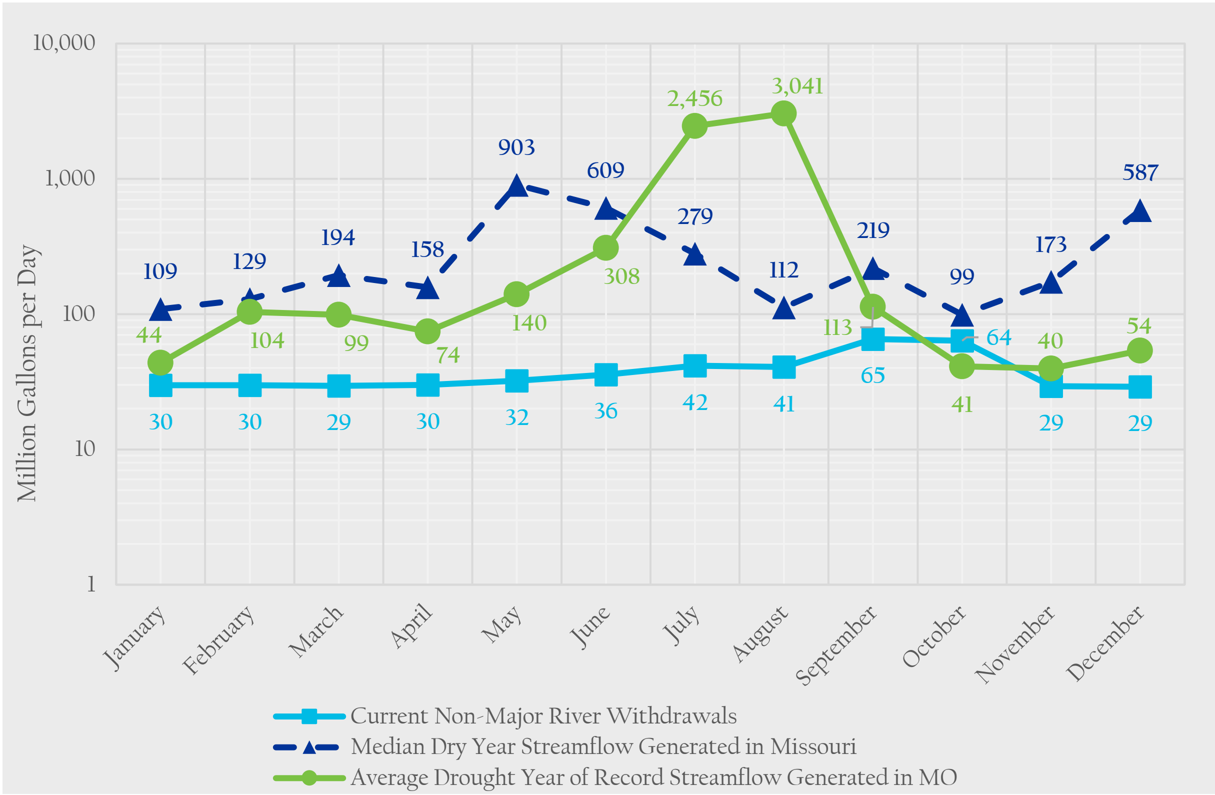


**Figure 4-20. Chariton-Grand Comparison of Streamflow and Dry Year Withdrawals**
*Note: This compares in-state generated streamflow to total surface water withdrawals. Streamflow that originates in Iowa is not included. Seventy-six percent of the subregion is in Missouri and 24 percent is in Iowa.*

## Reservoir Analysis

The Chariton-Grand subregion includes 32 water supply reservoirs with a total storage of 96,707 acre-feet or 31,512 mgal. Rathbun Lake in Iowa also provides water to several Missouri water districts. Reservoirs are an important component of the subregion's overall water supply system due to the availability limitations of groundwater, lower average rainfall, and history of drought. About two-thirds of the reservoirs have a total storage of less than 1,000 acre-feet (326 mgal). Long Branch Lake is the largest reservoir, with 24,400 acre-feet (7,951 mgal) of total storage. Assuming average demands from 2011, average free water surface evaporation, and dry year inflow based on the lowest streamflow year between 1980 and 2016, four reservoirs have less than 6 months of total storage. As part of the Northcentral Missouri Regional Water Source Evaluation (Allstate Consultants and Olsson Associates 2016), reservoir capacity and surface water available in streams were evaluated in detail. The study found that under severe drought conditions, more than half of the water suppliers within the region would lack an adequate supply of source water and storage to meet average water demands.

## Groundwater Budget

**Figure 4-21** depicts the groundwater budget for the Chariton-Grand subregion using a generalized representation of the major aquifers. Estimated potable groundwater storage and projected 2060 groundwater demands are shown by major aquifer. Potable groundwater is stored in the Missouri River Alluvial and Glacial Drift aquifers, where present. Projected 2060 groundwater withdrawals of 14 MGD are 3 percent of average annual recharge from precipitation.

Although the water budget suggests that potable groundwater storage is sufficient to meet water supply needs, much of the stored water is not easily accessible to users north of the Missouri River and away from thick glacial drift deposits. As is the case across much of northern Missouri, location determines whether groundwater can economically and reliably be used as a water supply source.

Because of limited potable groundwater availability and the potential for surface water gaps under drought conditions, the Chariton-Grand subregion was further evaluated at the subbasin level. The results of the subbasin level analyses are presented in **Section 4.6.1**.

**Northcentral Missouri Regional Water Source Evaluation**

The Northcentral Missouri Regional Water Source Evaluation was conducted in 2016 for a 10-county portion of the Chariton-Grand subregion. This region includes the counties of Adair, Chariton, Grundy, Linn, Livingston, Macon, Mercer, Putnam, Schuyler, and Sullivan. The study evaluated the adequacy of current water supply sources to meet average demand in the event of a severe drought. Public water system providers were separated into a total of 18 clusters based on their source of water supply. A total of six surface water clusters, nine groundwater clusters, and three out-of-region clusters provide finished water in this region of north Missouri. Each cluster has a primary water provider that treats water from the source and transmits it to other public water systems within the cluster.

Reservoir capacity and streamflow levels from the drought of record were used to identify surface water clusters with insufficient water supply during a severe drought. Five out of the six surface water clusters were found to have inadequate sources of water to meet normal demand. Analysis of groundwater sources was based on regional and local geology, historical data, and engineering design criteria. Of the nine groundwater clusters, it was found that six yielded inadequate water supplies during severe drought conditions. Out-of-region clusters used a combination of surface and groundwater sources to supply drinking water to communities within the 10-county region. One out of the three out-of-region clusters was found to have inadequate water supply to meet normal demand.

The study concluded that under severe drought conditions, more than half of the water suppliers within the region would lack an adequate supply of source water to meet average water demands. It was estimated that a 9.19 MGD gap in water supply is possible if a severe drought like the drought of record occurs. This risk of insufficient water supply was found to be caused by multiple factors, including lack of regionalization and infrastructure, challenges related to supporting drinking water treatment systems, gaps in supply (especially during a drought), and use of small-scale onsite shallow well systems. Water shortages could have significant and detrimental impacts on communities and economic growth within the region. The study recommended identifying a new, reliable source (or sources) of water to supplement current water supply sources in northcentral Missouri.

These conclusions are further supported by the subregional Chariton-Grand supply analysis described in this section, which shows vulnerability in a drought year during months which typically receive less rainfall (**Figure 4-20**). This subregion is further analyzed at the subbasin level as described in **Section 4.6.1**, which describes vulnerability in four of the five subbasins which comprise the Chariton-Grand subregion. Additionally, future stresses on this area may lead to increased hydrologic gaps in the future, as described in **Section 9**.

*Source: Allstate Consultants and Olsson Associates 2016*

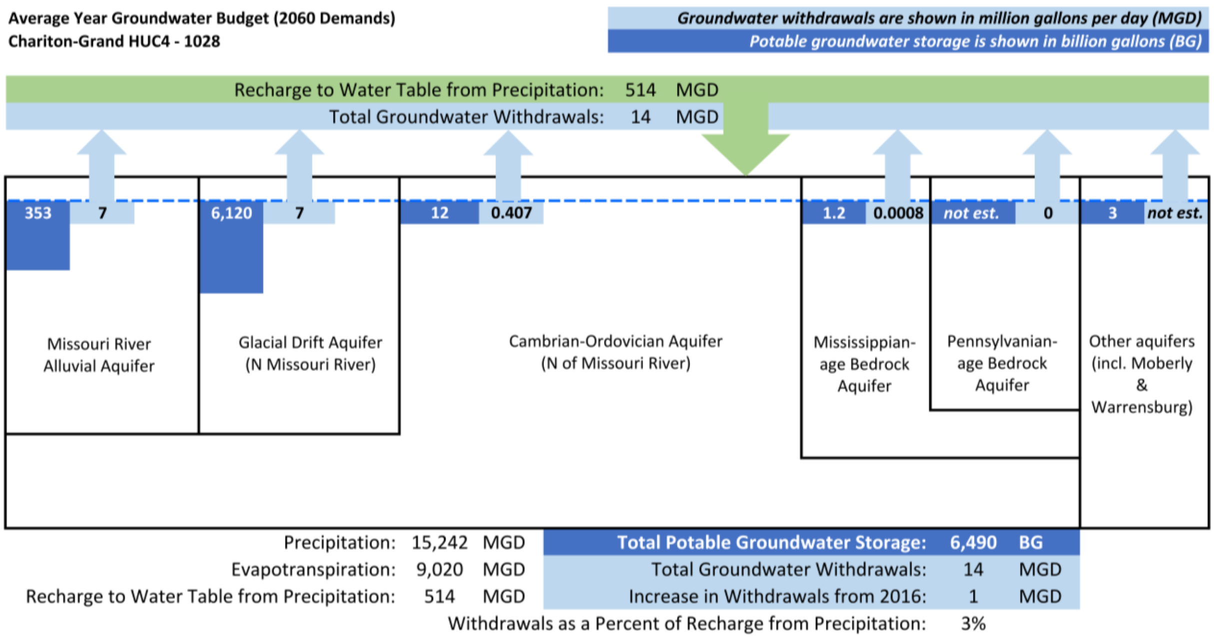


**Figure 4-21. Chariton-Grand Groundwater Budget**

## 4.4.6 Gasconade-Osage Subregion

The Gasconade-Osage subregion (HUC 1029) is in west central Missouri and covers 14,301 square miles within the state (USGS and NRCS 2018). Major rivers within the subregion include the Osage River, the South Grand River, the Pomme de Terre River, and the Gasconade River. The Osage and Gasconade rivers eventually drain to the Missouri River.

The subregion includes portions of the West-Central, Springfield Plateau, and Salem Plateau groundwater provinces. Usable groundwater resources are limited in the West-Central Province compared to the Ozark Aquifer System of the Springfield and Salem plateaus, which store relatively large quantities of potable groundwater.

### Water Use by Sector and Source

Thermoelectric power is the largest water use sector in the subregion, accounting for 65 percent of surface water withdrawals as shown in **Figure 4-22**. Not including thermoelectric power, the subregion relies about equally on groundwater resources (76.5 MGD or 51 percent of total withdrawals) and surface water (74.2 MGD or 49 percent of total withdrawals). The largest water use sector outside of thermoelectric power is aquaculture and wetlands, followed by agriculture, and major water systems. Groundwater withdrawals occur mostly in the Ozark Aquifer; however, the Springfield Plateau Aquifer and Pennsylvanian-age sandstones and limestones can be utilized to a limited extent as a source for agriculture and domestic supply.

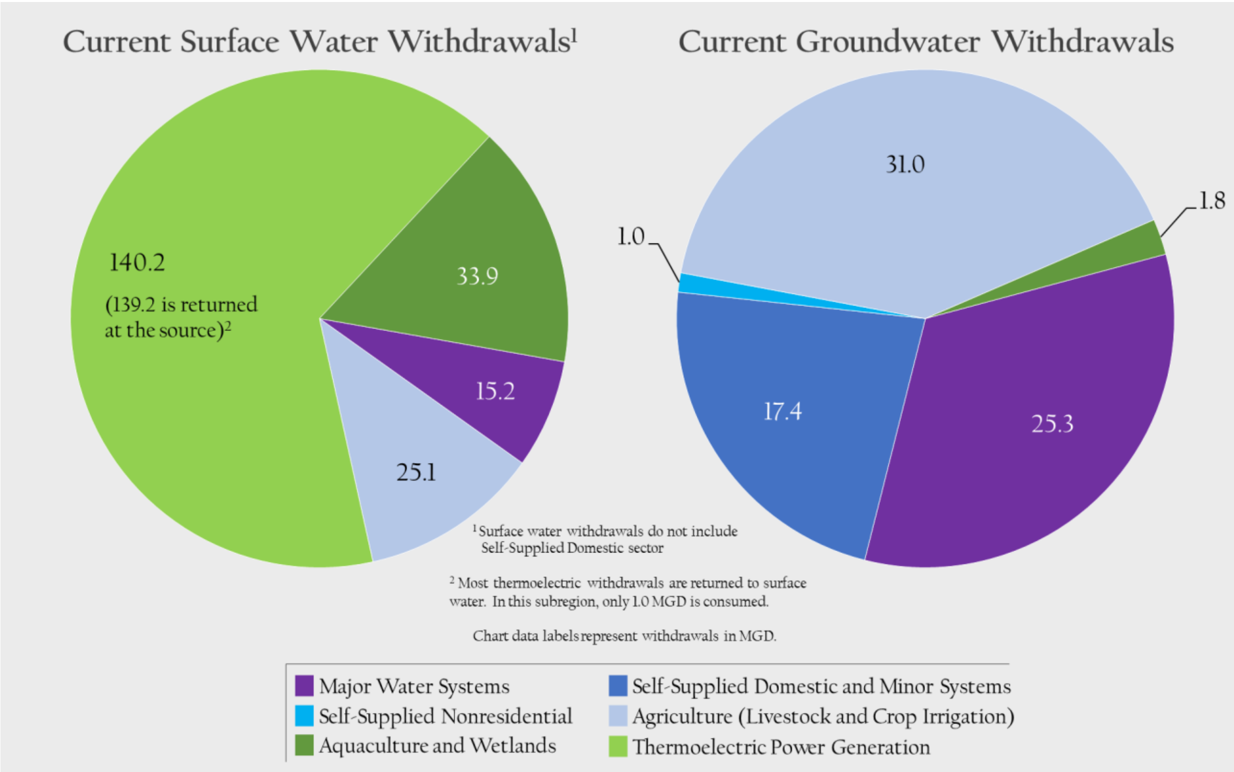


**Figure 4-22. Gasconade-Osage Surface and Groundwater Withdrawals by Sector**

Surface water withdrawals (including withdrawals for thermoelectric power generation) are projected to increase by 19 percent to 255 MGD in 2060 and nonthermoelectric surface water withdrawals are projected to increase by 22 percent to 90.4 MGD. Groundwater withdrawals are also projected to increase by 26 percent to just under 96 MGD in the same timeframe. There are three hydropower dams operated by USACE in this subregion (Harry S. Truman, Osage, and Stockton) and one run-of-the-river facility (Niangua) as described in **Section 3.10.2**. The operation of, and water demand for, these facilities is complex, varies between each facility, and is dependent on multiple factors including reservoir pool operation, downstream flood condition, and requirements of the reservoir's other authorized uses. This results in a complex series of operational rules that are not summarized in this report. These facility's importance as a source of renewable energy is anticipated to continue to increase, and planning to provide for their water demands will therefore be an ongoing priority.

## Monthly Streamflow Analysis

**Figure 4-23** compares current surface water withdrawals to median dry year and drought of record year streamflow for the Missouri portion of the subregion. Streamflow that originates in Kansas, which accounts for 23 percent of the subregion's area, is not included. This was done to focus the supply analysis on water that is within Missouri's control. This assumption does not imply that out-of-state surface water is unimportant to the state's water supply. This is further illustrated as part of the scenario planning process described in **Section 9**.

Dry year streamflow is based on median monthly flows for the driest year between 1980 and 2016. Drought of record year streamflow is based on the historically dry years of 1954 or 1956, whichever year had the lowest gaged flow. The summer-month withdrawals for the major water users and agriculture sectors are adjusted to reflect increases that would be expected during a dry year. The comparisons show that withdrawals remain an order of magnitude below median dry year flows in any month. This relatively consistent streamflow, even during dry periods, is in part due to the thousands of springs and outlet points in the Salem Plateau portion of the subregion. At these springs, groundwater moving through karst systems discharges to the surface, providing relatively consistent base flow to streams.

While the results of the monthly streamflow analysis at the subregion level do not indicate the potential for stress or a surface water gap under current or future conditions, water stress and the potential for water shortages have previously been identified in more localized areas of southwest Missouri, including the western portion of the Gasconade-Osage subregion. The Southwest Missouri Water Resources Study (CDM Smith et al. 2014) identified potential water supply gaps during severe drought conditions. For this reason, the Little Osage subbasin was evaluated in further detail. The results of the Little Osage subbasin level analyses are presented in **Section 4.6.2**.

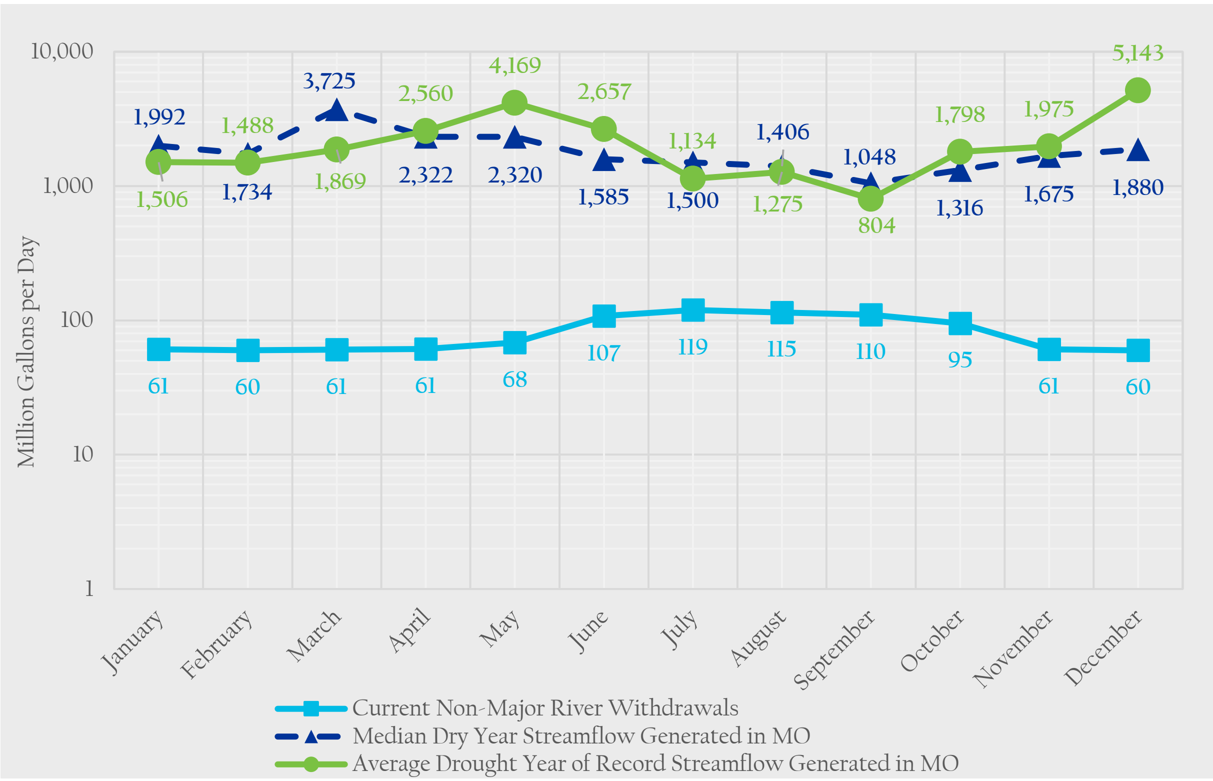


**Figure 4-23. Gasconade-Osage Comparison of Streamflow and Dry Year Withdrawals**

*Note: This compares in-state generated streamflow to total surface water withdrawals. Streamflow that originates in Kansas is not included. Seventy-seven percent of the subregion is in Missouri and 23 percent is in Kansas.*

## Reservoir Analysis

The Gasconade-Osage subregion includes 11 water supply reservoirs with a total water supply storage of 95,396 acre-feet or 31,085 mgal; 5 of the 11 reservoirs have a water supply storage equal to or greater than 1,000 acre-feet (326 mgal). Stockton Lake is the largest reservoir, with 50,000 acre-feet (16,293 mgal) of allocated water supply storage. Assuming average demands from 2011, average free water surface evaporation, and dry year inflow based on the lowest streamflow year between 1980 and 2016, two reservoirs—McDaniel Lake and City Lake in Adrian—only have enough storage to meet demands for 12 months or less.

**Southwest Missouri Water Resource Study**

The Southwest Missouri Water Resource Study area is made up of sixteen counties: Barry, Barton, Cedar, Christian, Dade, Greene, Hickory, Jasper, Lawrence, McDonald, Newton, Polk, St. Clair, Stone, Taney, and Vernon. The Southwest Missouri Water Resource Study was conducted in three phases. Phase I of the study evaluated regional demand forecasts by water use sector through 2060. Results showed that there will be an estimated 40 percent increase in water demand over the next 50 years. Phase II of the study evaluated current and future water supply availability through 2060 and compared the results to projected 2060 demands to identify potential gaps.

The Phase II analysis determined that water supply gaps arise during severe drought conditions for the public supply, self-supplied residential, and self-supplied industrial sectors. Additionally, the infrastructure to capture, store, treat, and deliver water for at-risk communities is currently not in place to meet projected demands, especially during severe drought. Based on this analysis, 10 of the 16 counties within the study area were projected to encounter water supply deficits during drought conditions if additional supplemental water supplies are not in place. These counties were Barry, Barton, Christian, Greene, Jasper, Lawrence, Newton, McDonald, Polk, and Stone.

Phase III of the study investigated supplemental water reallocations from Stockton Lake to fill potential regional water supply gaps during drought. Additional reallocations from Pomme de Terre Lake and Table Rock Lake may also be considered as supplemental water supply sources to ensure the future supply gap is adequately covered to meet the needs of the Southwest Missouri region.

*Source: CDM Smith et al. 2014*

### Groundwater Budget

**Figure 4-24** depicts the groundwater budget for the Gasconade-Osage subregion using a generalized representation of the major aquifers. Estimated potable groundwater storage and projected 2060 groundwater demands are shown by major aquifer. Within the subregion, the Ozark and St. Francois aquifers are estimated to store a combined 138 trillion gallons of potable groundwater. The St. Francois Aquifer is accessed, to a limited extent, in the eastern half of the subregion, but not utilized in the western half due to the highly mineralized content of the water. Projected 2060 groundwater withdrawals of 96 MGD are 5 percent of average annual recharge from precipitation. Even though at a subregion level, groundwater recharge greatly exceeds withdrawals and large amounts of potable groundwater are available in storage, localized stress may still occur due to over-pumping. In the western portion of the subregion, on the saline side of the freshwater-saline transition zone, groundwater is used to a lesser extent due to poor water quality.

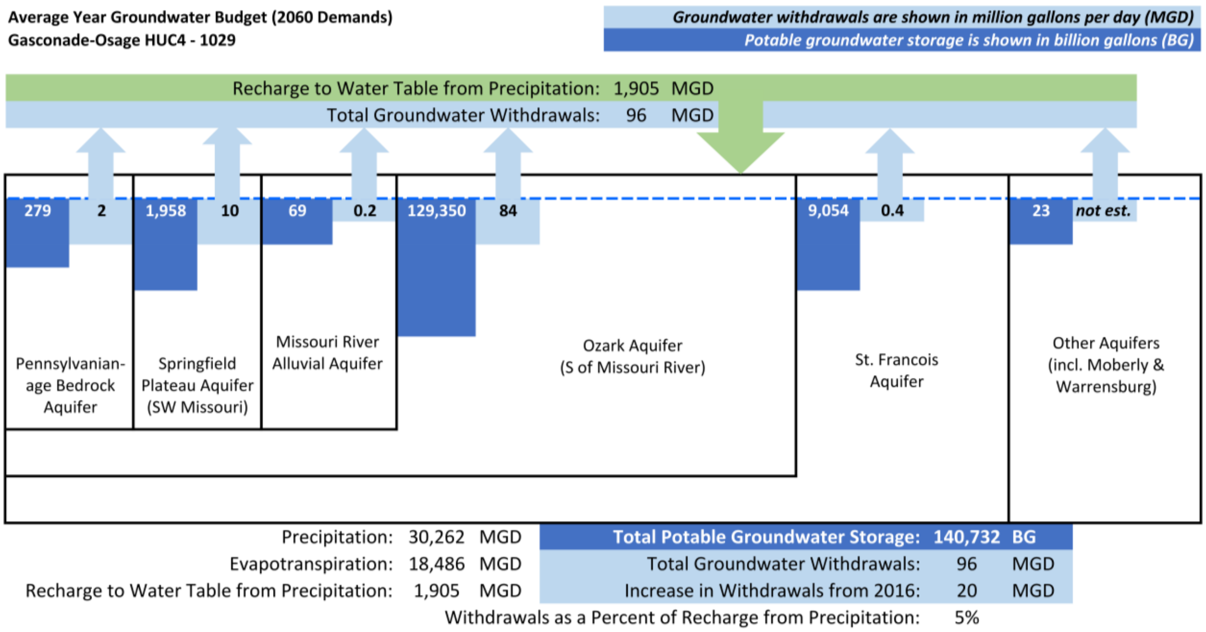


**Figure 4-24. Gasconade-Osage Groundwater Budget**

## 4.4.7 Lower Missouri Subregion

The Lower Missouri subregion (HUC 1030) is in central Missouri, bordering Kansas to the west and culminating at the Mississippi River, the border with Illinois, to the east. The subregion covers 10,182 square miles within the state (USGS and NRCS 2018).The subregion receives flows from the Missouri-Nishnabotna, Chariton-Grand, and Gasconade-Osage subregions within Missouri, and the Kansas River at Kansas City.

Stretching across the middle of the state, the subregion includes a portion of nearly every major groundwater province. The Missouri River Alluvial Aquifer is the most important source of groundwater in the subregion.

It should be noted that the term "Lower Missouri" is used in this report to refer to a specific subregional area within the state, consistent with USGS naming convention. This term should not be confused with its common definition as the Missouri River reach which extends from Gavins Point Dam to its confluence with the Mississippi River.

## Water Use by Sector and Source

Thermoelectric power is the largest water use sector in the subregion, accounting for 93 percent of surface water withdrawals (**Figure 4-25**). Not including thermoelectric power, the subregion relies more on surface water resources (171.8 MGD or 57 percent of total withdrawals) than groundwater (130.5 MGD or 43 percent of total withdrawals). The alluvial aquifer along the Missouri River is the primary source for most sectors using groundwater; however, the Ozark Aquifer south of the Missouri River is more important for the self-supplied sectors. The Cambrian-Ordovician Aquifer is an important source of bedrock groundwater in the eastern portion of the subregion north of the Missouri River. The Missouri River is the primary surface water source, accounting for approximately 60 percent of surface water withdrawals.

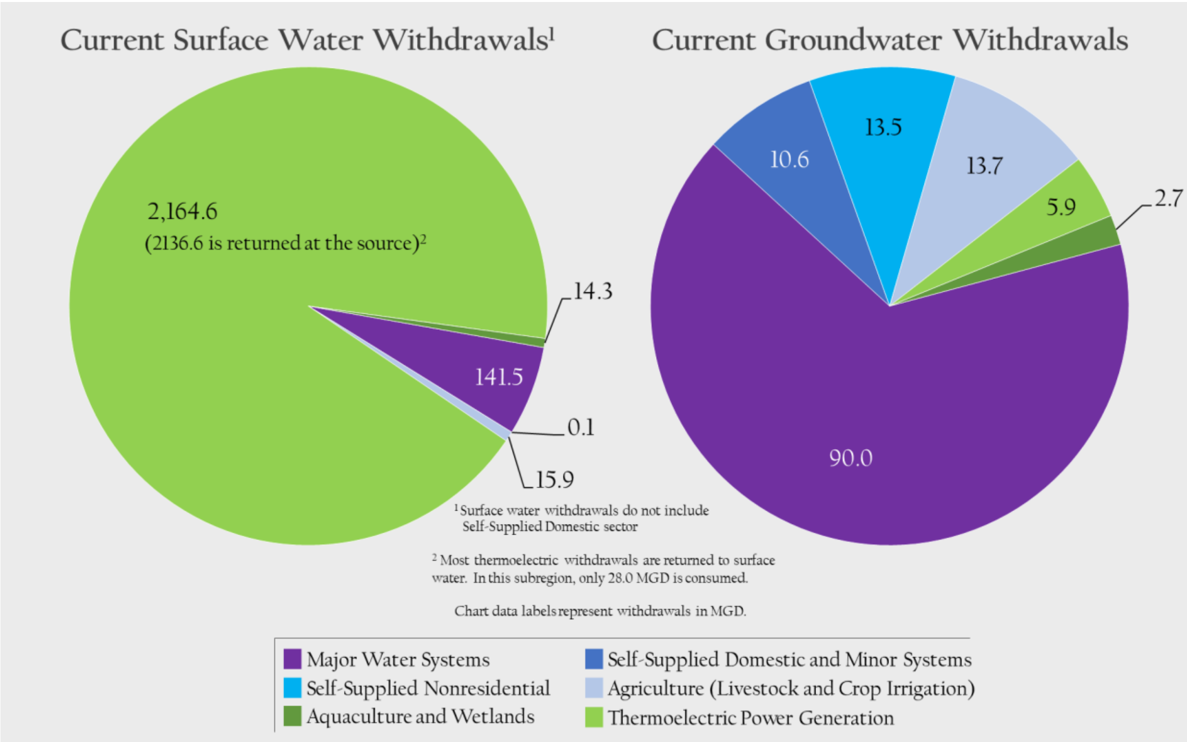


**Figure 4-25. Lower Missouri Surface and Groundwater Withdrawals by Sector**

Total surface water withdrawals are projected to decrease by 23 percent to 1,787 MGD in 2060, primarily driven by projected decreases in water needed for thermoelectric power generation. Not including water needed for thermoelectric power, surface water withdrawals are projected to increase by 18 percent to 202.8 MGD due to increased demand in the major water system and agriculture sectors. Groundwater withdrawals are projected to increase by 22 percent to 167 MGD.

## Monthly Streamflow Analysis

Although flow in the Missouri River greatly exceeds total surface water withdrawals in the subregion, even during dry years and the drought of record year, surface water users that do not have access to the Missouri River must rely on its tributaries for water supply. **Figure 4-26** compares current surface water withdrawals not from the Missouri River to median dry year and drought of record year streamflow for the subregion. Dry year streamflow is based on median monthly flows for the driest year between 1980 and 2016. Drought of record year streamflow is based on streamflow from 1954 or 1956, whichever year had the lowest gaged flow. Streamflow at the USGS gages used for this analysis dropped to zero for September through December of the drought of record year. This was, in part, due to the relatively small drainage area of the gages that were deemed suitable for this analysis. The summer-month withdrawals for the major water users and agriculture sectors are adjusted to reflect increases that would be expected during a dry year. The comparisons show that withdrawals exceed median dry year flows in 5 months (July through November) of the dry year and in 8 months (January, March, June, and August through December) of the drought of record year. These results suggest the potential for a surface water gap in areas of the subregion that do not have access to the Missouri River for supply and emphasize the importance of reservoir storage, interconnections with other systems, conjunctive use of groundwater, or other means to bridge these potential supply gaps. This potential gap is also apparent in the flow-duration curve included in the subregion summary in **Appendix E**. The curve suggests that streamflow generated within the subregion will be below average annual withdrawals approximately 8 percent of the time; however, the projected dry year maximum monthly withdrawals in 2060 of approximately 190 MGD would exceed streamflow about 11 percent of the time.

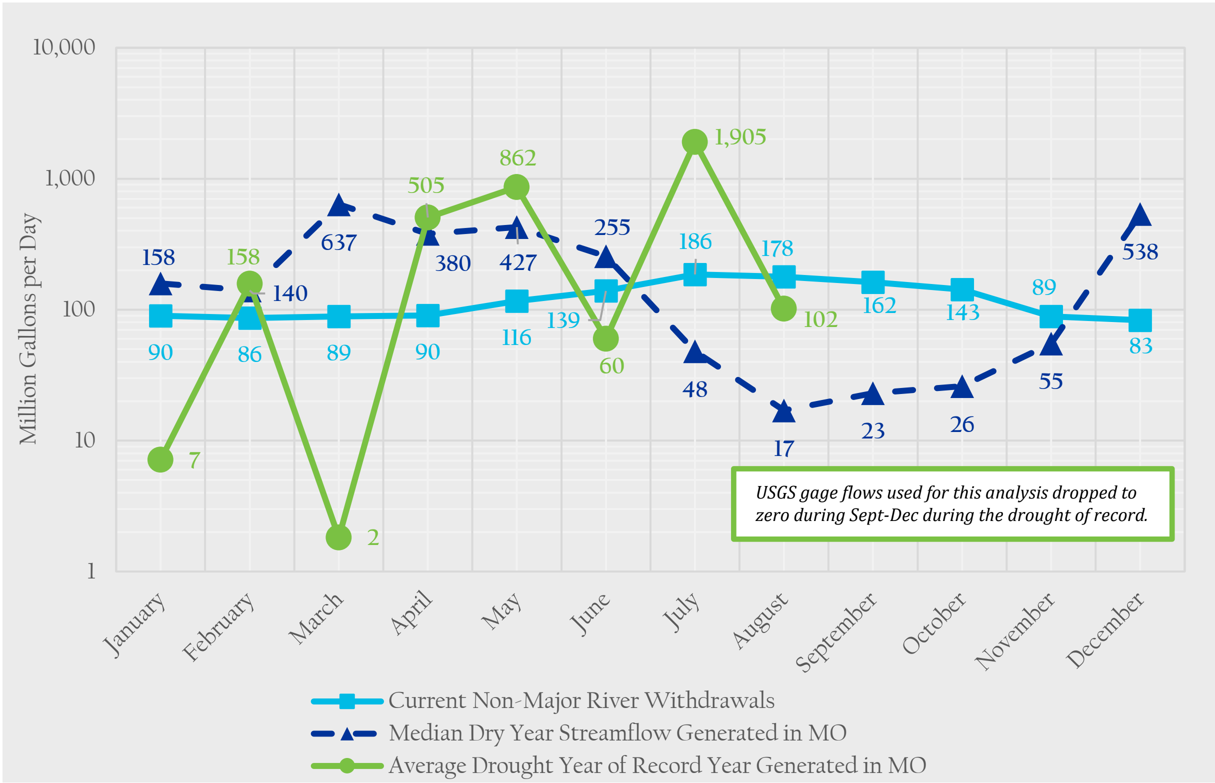


**Figure 4-26. Lower Missouri Comparison of Streamflow and Dry Year Withdrawals**

*Note: This compares in-state generated streamflow to total surface water withdrawals not including Missouri River withdrawals.*

## Reservoir Analysis

The Lower Missouri subregion includes six water supply reservoirs with a total water supply storage of 12,498 acre-feet or 4,072 mgal. Four of the six reservoirs are located south of the Missouri River, in the western half of the subregion. The two reservoirs that supply the City of Fayette are north of the river. Assuming average demands from 2011, average free water surface evaporation, and dry year inflow based on the lowest streamflow year between 1980 and 2016, the six reservoirs individually have enough storage to meet demands for between 6 and 51 months. Fayette Lake would not empty under those conditions. With no net inflow, the reservoirs individually have between 4 and 44 months of storage and an average of 24 months of storage. The reservoirs provide much needed storage, given the potential for low streamflow during dry and drought years. None of the reservoirs have large drainage areas, and are therefore slow to refill. Potential water supply stress would be expected during a prolonged drought if other sources were not available as a supplement.

## Groundwater Budget

**Figure 4-27** depicts the groundwater budget for the Lower Missouri subregion using a generalized representation of the major aquifers. Estimated potable groundwater storage and projected 2060 groundwater demands are shown by major aquifer. Just over 62 trillion gallons of potable groundwater is stored in the Ozark and Cambrian-Ordovician aquifers; however, withdrawals are only half what they are in the Missouri River Alluvial Aquifer, primarily due to the high yields of and ease of access to the shallow, alluvial aquifers. Projected 2060 groundwater withdrawals of 167 MGD are 29 percent of average annual recharge from precipitation. The Missouri River is likely an even greater source of recharge to the Missouri River Alluvial Aquifer than precipitation.

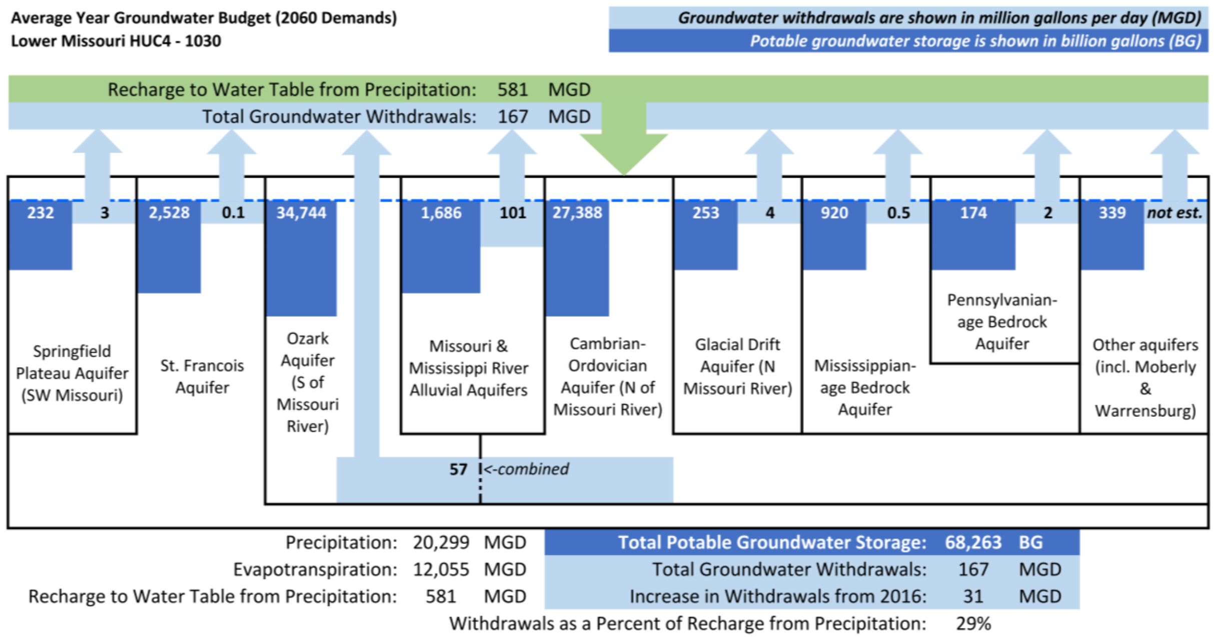


**Figure 4-27. Lower Missouri Groundwater Budget**

## 4.4.8 Upper White Subregion

The Upper White subregion (HUC 1101) is in southern Missouri and covers 10,606 square miles within the state. An additional 2,171 square miles of the subregion which contributes surface water flow to Missouri is within northern Arkansas (USGS and NRCS 2018). The subregion's major rivers include the Current, Eleven Point and Black rivers, which flow south to the White River, and the White River, which flows to the southeast into Arkansas and eventually drains to the Mississippi River.

The subregion lies mostly within the Salem Plateau groundwater province but includes portions of the Springfield Plateau province in the west and the Southeastern Lowlands to the east.

### Water Use by Sector and Source

Agriculture is the largest water use sector in the subregion, accounting for 86 percent of groundwater withdrawals as shown in **Figure 4-28**. Withdrawals for agriculture primarily occur in the Mississippi River Alluvial Aquifer, which extends only slightly into the subregion's southeastern extent. As a result, the subregion relies more on groundwater resources (359.7 MGD or 71 percent of total withdrawals) than surface water (147.1 MGD or 29 percent of total withdrawals). Outside of agriculture, the largest water use sector is aquaculture and wetlands, which relies primarily on surface water and is largely nonconsumptive. The major water systems sector uses the next highest amount of water from both sources. Groundwater withdrawals for all sectors, except agriculture, occur mostly in the Ozark Aquifer, which holds large quantities of potable groundwater.

Total surface water withdrawals are projected to increase by 13 percent to 166 MGD in 2060; nonthermoelectric surface water withdrawals are project to increase by 12 percent to 145.1 MGD. Total groundwater withdrawals are projected to increase by 21 percent to 435 MGD.

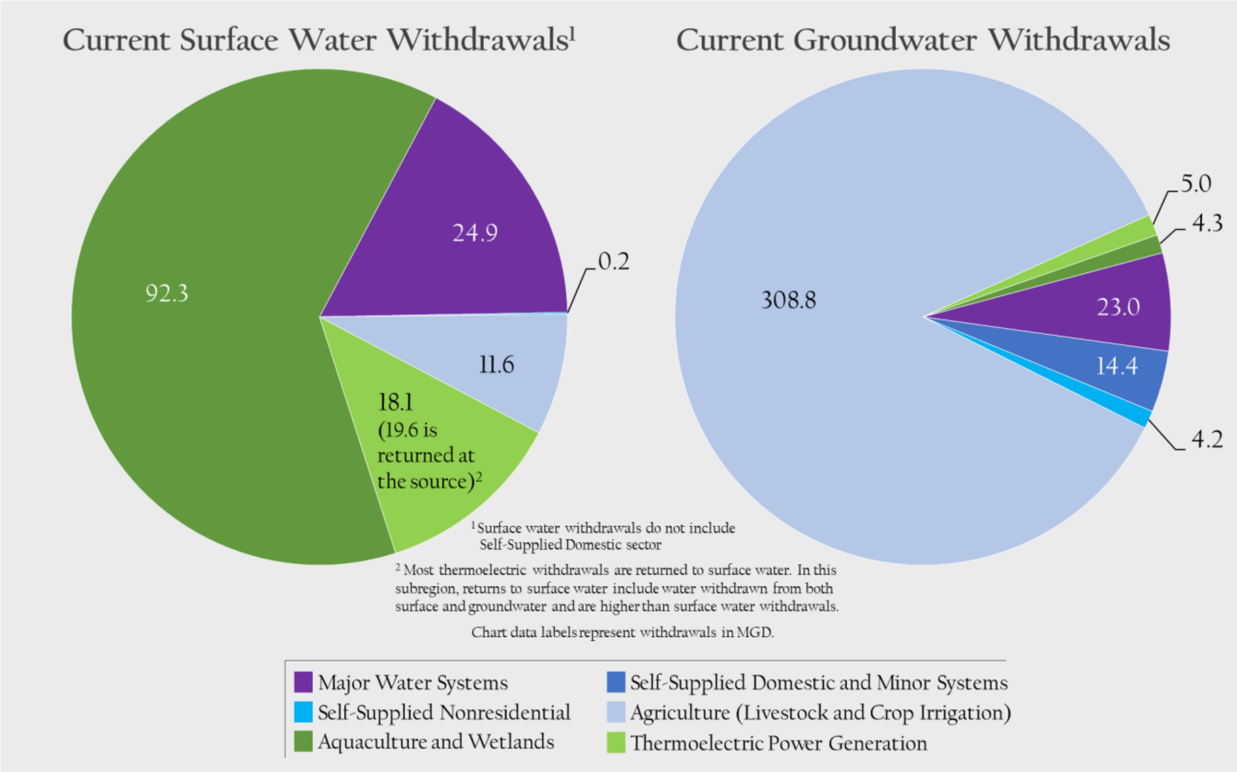


**Figure 4-28. Upper White Surface and Groundwater Withdrawals by Sector**

Additionally, there are three hydropower facilities in this subregion, including the hydropower dam at Table Rock Lake, the run-of-river facility at Ozark Beach, and the pumped-storage facility at Taum Sauk, as described in **Section 3.10.2**. The operation of and water demand for these facilities is complex, and dependent on multiple factors including reservoir pool operation, downstream flood condition, and, in the case of the USACE-operated Table Rock Dam, the requirements of the reservoir's other authorized uses. This results in a complex series of operational rules that are not summarized in this report. These facility's importance as a source of renewable energy is anticipated to continue to increase, and planning to provide for their water demands will therefore be an ongoing priority.

### Monthly Streamflow Analysis

**Figure 4-29** compares current surface water withdrawals to median dry year streamflow and the drought of record year streamflow for the Missouri portion of the subregion. Dry year streamflow is based on median monthly flows for the driest year between 1980 and 2016. Drought of record year streamflow is based on the historically dry years of 1954 or 1956, whichever year had the lowest gaged flow. The summer-month withdrawals for the major water users and agriculture sectors are adjusted to reflect increases that would be expected during a dry year. The comparisons show that withdrawals remain an order of magnitude below median dry year flows in any month. The relatively consistent streamflow, even during dry periods, is in part due to the thousands of springs and outlet points in the Salem Plateau portion of the subregion. At these springs, groundwater moving through karst systems discharges to the surface, providing relatively consistent base flow to streams.

While the results of the monthly streamflow analysis at the subregion level do not indicate the potential for stress or a surface water gap under current or future conditions, the potential for shortages is a concern in growing areas such as Springfield, which sits on the drainage divide between the Upper White and Gasconade-Osage subregions.

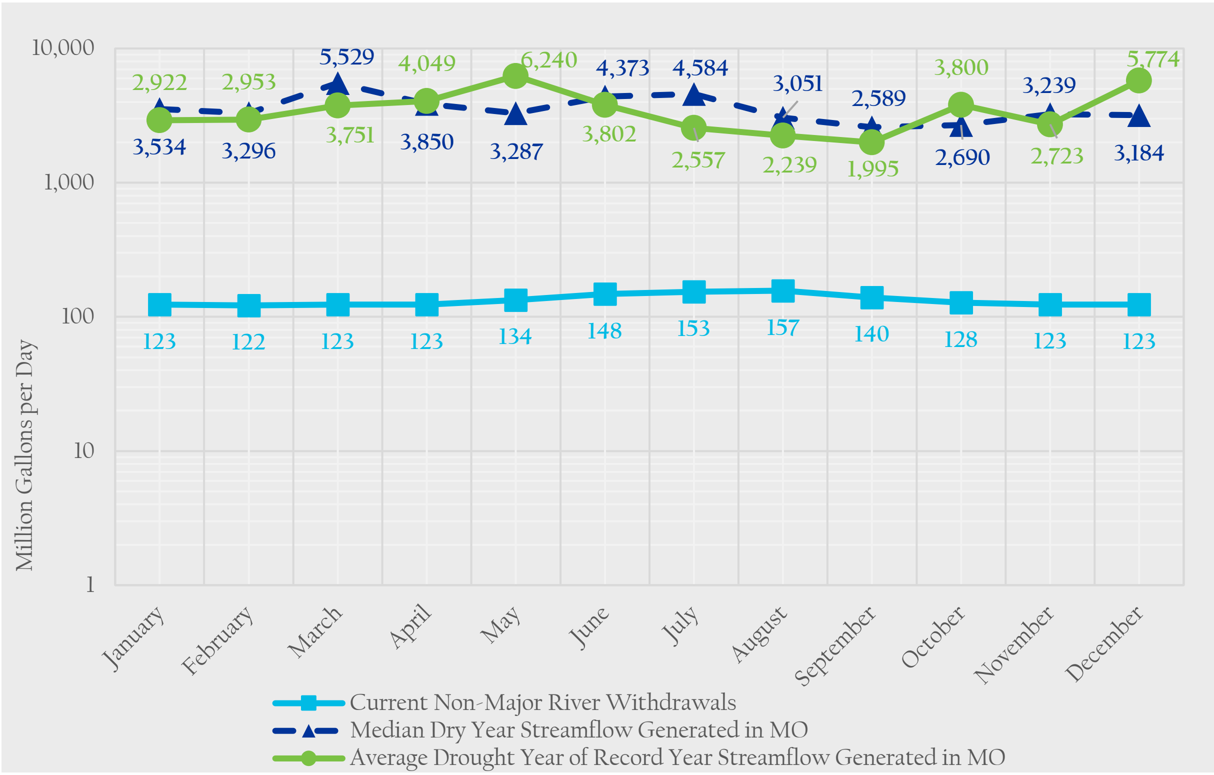


**Figure 4-29. Upper White Comparison of Streamflow and Dry Year Withdrawals**

*Note: This compares in-state generated streamflow to total surface water withdrawals. Streamflow that originates in Arkansas is not included. Of the 12,777 square miles of the subregion which contributes surface water to the state, 83 percent is in Missouri, while 17 is in Arkansas.*

## Reservoir Analysis

No reservoirs are used for public water supply in Missouri, except Lake Taneycomo. which serves as the primary water source for the City of Branson. Lake Taneycomo covers 2,119 acres from below Table Rock Dam to Ozark Beach Dam, which empties into Bull Shoals Lake (MoDNR 2010). Storage information was not available for Lake Taneycomo. Table Rock Lake, which has a flood control pool of 760,000 acre-feet, is not currently used for public water supply. Bull Shoals Lake and Norfork Lake are primarily located in Arkansas but have arms that extend into Missouri. Both are used for public water supply in Arkansas (USACE 2016).

## Groundwater Budget

**Figure 4-30** depicts the groundwater budget for the Upper White subregion using a generalized representation of the major aquifers. Estimated potable groundwater storage and projected 2060 groundwater demands are shown by major aquifer. Within the subregion, the Ozark and St. Francois aquifers are estimated to store a combined 105 trillion gallons of potable groundwater. Except in the northeastern portion of the subregion, access to the St. Francois Aquifer is limited due to its depth. Projected 2060 groundwater withdrawals of 435 MGD are 15 percent of average annual recharge from precipitation. An unknown but likely large amount of recharge from the Ozark Aquifer enters the Mississippi River Alluvial Aquifer in the southeast part of the subregion, helping maintain relatively constant water levels, even though groundwater withdrawals exceed recharge from precipitation in this part of the subregion.

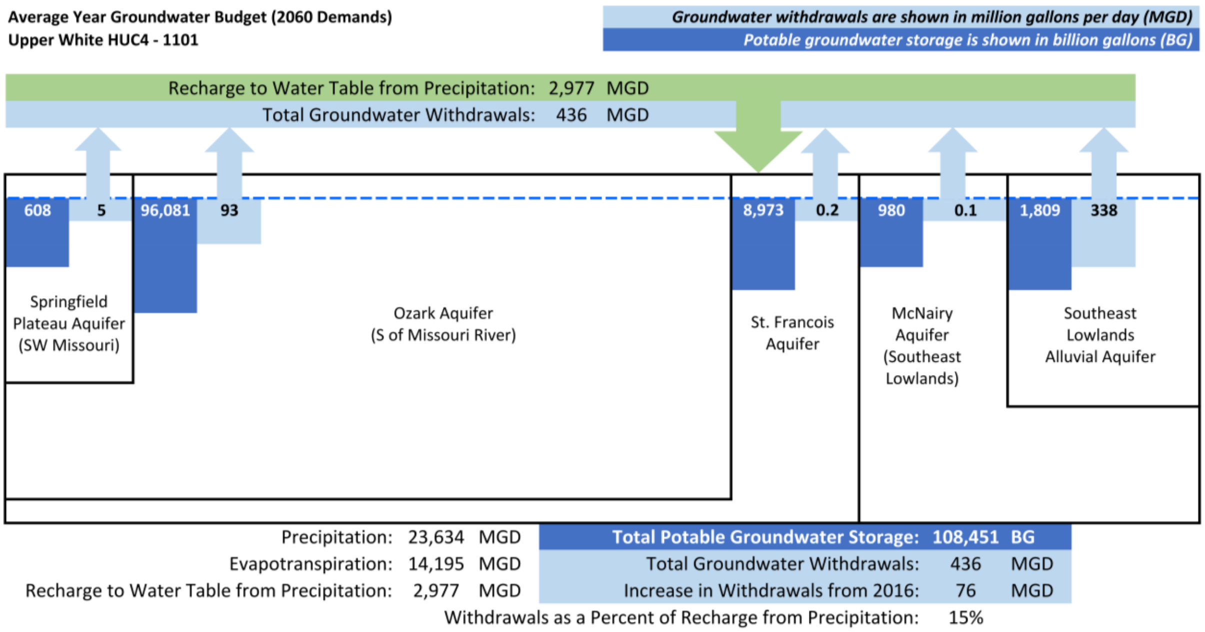


**Figure 4-30. Upper White Groundwater Budget**

### 4.4.9 Neosho-Verdigris Subregion

The Neosho-Verdigris subregion (HUC 1107) is in the southwestern corner of Missouri and covers 2,908 square miles within the state of Missouri (USGS and NRCS 2018). Major rivers within the subregion include the Elk River and the Spring River, both of which flow generally west to the Neosho River.

The subregion lies entirely within the Springfield Plateau groundwater province.

### Water Use by Sector and Source

This subregion relies more on groundwater resources (54.2 MGD or 67 percent of total withdrawals) than surface water (26.4 MGD or 33 percent of total withdrawals). Major water systems are the largest water users in this subregion, accounting for just under 33 MGD of surface water and groundwater combined as shown in **Figure 4-31**. Other than major water systems, the largest water use sector is agriculture, which relies primarily on groundwater. Groundwater withdrawals for all sectors occur mostly in the Ozark and Springfield Plateau aquifers. Surface water withdrawals are projected to increase by 25 percent to over 33 MGD in 2060. Groundwater withdrawals are projected to increase by 26 percent to 68 MGD.

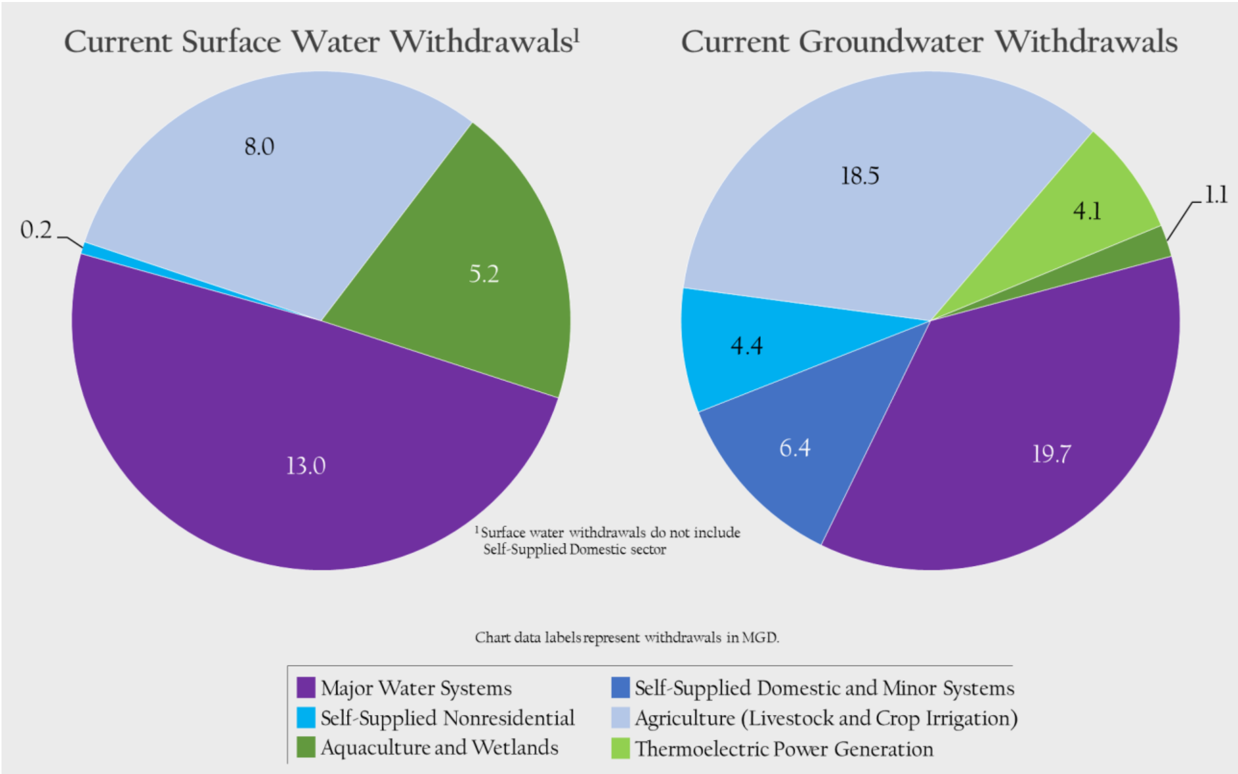


**Figure 4-31. Neosho-Verdigris Surface and Groundwater Withdrawals by Sector**

## Monthly Streamflow Analysis

**Figure 4-32** compares current surface water withdrawals to median dry year streamflow and the drought of record year streamflow for the subregion. Dry year streamflow is based on median monthly flows for the driest year between 1980 and 2016. Drought of record year streamflow is based on the historically dry years of 1954 or 1956, whichever year had the lowest gaged flow. The summer-month withdrawals for the major water users and agriculture sectors are adjusted to reflect increases that would be expected during a dry year. The comparisons show that withdrawals approach but do not exceed median dry year streamflow in August and drought of record year streamflow in August and September, indicating potential stress for that period.

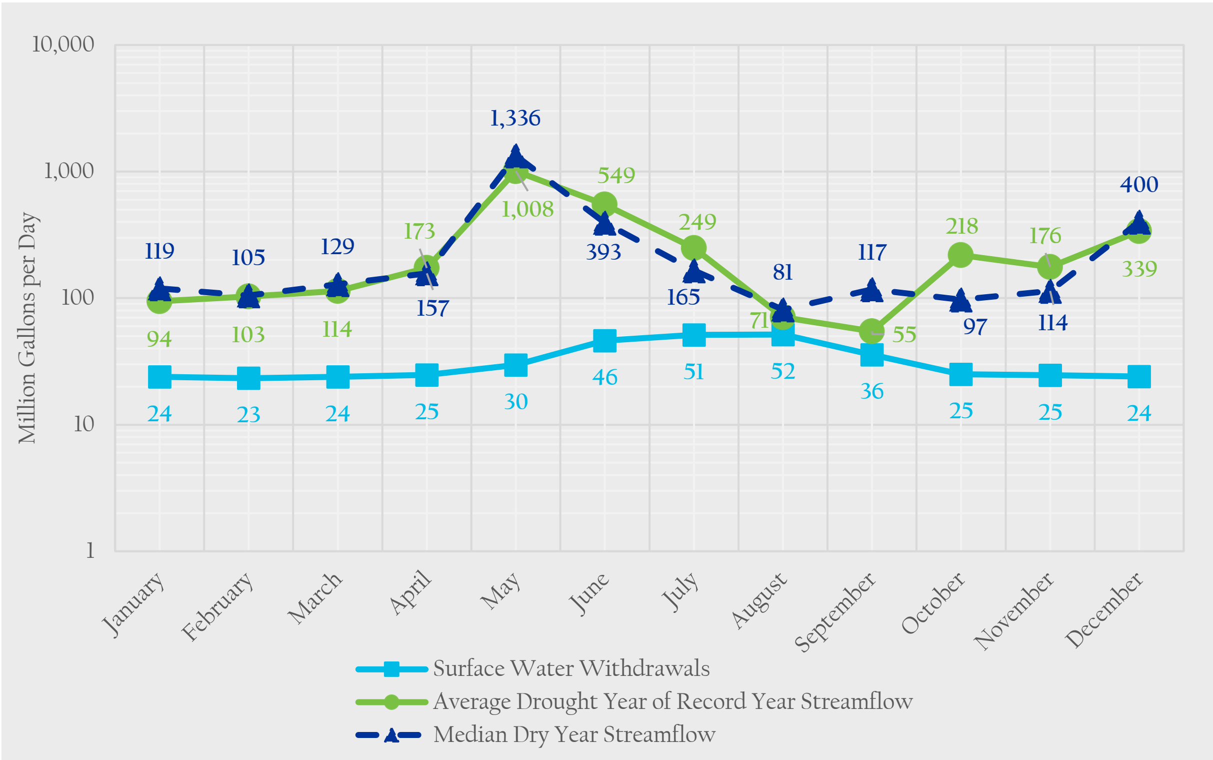


**Figure 4-32. Neosho-Verdigris Comparison of Streamflow and Dry Year Withdrawals**

*Note: This compares streamflow to total surface water withdrawals. In this subregion, all streamflow is generated in Missouri and eventually flows out of the state.*

## Reservoir Analysis

The Neosho-Verdigris subregion includes one water supply reservoir with a total storage of 1,582 acre-feet or 515 mgal. Assuming average demands from 2011, average free water surface evaporation, and dry year inflow based on the lowest streamflow year between 1980 and 2016, the reservoir, which provides water to the City of Lamar, has enough storage to meet 45 months of demands. The reservoir can meet 18 months of average demands with no net inflow. The reservoir itself can be supplemented by a well drawing from the Ozark Aquifer. The supplemental flow was not factored into the storage/demand calculations.

## Groundwater Budget

**Figure 4-33** depicts the groundwater budget for the Neosho-Verdigris subregion using a generalized representation of the major aquifers. Estimated potable groundwater storage and projected 2060 groundwater demands are shown by major aquifer. Within the subregion, the Ozark and Springfield Plateau aquifers store an estimated 27 trillion gallons and 2.7 trillion gallons of potable groundwater, respectively. Access to the St. Francois Aquifer, which holds another 887 billion gallons, is limited because of its depth. Projected 2060 groundwater withdrawals of 68 MGD are 10 percent of average annual recharge from precipitation.

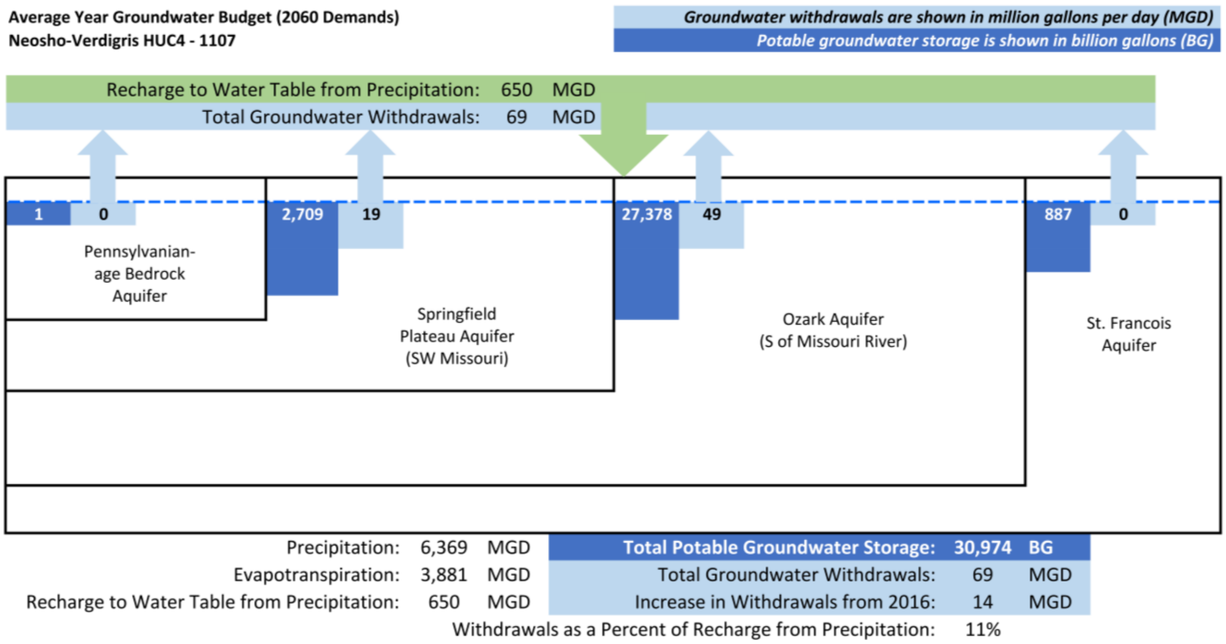


**Figure 4-33. Neosho-Verdigris Groundwater Budget**

Although the groundwater budget suggests that total withdrawals are less than average annual recharge to the water table, a gradual, long-term lowering of water levels has occurred in localized portions the Ozark Aquifer in southwestern Missouri from McDonald County to Jasper County, as originally documented by Miller and Vandike (1997). **Figure 4-34** depicts the steady drop in water levels from 1962 through 2018 at the 850-foot-deep observation well in Noel. The localized decline of water levels, which has continued since reported in the previous state water resources plan, is attributed to municipal withdrawals in Miami, Oklahoma; self-supplied residential and minor system withdrawals in northern Arkansas; and agriculture (poultry) withdrawals in McDonald County (Miller and Vandike 1997). The declining water levels indicate that withdrawals from the Ozark Aquifer in this area have exceeded long-term recharge to the aquifer and continue to reduce the amount in storage. Similar localized declines, although not as severe, have been observed in observation wells in other parts of the subregion, including wells in Jasper, McDonald, and Newton counties. Some declines, such as those at the Springfield Plateau Aquifer well in Newton County are not likely due to overuse of the aquifer, but rather to the construction of nearby production wells. In this case, the production wells penetrate both the Springfield Plateau and Ozark aquifers, causing the draining of water from the overlying Springfield Plateau down into the Ozark. This has led to localized water level declines in the Springfield Plateau Aquifer.

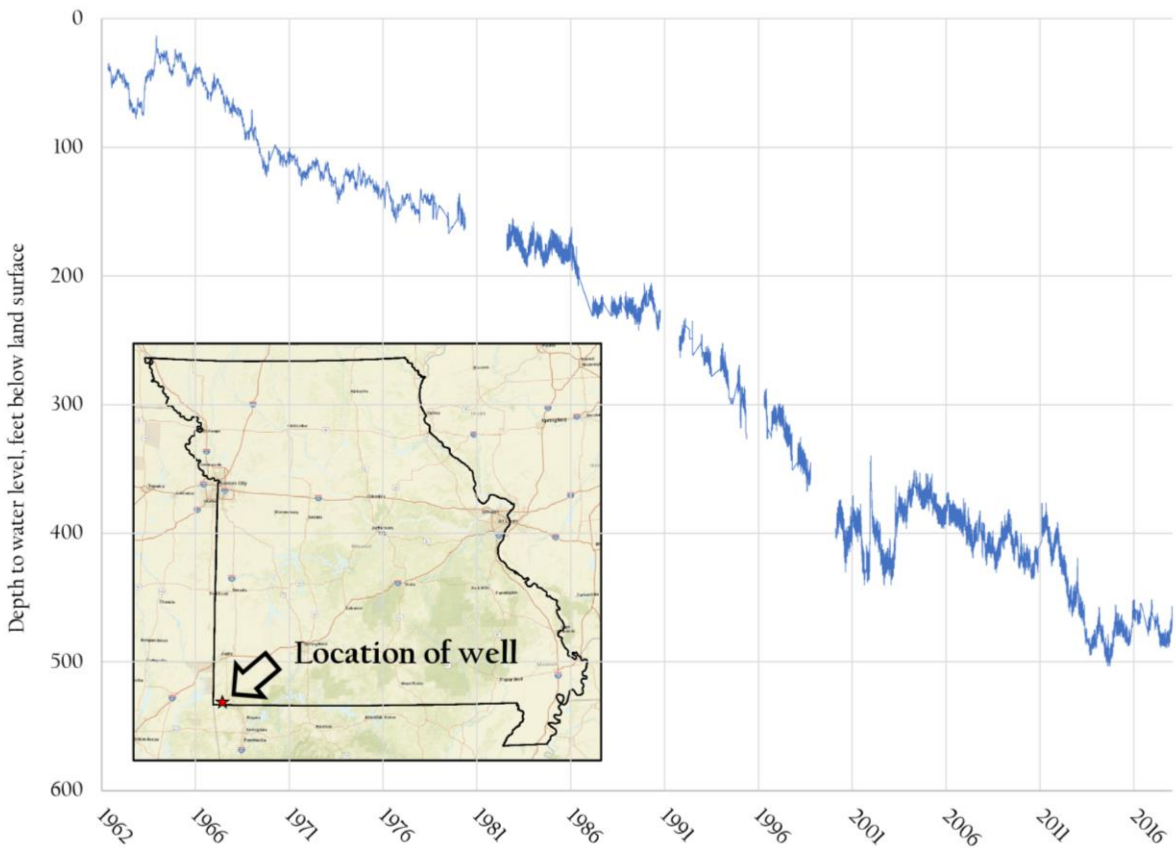


**Figure 4-34. Depth to Water from 1962–2018 in USGS Observation Well at Noel (363236094290301)**

## 4.5 Missouri River

The Missouri River—the longest river in the United States—is a vital natural resource in the State of Missouri. It drains 529,350 square miles of ten states, in addition to 9,700 square miles of Canada (USACE 2018). Upstream of Missouri, the USACE's Missouri River Basin Water Management Division in the Northwestern Division regulates six Missouri River mainstem reservoirs according to the *Missouri River Mainstem Reservoir System Master Water Control Manual* (USACE. 2018a). With about 72.4 million acre-feet of storage capacity, the Mainstem Reservoir System (the System) is the largest in the United States and provides nearly all of the downstream flow support on the Missouri River (USACE 2018).

Within the state of Missouri, 36,537 square miles—about 52 percent of the state—drains to the Missouri River. Although only 6.9 percent of the total drainage area of the entire Missouri River basin is in the state, runoff in Missouri makes up a significant portion of the river's flow (Vandike 1995). Flow in the Missouri River roughly doubles from where it enters the state of Missouri just south of Nebraska City, NE to where it empties into the Mississippi River at St. Louis. Over the past decade (2009 to 2018), flow in the Missouri River at Nebraska City averaged approximately 50,000 cfs, compared to just over 100,000 cfs at St. Louis. While some of this flow between Nebraska City and St. Louis flow originates as runoff in Nebraska, Kansas and Iowa, most originates in Missouri. This difference in flow is largely driven by the fact that Missouri receives an average of 40 inches of precipitation each year, compared to approximately 15 inches across much of the Upper Missouri River Basin (Vandike 1995, Missouri Climate Center 2019).

### 4.5.1 Authorized Purposes

The six mainstem reservoirs on the Missouri River are managed as a system to fulfill the authorized purposes listed below, with recognition that other incidental benefits are also achieved. Some of the recognized benefits and challenges specific to Missouri are discussed below.

- Flood Control
    - There are approximately 16.3 million acre-feet of System storage reserved for flood control. Between 1938 and 2017, the management of the System is estimated to have prevented $62.5 billion (indexed to 2017 dollars) in flood damages. (USACE 2018).
    - The regulation of the System has greatly reduced flood flows on the upper reaches of the Missouri River – from Fort Peck to the Platte-Missouri River confluence. While this also provides benefit to the state of Missouri, the large drainage area below Gavins Point Dam, the most downstream system project, is largely unregulated. As a result, flooding conditions along the Missouri River affecting the state of Missouri are often impacted by regional precipitation events that can overwhelm the more controlled releases from Gavins Point Dam.
- Navigation
    - Since 1967, seasonal (8-month) flow support for navigation has been provided on the 735-mile portion of the Missouri River from the confluence of the Big Sioux and Missouri rivers to the Missouri River's mouth near St. Louis. The System is operated to meet navigation flow targets at Sioux City, Iowa; Omaha, Nebraska; Nebraska City, Nebraska; and Kansas City, Missouri.
    - Movement of commerce on the Missouri River is very important to Missouri's economy. The Missouri River provides the state with a vital mode of transportation and a direct conduit to the Mississippi River and international markets. Between 2015 and 2017, barges moved an estimated 4.66 million tons of goods and materials each year (USACE 2018). It is anticipated that as the State's economy grows, low-cost waterborne commerce (navigation) will play a larger role in moving bulk commodities and meeting the states' transportation needs. Relatively little capital investment is needed for the navigation industry to grow, compared to the state's road and rail system, which requires significant capital investment to expand its capacity.
- Water Supply
    - The Missouri River is a very important water supply for the state of Missouri. Approximately fifty percent of the population receives their drinking water directly from the Missouri River or from the associated alluvium. Six of Missouri's municipal water suppliers withdraw surface water directly from the Missouri River to provide drinking water to Kansas City, St. Louis City, Boonville, Lexington, St. Charles County, and Jefferson City. Several other communities maintain an emergency intake on Missouri River. Additionally, there are 32 community well systems that withdraw water from the alluvium adjacent to the river. Twenty-five of these systems provide drinking water to municipalities. Three of these systems are used for emergency water supply only.
- Irrigation
    - Irrigation is an important use of the Missouri River and its alluvium. Within Missouri, direct withdrawals from the Missouri River for agriculture are rare, although irrigation withdrawals from the hydraulically connected alluvium are an important source of water for irrigating land adjacent to the river.

- Power Generation
  - Power is generated by hydroelectric and thermoelectric facilities located on or adjacent to the Missouri River. While there are no hydroelectric power stations on the Missouri River within the state of Missouri, numerous facilities are located on upstream portions of the Missouri River and its tributaries. Seven thermoelectric facilities withdraw water from the Missouri River in the state of Missouri. Low reservoir levels, river stages and flows can impact the operation of downstream powerplants (USACE 2018).
- Water Quality
  - In general, upstream System releases are enough to meet downstream quality requirements for public water supply purposes, including those in the state of Missouri. Water quality concerns on the Missouri River include nutrients (nitrogen and phosphorus), mercury, pesticides, pharmaceuticals and bacteria. The 2018 303(d) lists the Missouri River as impaired for high *Escherichia coli* counts between Atchison and Chariton counties in the western and central part of the state, and in St. Louis and St. Charles counties in the east.
- Fish and Wildlife
  - The Missouri River provides fish and wildlife habitat as well as economic and conservation opportunities. The diversity of wildlife present is a direct reflection of the diverse habitat in the Missouri River valley. There are many species of mammals, birds, reptiles and amphibians that depend on the habitat created from the Missouri River and its associated floodplain. In addition, there are endangered, threatened and species of special concern, including several species of birds and bats and the pallid sturgeon, that are protected within the Missouri River valley (USACE 2018b).
- Recreation
  - There are many recreational opportunities both on the Missouri River and on public land in the adjacent floodplain. River recreational activities, such as boating, canoeing, kayaking, camping, and fishing, provide economic opportunities to businesses along the river. There are large amounts of federal public land within the floodplain (e.g., Big Muddy Wildlife Refuge, and USACE Missouri River Mitigation Project lands) whose function is to restore wildlife habitat which provide opportunities for wildlife observation, hiking, fishing, environmental education, and photography. Katy Trail State Park, managed by MoDNR runs adjacent to a section of the Missouri River from approximately Boonville to St. Charles (river miles 197-0) and provides hiking, biking and wildlife watching opportunities. MDC manages over 30 conservation areas adjacent to the Missouri River from the mouth to Missouri's northwestern border.

### 4.5.2 Hydrology of the Missouri River

Upstream of Missouri, the majority of runoff into the System is from three primary sources: plains snowmelt, mountain snowmelt, and rainfall. Plains snowmelt occurs during March-April; and mountain snowmelt occurs during May-July. During the March-July period, runoff from snowmelt and rainfall contribute about 75 percent of the total annual runoff into the System's reservoirs.

Downstream of the System, flow in the Missouri River in the state of Missouri is driven more by rainfall that occurs in the lower portion of the basin. Peak flows in the Missouri River at Hermann, Missouri generally occur in March through May as a result of runoff from rainfall. During this period, flow in the river at Hermann averages 117,000 cfs. During the March-May period average Missouri River flow at Sioux City, IA is only 31,300 cfs. During this 3-month period, flow from the Upper Missouri River Basin, which is largely driven by plains snowmelt and rainfall, only accounts for about 25 percent of Missouri River flow at Hermann, MO. During the June-August period, flow from the Upper Missouri River Basin, which is largely driven by mountain snowmelt and rainfall, contributes slightly more, accounting for about 36 percent of Missouri River flow at Hermann, MO. From 1968 through 2017, the average annual Missouri River flow at Kansas City was approximately 58,800 cfs. The lowest recorded flow at this location occurred in 2006, during which time the annual flow was 34,000 cfs, or 42 percent lower than the 50-year average.

The Missouri River joins the Mississippi River just upstream of St. Louis. On an annual average basis, the Missouri River supplies 42 percent[8] of the flow to the Mississippi River; however, at certain times of the year during low flow periods, the Missouri River supplies as much as 72 percent. As such a dominant tributary, the Missouri River flow support to the Mississippi River is critical to maintaining the functionality of the nation's inland waterway system.

### 4.5.3 Ongoing Challenges

The movement of goods on the Missouri River is an important contributor to the state of Missouri's economy. The Missouri River is designed to perform as a self-scouring channel using bank reinforcements and rock structures that direct the river's current to a central channel, where the velocity of the water keeps the channel at the depth necessary to support navigation. This system is designed to function at a specific range of flows that are maintained by releases from the upstream reservoirs. Variations from this flow (from natural variation and due to policy) can significantly compromise the function of this navigation system and have substantial impacts on the navigation industry and other uses of the river.

In addition to supporting commercial navigation, the Missouri River supplies substantial flow to the Mississippi River downstream of the rivers' confluence north of St. Louis. In an average year, the Missouri River supplies 42 percent of flows in this reach, making it vulnerable to flow reductions in the Missouri River Basin. In 2006, low water levels in the Missouri and Mississippi rivers forced an early end to seasonal barge traffic (NOAA 2007). Low flows in 2006 were a result of a multiyear drought in the Missouri River Basin upstream of the state. Droughts in this and subsequent years have resulted in low flows on the Missouri River that have threatened to reduce the Mississippi River channel below the minimum depth required for navigation. Because supporting Mississippi River navigation is not an authorized use for the Missouri River, no additional releases from the System were made to address this issue.

Most the water intakes on the lower Missouri River that support drinking water and other critical industrial uses (including the seven thermoelectric energy facilities) are designed to function at the flows provided for proper operation of the navigation channel. Reductions in flows (or excessive flows) can degrade the performance of this water supply system by impacting Missouri River intake infrastructure and water quality.

Ongoing trends in the Missouri River basin and the Missouri River present challenges to the river's use as a source of water supply. In addition to the previously mentioned water quality problems associated with low flows, flooding is also a challenge. Upstream flooding degrades the quality of water entering the Missouri River, making treatment more difficult and expensive. During the spring flooding of 2019, Kansas City reported difficulty treating water from the Missouri River due to excessive suspended solids. During the late winter and spring, ice jams present a challenge because ice jams can reduce flows available at water supply intakes.

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[8] Based on annual flow records from 1958 through 2018 from USGS streamflow gages on the Missouri River at Hermann (06934500) and the Mississippi River at St. Louis (07010000).

Bed degradation, which is the lowering of the river's channel over time, is an emerging issue for the Missouri River, especially for a stretch of the river near Kansas City. From St. Joseph to Waverly, the river bed elevation has fallen an average of 10.1 feet between 1987 and 2014 (USACE 2017b). This has resulted in a lowering of water surface elevations over time, which threatens to expose water intakes making them more vulnerable to reduced winter flows and ice jams. It is anticipated that continued degradation could lower the riverbed by an additional 5 feet over the next 50 years. This issue is being studied by USACE for longer term impacts to the navigation and water supply system and possible changes to the performance of the channel maintaining structures used to guide the Missouri River's flow.

## 4.6 Water Availability Results for Select Subbasins

The water availability assessment at the subregion-level identified several potential areas of water supply stress and potential shortages during drought conditions. Two specific areas, the Chariton-Grand subregion and a portion of the Gasconade-Osage subregion, were assessed in more detail. The subbasins that were assessed in these subregions are shown in **Figure 4-35**.

### 4.6.1 Subbasins in the Chariton-Grand Subregion

Because of the limited potable groundwater availability and potential for surface water gaps under drought conditions, all six subbasins in the Chariton-Grand subregion were further assessed. The same analyses conducted at the subregion level were performed at the subbasin level. The results of the analyses are described in the subbasin summaries in **Appendix F**. The major findings of the analyses are summarized below, by subbasin.

#### Upper Grand

The Upper Grand is the westernmost subbasin in the subregion and covers 2,811 square miles within Missouri. An additional 513 square miles in Iowa drain to Missouri. An average annual streamflow of 234 MGD from Iowa combines with 1,284 MGD of streamflow generated in Missouri. Flow at the outlet of the basin in the Grand River averages 2,833 MGD and includes contributions from the Thompson River, just upstream of the outlet of the subbasin. Within the Missouri portion, 20 reservoirs are used for water supply and provide total storage of 21,231 acre-feet (6,818 mgal). All but three of the reservoirs are relatively small, with total storage below 1,000 acre-feet. Lake Viking, with 12,000 acre-feet of total storage, accounts for more than half of the storage in the subbasin.

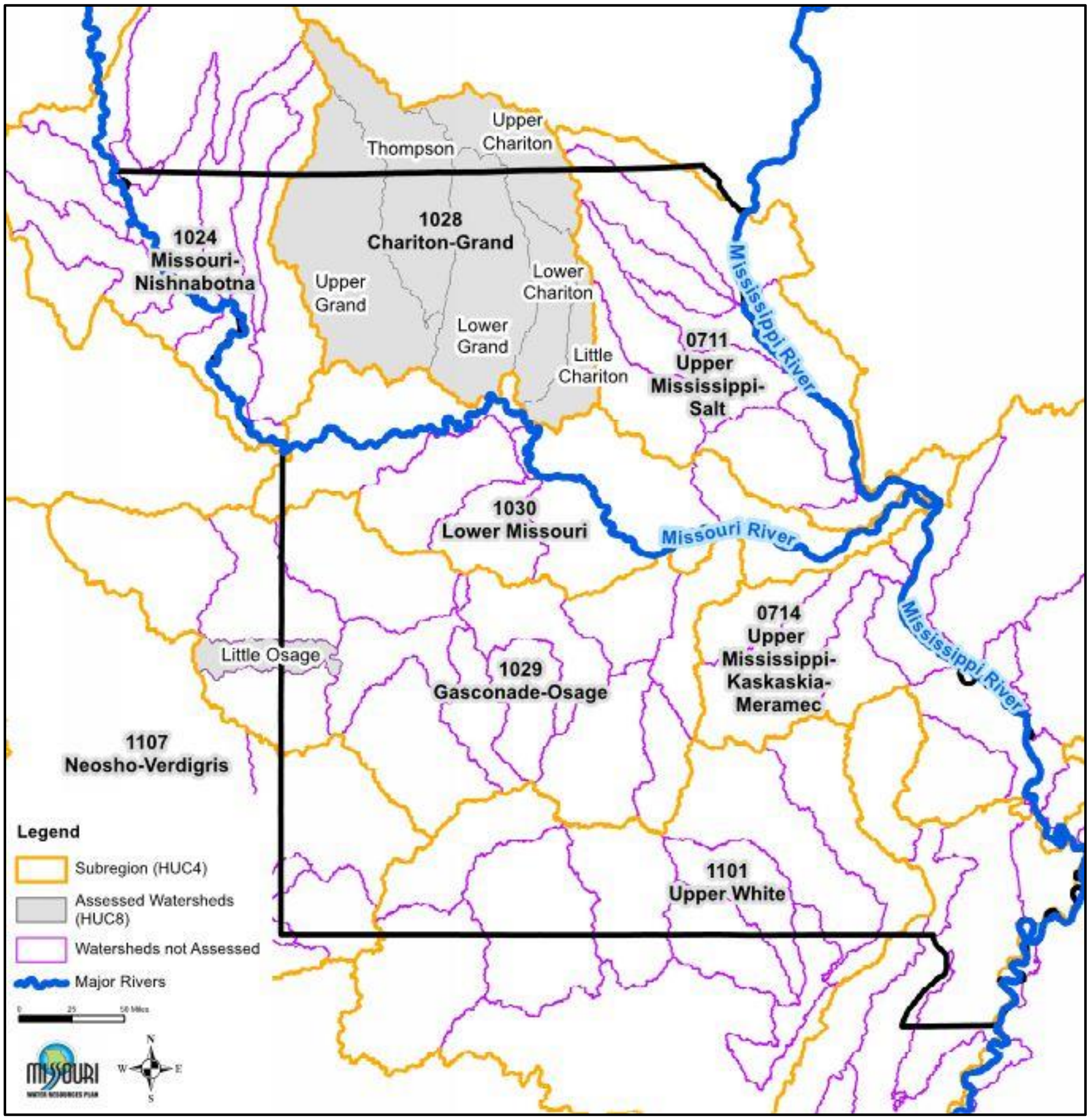


Figure 4-35. Subbasins of the Chariton-Grand and Gasconade-Osage Subregions Assessed in More Detail

The comparison of monthly dry year and drought of record year streamflow to withdrawals indicates potential for supply gaps in several months. The flow-duration curve indicates that at a maximum monthly projected 2060 withdrawal of 17.6 MGD, a supply shortage would occur 4 percent of the time. The subbasin's 20 reservoirs play an important role in mitigating these potential, short-term supply gaps.

Groundwater use is low and totals only 4.3 MGD. Most of the withdrawals are from glacial and alluvial deposits and are used to provide water to major water supply systems.

### Thompson

The Thompson is directly east of the Upper Grand subbasin and covers 1,105 square miles within Missouri. A nearly equal area of the subbasin in Iowa drains to Missouri. An average annual streamflow of 656 MGD from Iowa combines with 653 MGD generated in Missouri. Flow at the outlet of the basin in the Thompson River averages 1,317 MGD. The subbasin includes one reservoir used for water supply (Rock House Lake serving Ridgeway) with a total storage of 461 acre-feet (150 mgal) (Edwards et al. 2011).

The comparison of monthly dry year and drought of record year streamflow to withdrawals indicates potential for a supply gap during 1 month, when considering only streamflow generated in Missouri. Accounting for streamflow coming from Iowa, no supply gaps are evident under current or projected 2060 withdrawals.

Groundwater use is very low in the subbasin and totals only 0.4 MGD.

### Lower Grand

The Lower Grand is directly east of the Thompson subbasin and covers 2,234 square miles in Missouri and 125 square miles in Iowa. An average annual streamflow of 65 MGD from Iowa combines with 1,169 MGD generated in Missouri. Flow from the Upper Grand and Thompson subbasins enters the Lower Grand via the Grand River, and the combined average flow of 4,061 MGD empties into the Missouri River. The subbasin includes 5 reservoirs used for water supply with a total storage of 7,546 acre-feet (2,459 mgal). The 5 reservoirs have between 13 and 85 months of total storage, assuming average water demand, 30-year minimum inflow, and no outflow.

The comparison of monthly drought of record year streamflow to withdrawals indicates potential for supply gaps during 2 months. Dry year streamflow is higher than current and projected withdrawals in all months, but potential stress is evident in the late summer months. The flow-duration curve indicates that at a maximum monthly projected 2060 withdrawal of 19.2 MGD, a supply shortage would occur about 11 percent of the time.

Groundwater use is low and totals just under 6 MGD. More than half of it is pumped from alluvial aquifers and is used to establish and maintain seasonal wetlands, with the remainder of groundwater supply primarily pumped from Pennsylvanian and glacial drift aquifers.

### Upper Chariton

The Upper Chariton is in the northeastern corner of the subregion and covers 438 square miles in Missouri. The Iowa portion covers 913 square miles and drains into Missouri primarily via Shoal Creek and the Chariton River. An average annual streamflow of 439 MGD from Iowa combines with 211 MGD generated in Missouri. At the outlet, streamflow averages 649 MGD. The Missouri portion of the subbasin includes three reservoirs used for water supply with a total storage of 24,700 acre-feet (8,048 mgal). Lake Thunderhead is the largest, with a total storage of 15,400 acre-feet (5,018 mgal). It, along with the much smaller Lake Mahoney (620 acre-feet), serves the City of Unionville. Hazel Creek Lake serving Kirksville and Adair County, has a total storage of 8,680 acre-feet (2,828 mgal). The three reservoirs have between 16 and 63 months of total storage, assuming average water demand, 30-year minimum inflow, and no outflow.

The comparison of monthly dry year and drought of record year streamflow to current withdrawals indicates the potential for supply gaps in several months, when considering only streamflow generated in Missouri. Accounting for streamflow entering from Iowa, no gaps occur. The flow-duration curve indicates that at a maximum monthly projected 2060 withdrawal of 4.6 MGD, a supply shortage would occur about 3 percent of the time when only Missouri-generated streamflow is considered.

There is no appreciable use of groundwater in the subbasin.

### Lower Chariton

The Lower Chariton is south of the Upper Chariton and covers 438 square miles in Missouri. An average annual streamflow 625 MGD from the Upper Chariton combines with 490 MGD generated in the subbasin. At the outlet, streamflow in the Chariton River averages 1,137 MGD where it empties into the Missouri River. The subbasin includes three reservoirs used for water supply with a total storage of 13,119 acre-feet (4,275 mgal). Forest Lake, which serves the City of Kirksville, is the largest, with a total storage of 12,500 acre-feet (4,073 mgal). Two much smaller reservoirs, which serve Bucklin and Marceline, have 157 acre-feet (51 mgal) and 462 acre-feet (151 mgal) or total storage respectively. The three reservoirs have between 16 and 36 months of total storage each, assuming average water demand, 30-year minimum inflow, and no outflow. Surface water withdrawals are relatively minor, and are only projected to reach a 2060 maximum of 3.3 MGD during dry year conditions. The comparison of monthly dry year and drought of record year streamflow to current and projected withdrawals shows no sign of stress or potential supply gaps for any month.

Groundwater use is very low and totals under 2 MGD. Most groundwater is pumped from the alluvial aquifer and is used to establish and maintain seasonal wetlands.

### Little Chariton

The Little Chariton is in the southeast corner of the subregion and covers 698 square miles in Missouri. Streamflow generated in the subbasin totals 374 MGD. The subbasin includes two reservoirs used for water supply with a total storage of 29,650 acre-feet (9,662 mgal). Long Branch Lake is the largest, with a total storage of 24,400 acre-feet (7,951 mgal). The reservoirs have 30 and 78 months of total storage each, assuming average water demand, 30-year minimum inflow, and no outflow. Withdrawals for thermoelectric power from Thomas Hill Reservoir (which is not used for water supply) use a total of 763 MGD and are projected to increase to 896 MGD by 2060. Surface water withdrawals for all other sectors are relatively minor, and are only projected to reach a 2060 average annual demand of 5.3 MGD and a monthly maximum demand of 9.5 MGD during dry year conditions. The comparison of monthly dry year and drought of record year streamflow to current and projected withdrawals shows no sign of stress or potential supply gaps for any month, except in September and October, when water use for establishing and maintaining wetlands occurs. Demands would exceed supply for a total of two months during the drought of record year flow conditions under both current and future withdrawals.

Groundwater use is very low and totals under 1 MGD. Most is pumped from alluvial aquifers and is used for major water systems and agriculture.

### 4.6.2 Little Osage Watershed in the Gasconade-Osage Subregion

The Little Osage subbasin covers 217 square miles in Missouri and 364 square miles in Kansas. An average annual streamflow of 147 MGD from Kansas combines with 88 MGD generated in Missouri. At the outlet, streamflow averages 234 MGD on the Little Osage River. The subbasin does not have any reservoirs that are used for water supply. Surface water withdrawals for aquaculture and wetlands average 4.5 MGD annually; however, use is primarily limited to several months in the fall, presumably for wetland establishment and maintenance to support hunting. There are no surface water withdrawals for major public systems.

The comparison of monthly dry year and drought of record year streamflow to current withdrawals indicates the potential for supply gaps in July through October, even when considering streamflow generated in Kansas that enters the subbasin via the Little Osage River. The gaps occur due to the seasonal nature of the agriculture and aquaculture and wetlands sectors, which are largely nonconsumptive uses, and serve to highlight the importance of out-of-state flows to this subbasin. Most water use by these sectors occurs in July through October. The flow-duration curve indicates that at a maximum monthly withdrawal of 28 MGD, a supply shortage would occur about 30 percent of the time when only Missouri-generated streamflow is considered.

The only appreciable use of groundwater in the subbasin is for agriculture. Less than 2 MGD is withdrawn from the Ozark Aquifer.

## 4.7 County-Level Assessment of Groundwater Sustainability

Comparisons of estimated average annual recharge to groundwater withdrawals can help identify areas where groundwater mining is occurring and provide evidence of potential future stress or supply gaps. Groundwater mining is the long-term withdrawal of groundwater that exceeds the recharge rate. Average recharge from precipitation across the state was previously estimated by USGS (Wollock 2003). The recharge estimates were applied at the county-level for comparison to current (2016) and projected 2060 groundwater withdrawals.

Current groundwater withdrawals by county as a percent of average annual recharge are shown in **Figure 4-36**. Withdrawals in the Missouri and Mississippi River Alluvial aquifers are included in the totals. The alluvial aquifers receive recharge from precipitation and from the Missouri and Mississippi rivers via induced recharge. Induced recharge occurs when pumping lowers the groundwater table in aquifers that are hydraulically connected to surface water. Counties where alluvial aquifer withdrawals occur along the Missouri and Mississippi rivers include some whose withdrawals are greater than 25 percent of recharge from precipitation (yellow-, orange-, and red-shaded counties in the figure).

The Bootheel and adjacent counties where withdrawals are greater than 100 percent of recharge from precipitation receive recharge from the Mississippi River as well as other streams and rivers. The alluvial aquifers in these counties also receive flow from the Ozark Aquifer. Long-term observation wells in the Bootheel do not show evidence of declining alluvial aquifer water levels, suggesting that induced recharge from rivers and streams, in addition to flow from the Ozark Aquifer, are more than enough to make up the difference between pumping and recharge from precipitation. Hydrographs depicting groundwater levels in select USGS observation wells are also shown in **Figure 4-36**. The hydrograph for the USGS observation well in Butler County shows seasonal fluctuations but no apparent trend over the period 2002 to 2019. The well is 81 feet deep and is completed in the Southeast Lowlands Alluvial Aquifer. Similarly, only seasonal trends are evident in the USGS observation wells in Dunklin and Scott counties, which are also screened in the Southeast Lowlands Alluvial Aquifer.

Groundwater withdrawals are 10 percent or more of recharge from precipitation in Barton, Dade, Greene, and Jasper counties. While the Ozark Aquifer in this area receives some recharge from precipitation that enters through the overlying Springfield Aquifer and then flows downward through a leaky confining unit, most of the Ozark Aquifer's recharge comes from precipitation to the east where it is exposed at the surface in the Salem Plateau province. In areas where this occurs, the comparison of withdrawals to local recharge from precipitation has limitations. As noted in **Section 4.4.9**, some observation wells in several of these counties show localized, long-term declining water levels in the Ozark Aquifer. The hydrograph for the USGS observation well in Barton County shows a 50-foot decline in water levels over the last 50 years; the decline, however, represents a reduction in artesian head and has not reduced the saturated thickness of the aquifer itself. The well is 981 feet deep and is completed in the Ozark Aquifer. Other observation wells in this area do not show a declining trend or show increasing water levels, such as the USGS observation well near Cassville in Barry County, reflecting the localized nature of these trends.

Annual average recharge estimates for Audrain County are the lowest in the state, at 0.9 in/yr (see **Figure 4-4**). The relatively nonporous soils of the Central Claypan area, which extend across the entirety of the county, limit the amount of water that recharges the aquifer. Groundwater withdrawals are 67 percent of average annual recharge from precipitation. The 18 public supply wells in Audrain County produce from the Cambrian-Ordovician Aquifer, which receives most of its recharge from the south, where it is exposed. Only a small portion is expected to come from recharge directly above. The hydrograph for the MGS observation well in Audrain County near Mexico shows both seasonal fluctuations and a general declining trend of about 10 feet over the period from 2007 to 2019. The well is 610 feet deep and is completed in the Cambrian-Ordovician Aquifer. In eastern Audrain County near Vandalia, the MGS observation well completed in the Cambrian-

Ordovician Aquifer shows smaller seasonal fluctuations and a slightly increasing trend in water level over the period from 2007 to 2017.

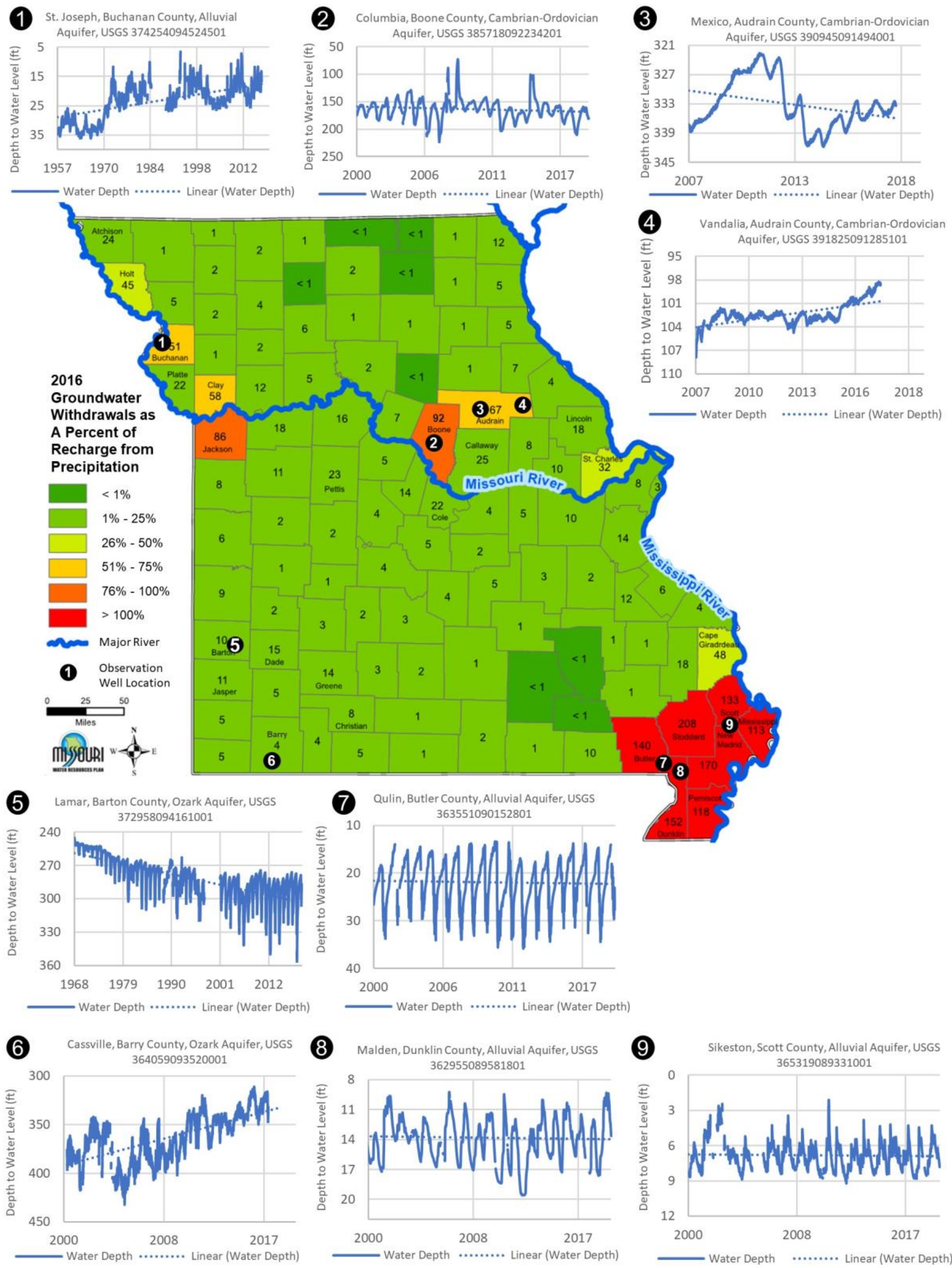


**Figure 4-36. Current Groundwater Withdrawals as Percent of Average Annual Recharge from Precipitation**

*Source: Hydrographs from USGS NWIS (https://waterdata.usgs.gov/nwis)*

In Boone County, southwest of Audrain County, the need for alluvial recharge from the Missouri River is apparent as groundwater withdrawals are 92 percent of average annual recharge from precipitation. The hydrograph for the MGS bedrock observation well in Boone County at Columbia shows seasonal fluctuations of up to 75 feet, but no overall declining trend over the period from 2002 to 2019. The well is 1,353 feet deep and is completed in the Cambrian-Ordovician Aquifer. The City of Columbia uses both deep (bedrock) and shallow (alluvial) wells. The alluvial wells receive the majority of their water via induced recharge from the Missouri River, which is not accounted for in the comparison of withdrawals to recharge. Removing these withdrawals from the equation would cause the percentage of withdrawal to recharge from precipitation to be lower.

In Buchanan County, north of Kansas City on the Missouri River, groundwater withdrawals are 51 percent of average annual recharge from precipitation. In Buchanan County, groundwater withdrawals are primarily from the alluvial aquifer along the Missouri River. The wells receive most their water via induced recharge from the Missouri River – not from recharge due to precipitation. The hydrograph for the MGS alluvial aquifer observation well in Buchanan County shows seasonal fluctuations and no overall trend from the 1970s through 2019. In the late 1950s, groundwater levels were lower by about 15 feet, compared to the mid-1970s through 2019.

Projected 2060 groundwater withdrawals by county as a percent of average annual recharge are shown in **Figure 4-37.** Withdrawals in Audrain, Boone, Callaway, and Cole counties in central Missouri are projected to increase. In Boone County, projected withdrawals will exceed 100 percent of annual average recharge from precipitation; however, as noted previously, much of the water withdrawn in this area is from the Missouri River Alluvial Aquifer, which receives a large portion of its recharge from the Missouri River. Withdrawals in Barton, Dade, Greene, and Jasper counties in southwest Missouri are also projected to increase. As a result, continued localized declines in Ozark Aquifer water levels in this region are expected.

Counties in the Bootheel, which include Butler, Stoddard, Scott, Mississippi, New Madrid, Pemiscot, and Dunklin, have projected withdrawals that exceed 100 percent of annual average recharge from precipitation. Seepage from underlying aquifers and adjacent rivers, streams, and ditches, while difficult to quantify, is also a very important source of recharge in this region. Similar to the locations along the Missouri River mentioned above, the comparison of withdrawals to recharge from precipitation only does not tell the entire story.

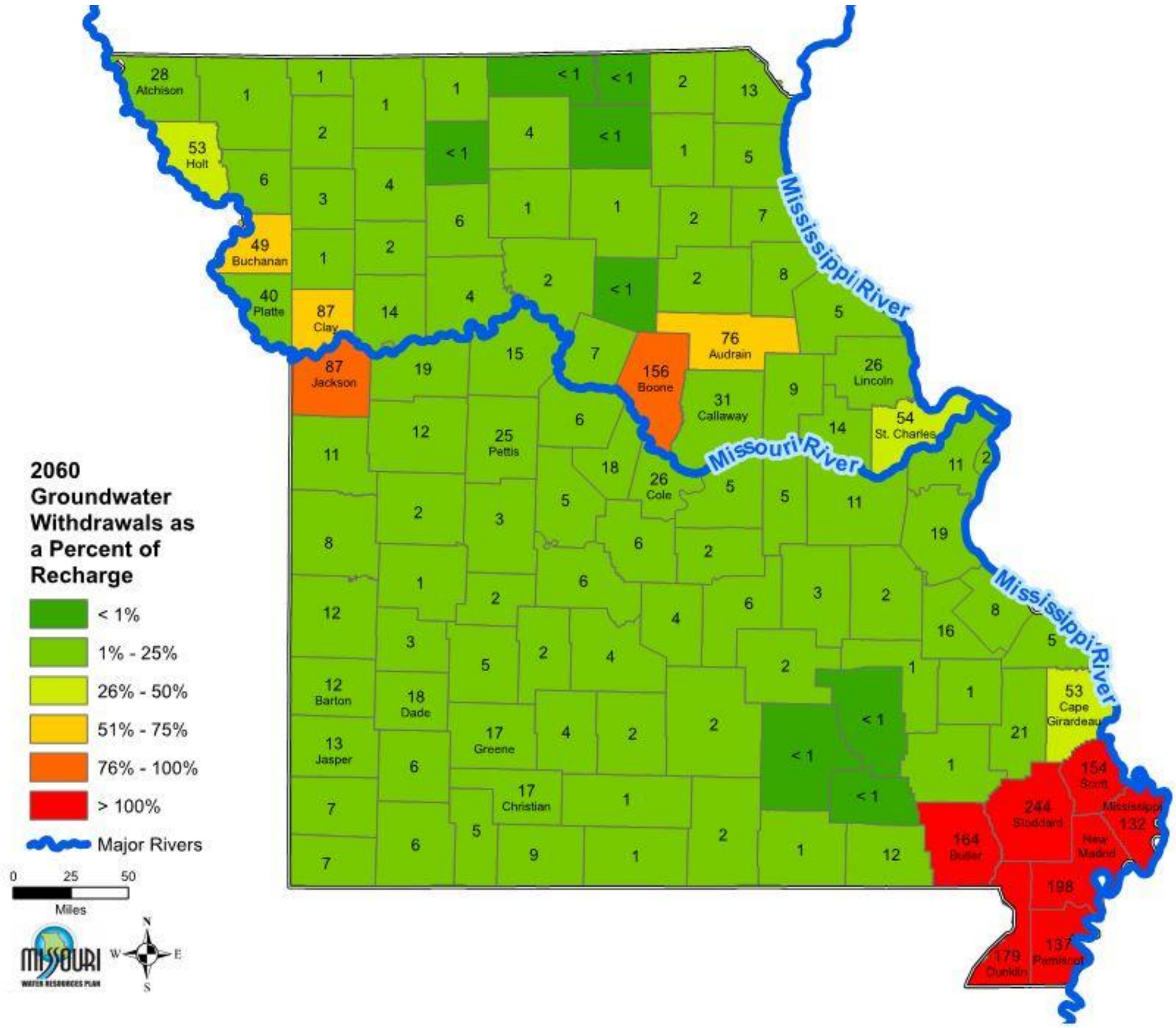


**Figure 4-37. Projected 2060 Groundwater Withdrawals as Percent of Average Annual Recharge from Precipitation**

## 4.8 Ozark Plateaus Aquifer System Groundwater Flow Model Assessment

The USGS Ozark Plateaus Aquifer System groundwater flow model was used to evaluate potential impacts at projected 2060 withdrawals within the Missouri portion of the Ozark Plateaus Aquifer System.

### 4.8.1 Existing USGS Groundwater Flow Model

The Ozark Plateaus Aquifer System model was published by USGS in 2018. The model was developed at a regional scale to assess regional groundwater availability (Clark et al. 2018). The model covers most of Missouri south of the Missouri River and parts of Kansas, Oklahoma, and Arkansas (**Figure 4-38**). The Bootheel of Missouri in the southeastern corner of the state is not included in the model. The model is divided into nine layers encompassing the Springfield Plateau Aquifer, the Ozark Aquifer, and the St. Francois Aquifer. The model simulates domestic, public supply, agriculture, livestock, and nonagriculture withdrawals from 1900 to 2016. The development of the withdrawal file is detailed in Knierim et al. 2017. Withdrawals are aggregated within model cells, which are 1 square mile each.

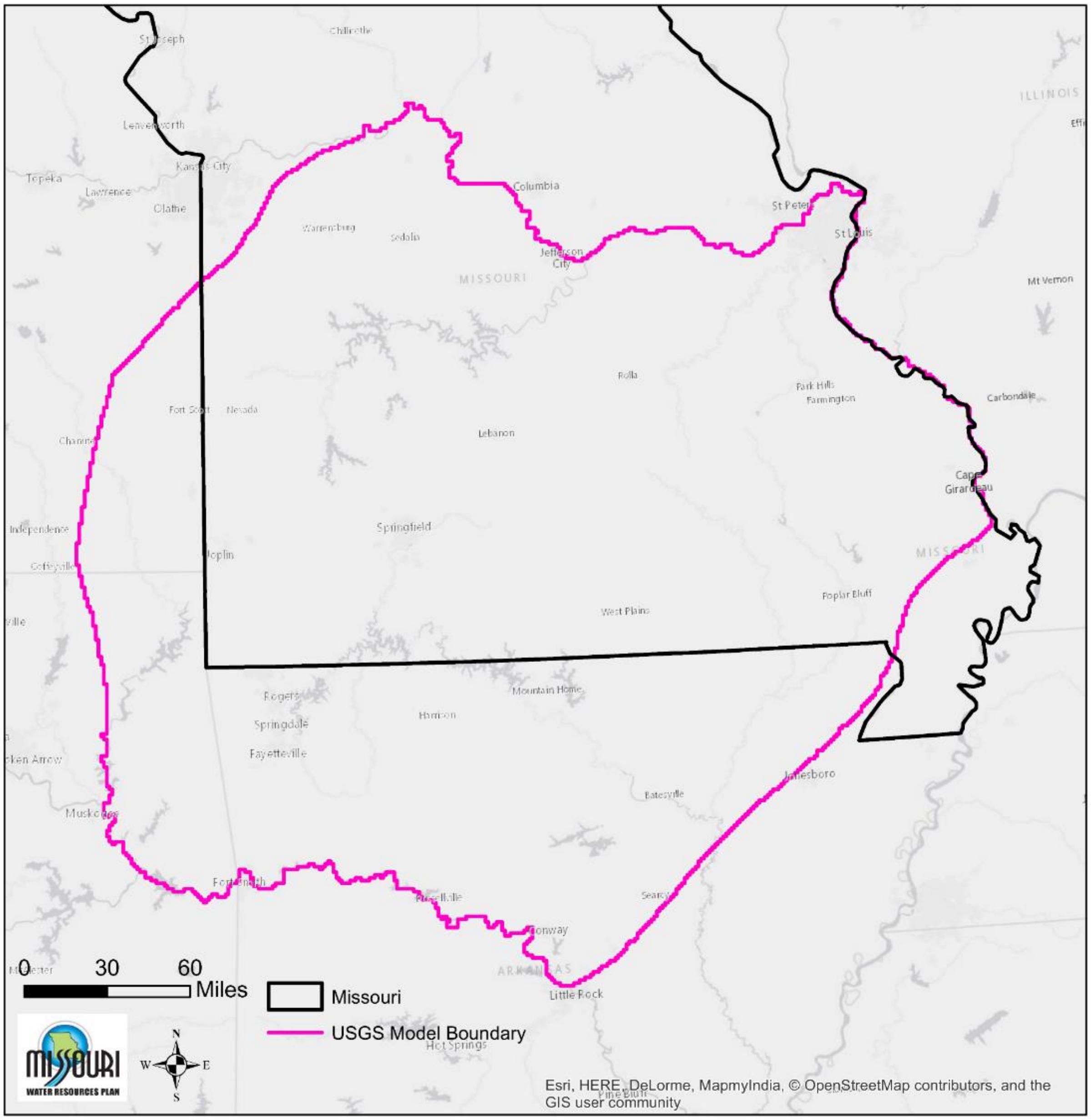


**Figure 4-38. Ozark Plateaus Groundwater Model Extent**

### 4.8.2 Application of USGS Groundwater Flow Model

The USGS model was modified to run additional transient stress periods from 2016 to 2060 to assess the impact of projected demand increases on groundwater availability. Since individual withdrawals were aggregated to model cells, it was not possible to correlate withdrawals in the USGS model with site-specific projected demands. Demand projections and model withdrawals were instead aggregated to a county level for this assessment. A comparison of 2016 withdrawals from the USGS model (2010 withdrawals were applied to 2010 to 2016) with estimated 2016 county-level demands developed as part of this study demonstrated general agreement on withdrawal rates by sector (**Figure 4-39**). The withdrawal rates in **Figure 4-39** are only for the Missouri counties in the USGS model. Withdrawal rates from counties in other states in the USGS model were excluded and demand projections for counties in Missouri outside the USGS model extents were excluded.

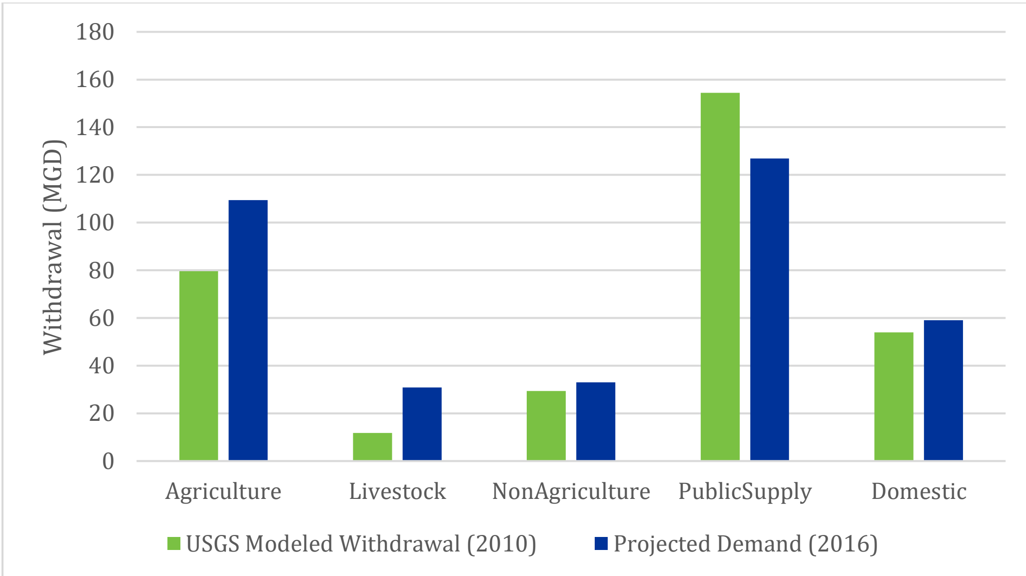


**Figure 4-39. Comparison of Modeled 2016 Demands with 2016 Withdrawals from the USGS Groundwater Model**

Estimated 2016 demands for each county were then applied to the model using the spatial distribution of withdrawals in the USGS model. It was assumed that the spatial distribution of withdrawals in the model (both horizontally throughout a county and vertically among aquifer layers) was reasonably representative of future withdrawal locations and that the magnitude of withdrawals would be the variable that changes with time. For each withdrawal type, the percentage of county-wide pumping occurring within a model cell in that county was calculated. The percentage was then multiplied by the projected demand for the county and withdrawal type, such that the total county pumping summed to the projected demand, while the distribution of pumping within the county was unchanged. This process was followed for 2016, 2020, 2030, 2040, 2050, and 2060 withdrawal rates for all types except domestic withdrawals.

For domestic withdrawals, county-wide withdrawal rates in each model layer were available from the USGS model, but the distribution of domestic withdrawals throughout the counties was not known. USGS identified domestic withdrawals as occurring at wells located within forested land, assuming wells in pasture and crop land were for agriculture/livestock and urban areas would be on city/public supply water (Clark et al. 2018). Therefore, countywide domestic demand projections were distributed to model cells based on the percentage of total county forested area present in that cell. Withdrawals were further disaggregated to model layers according to the percentage of county withdrawals occurring in each model layer.

Withdrawal rates in the USGS model outside of the state of Missouri were not modified and held at 2016 rates through all model simulations. This was done since no demand projections were developed for groundwater users in other states. It also provides a way to evaluate impacts of future in-state withdrawals irrespective of what may occur outside of the state. Average 2000 to 2013 recharge rates were applied for 2016 to 2060. Recharge rates are based on Empirical Water Balance regression-based methods and were spatially modified during the history-matching process (Clark et al. 2018).

**Figure 4-40** shows the projected increase in pumping between 2016 and 2060 by model cell. The majority of changes in withdrawals are modest and between -10 MGD (decreasing demand) and 10 gpm (increasing demand). Since projected domestic demands for Missouri were distributed according to landcover, small withdrawals cover nearly every model cell in Missouri (withdrawal less than 10 gpm) but not areas of the model in adjacent states, where withdrawals were unchanged. The regions with the largest demand increases are in the southwestern corner of the state (Christian, Dade, McDonald, and Taney counties). Bollinger, Cape Girardeau, and Ripley counties have 3 to 4 MGD projected increases in agricultural demand; however, these demands are primarily from alluvial wells, and not from the Ozark Aquifer as this model indicates. Cape Girardeau also has an approximately 2.8 MGD (35%) projected increase in public supply demand. This increase is also from alluvial wells and not from the Ozark Aquifer.

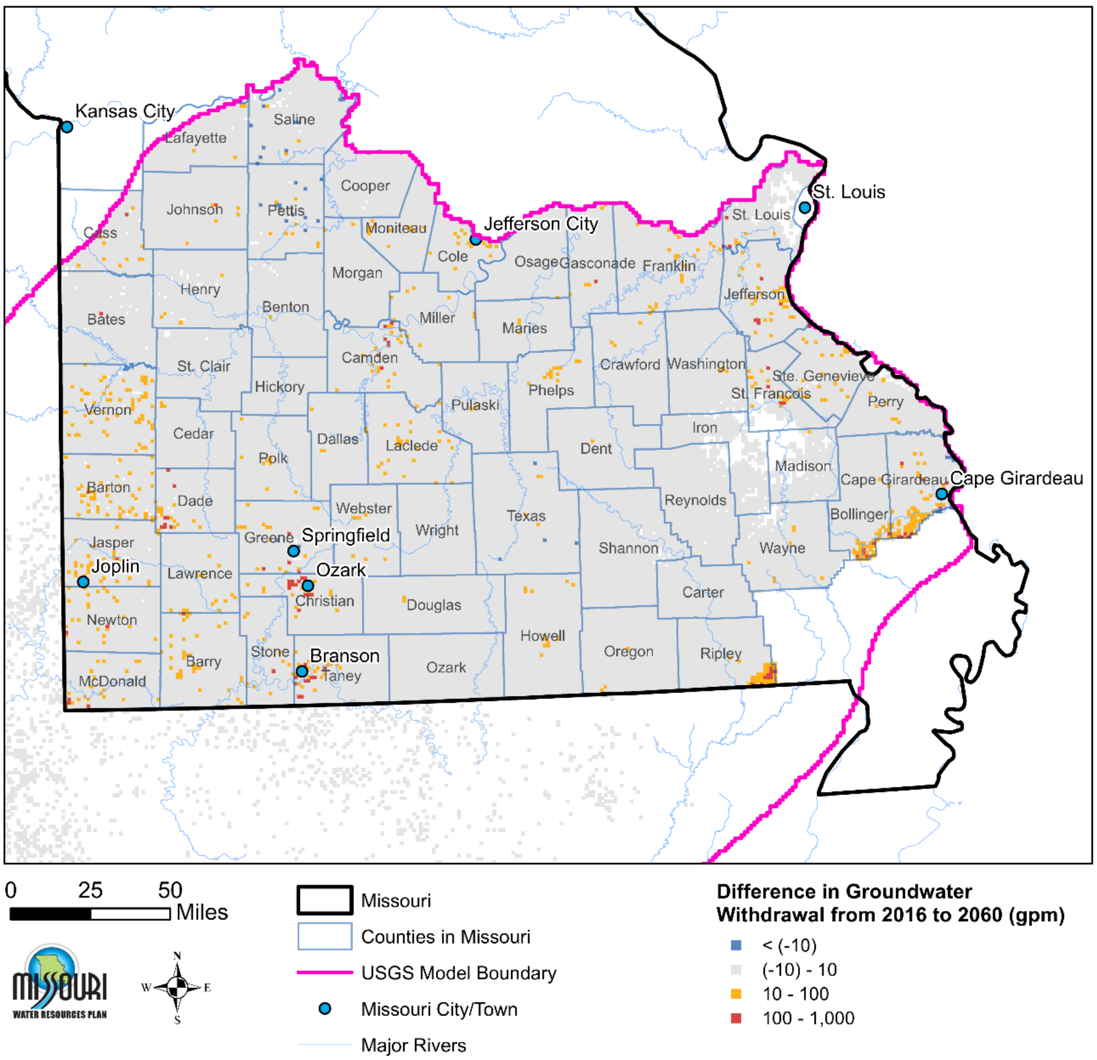


**Figure 4-40. Projected Changes in Withdrawal from 2016–2060 (gpm)**

In the southwestern corner of the state:

- Dade County has a 2.2 MGD increase in irrigation demand from 12.6 MGD in 2016 to 14.8 MGD in 2060.
- Christian County has a 7.4 MGD increase in public supply demand from 6.0 MGD in 2016 to 13 MGD in 2060.

- Taney County has a 3.2 MGD increase in public supply, from 5.0 MGD to 201 to 8.2 MGD in 2060, and a 2.2 MGD increase in self-supplied nonresidential demand, from 2.5 MGD in 2016 to 4.6 MGD in 2060.
- McDonald County has a 2.5 MGD increase in self-supplied residential demand from 2.6 MGD in 2016 to 5.1 MGD in 2060.

**Figure 4-41** illustrates where these county-wide demand increases are spatially distributed throughout the counties.

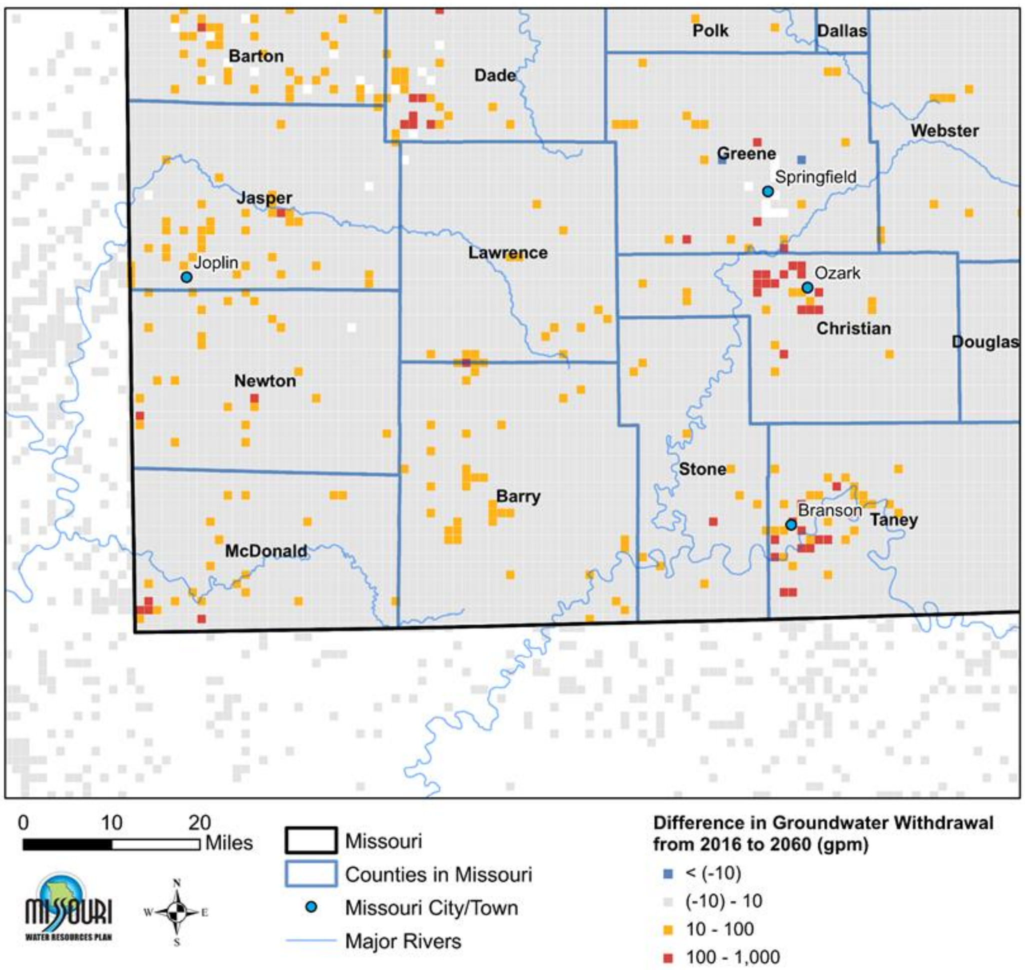


Figure 4-41. Projected Changes in Withdrawal from 2016–2060 in the Southwestern Corner of Missouri (gpm)

### 4.8.3 Groundwater Modeling Results

Model-simulated groundwater head contours for 2016 and 2060 were generated and compared. **Figure 4-42** illustrates the difference in groundwater heads between 2016 and 2060 in layer 6, which represents the Lower Ozark Aquifer in the model, where the largest percentage of pumping occurs. Overall trends show minor decreases in Lower Ozark Aquifer head. The greatest changes in groundwater heads occur near the areas noted above with the greatest increases in withdrawals. The greatest declines, over 200 ft, are seen just south of Springfield, in Christian County (**Figure 4-43**). These are likely due to the large increases in public supply withdrawals predicted between 2016 and 2060. In McDonald County in the southeast corner of Missouri, increases in self-supplied nonresidential and livestock demands also result in 200 foot declines in water levels (**Figure 4-43**). Smaller, yet still significant, declines are noted in Dade and Taney counties, where irrigation and self-supplied nonresidential demands, respectively, increase by approximately 2.5 MGD from 2016 to 2060.

The decline in head in Bollinger and Cape Girardeau counties, shown in **Figure 4-42**, should be ignored. Most of the projected increases in withdrawals in these counties occurs in the alluvium. Since the alluvium is not explicitly modeled in the USGS groundwater model, withdrawals were assigned to the Ozark Aquifer so that declines in Ozark Aquifer head are likely overestimated.

Potential impacts of the modeled water level declines may include dry wells, reduced well yields, and/or potential changes in water quality. Streams that are primarily supported by discharging groundwater (baseflow) may experience reduced flow, reduced length (change in headwater location), and/or the stream may become dry for a longer duration during periods of low precipitation.

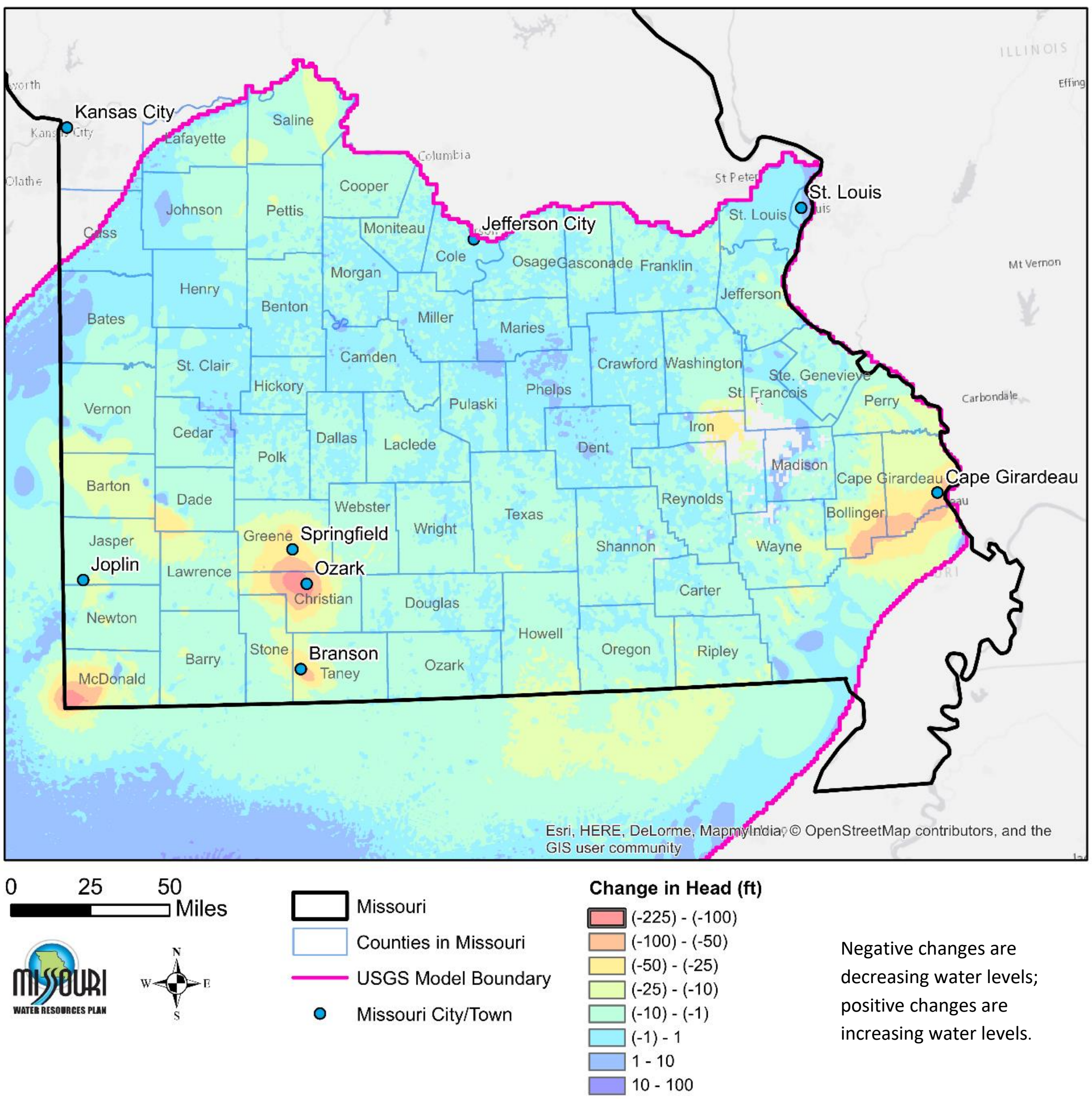


**Figure 4-42. Simulated Changes in Water Levels from 2016–2060 in the Lower Ozark Aquifer**

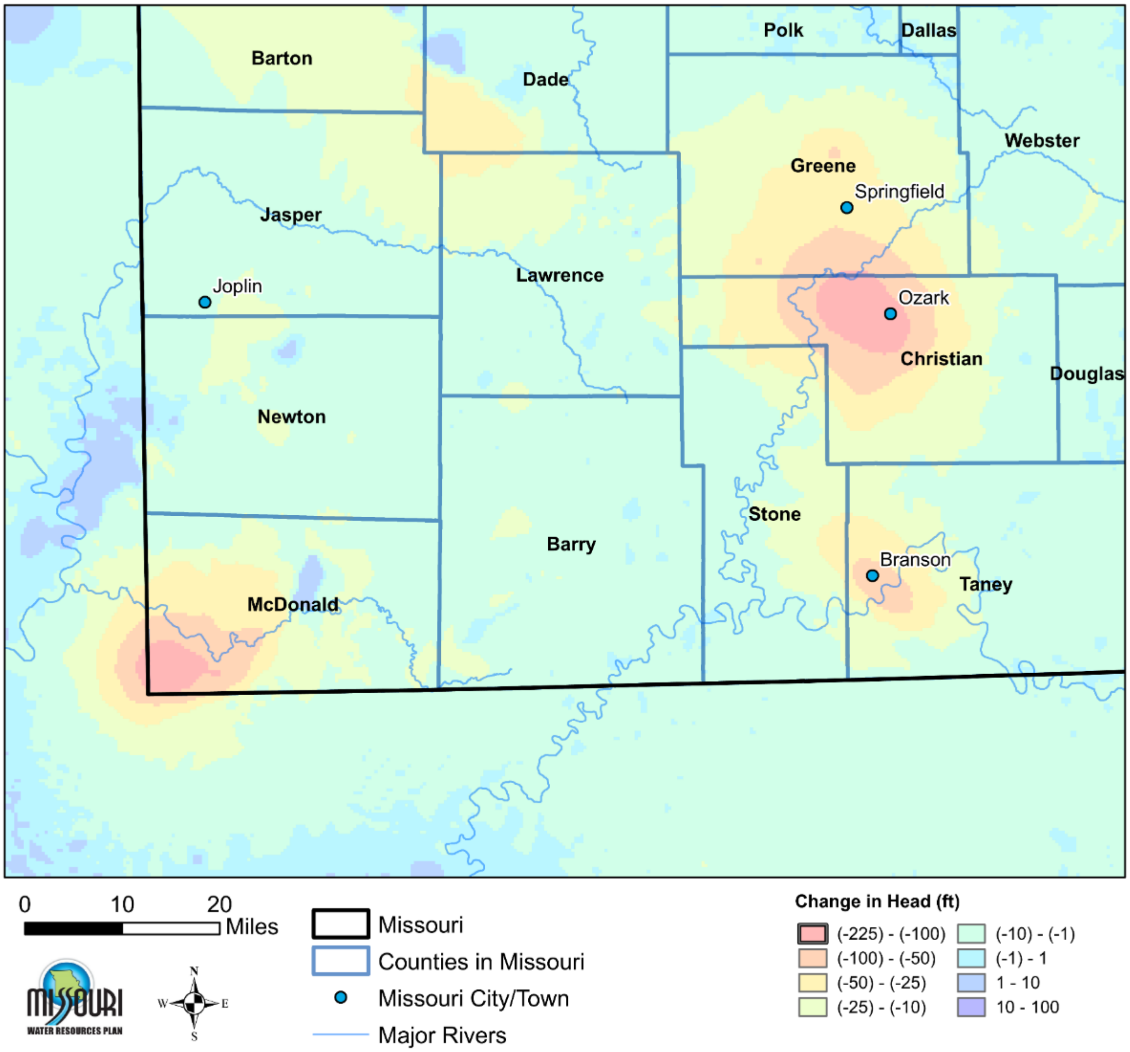


**Figure 4-43. Simulated Changes in Water Levels from 2016–2060 in the Lower Ozark Aquifer in the Southwestern Corner of Missouri**

## 4.9 Summary

Although water is generally plentiful in the state, making water available to meet demands can be a challenge in some areas and at select times of the year. In west central and northern Missouri, where poor bedrock groundwater quality limits use of the resource to areas where alluvial and glacial drift deposits can be utilized, water supply reservoirs provide storage that is necessary to maintain a constant supply especially during years of below-average precipitation. Effective water planning recognizes that most water supply problems do not occur during average conditions, but during periods of dry weather that may extend months and even years.

In general, the surface water and groundwater budgets demonstrate that Missouri has an abundant supply of water for consumptive uses. On an average annual basis, surface water withdrawals, both consumptive and nonconsumptive, are only a small fraction of total streamflow however, this does not negate the need to continue to maintain flows on the state's waterways for nonconsumptive uses, such as power generation and navigation. In addition, minimum flows must be maintained even when demands are being met in order to preserve water temperature, water quality, and the viability of existing water supply intakes, all of which are put at risk should surface water supply decrease in the future.

Similarly, projected groundwater withdrawals in most subregions are less than 20 percent of average annual recharge from precipitation and other aquifers and only a fraction of potable groundwater available in storage. In the few subregions where groundwater withdrawals are greater than 20 percent of average annual recharge from precipitation, much of the pumping is from alluvial aquifers, which are hydraulically connected to major rivers and other aquifers.

The following summarizes water supply availability in each of the state's nine subregions:

- **Upper Mississippi-Salt** – Surface water withdrawals not from the Mississippi River approach or exceed median dry year flows in 3 months of the dry year and in 3 months of the drought of record year. The results suggest a potential for surface water gaps in areas of the subregion that do not have access to the Mississippi River and emphasize the importance of reservoir storage, interconnections with other systems, conjunctive use of groundwater, or other means to bridge these potential supply gaps. The subregion includes eight water supply reservoirs that help mitigate against the potential surface water supply gaps identified in the monthly streamflow analysis. Groundwater availability, especially in the Mississippi River Alluvial Aquifer and Cambrian-Ordovician Aquifer, is enough to meet current and future needs through 2060.

- **Upper Mississippi-Kaskaskia-Meramec** – Flow in the Mississippi River exceeds total surface water withdrawals in the subregion. Surface water users in the western part of the subregion withdraw from tributaries to the Mississippi River that provide ample supply even during dry years and the drought of record year. Groundwater availability, especially in the Mississippi River Alluvial Aquifer and Ozark Aquifer, is enough to meet current and future needs through 2060. No stress or gaps were identified at the subregion level.

- **Lower Mississippi-St. Francis** – The subregion relies heavily on the groundwater stored in the northern portion of the Mississippi Embayment Aquifer System. Current groundwater withdrawals from this subregion of 1,620 MGD are approximately 70 percent greater than the combined groundwater withdrawals from all other subregions of the state. Although current groundwater withdrawals exceed average annual recharge from precipitation, observation wells in the subregion have shown no long-term declines. Recharge sources other than precipitation, namely the Mississippi, St. Francis and Black rivers to the east and Ozark Aquifer to the northwest, likely contribute significant amounts of flow into the Southeast Lowlands Alluvial Aquifer. As a result, groundwater availability is enough to meet current and projected needs without imposing stress or resulting in supply gaps. Potable groundwater stored in the aquifers is enough to meet groundwater demands even during prolonged droughts, when recharge from precipitation is much lower.

- **Missouri-Nishnabotna** – The Missouri River and Missouri River Alluvial Aquifer are the major sources of water in this subregion. Eighty percent of surface water withdrawals and 95 percent of groundwater withdrawals are from the Missouri River and its alluvial aquifer, respectively. Water users in the eastern part of the subregion must rely on tributaries to the Missouri River. The combined withdrawals from tributaries to the Missouri River approach or exceed median dry year streamflow in 3 months and drought of record year streamflow in 5 months. There is the potential for surface water gaps in areas of the subregion that do not have access to the Missouri River. A potential gap is also apparent in the flow-duration curve, which suggests that streamflow generated within the subregion will be below average annual withdrawals approximately 10 percent of the time.

- **Chariton-Grand** – Not accounting for thermoelectric withdrawals, total water use is relatively low in this subregion and reflects the relatively low population density. Water users rely primarily on surface water resources since good-quality groundwater is limited to portions of the Glacial Drift Aquifer and the Missouri River Alluvial Aquifer in the south. Surface water withdrawals exceed drought of record year flows in 1 month of the year, suggesting the potential for a surface water gap. The six subbasins within the Chariton-Grand were investigated in more detail. A potential supply gap was identified in 1 or more months when comparing dry year and drought of record year streamflow to surface water demands in the Upper Grand, Thompson, Lower Grand, Upper Chariton and Little Chariton subbasins. The Chariton-Grand subregion includes 32 water supply reservoirs with a total storage of 96,707 acre-feet. Reservoirs are an important component of the subregion's overall water supply system due to the limited availability of potable groundwater, lower average rainfall, and history of drought.

- **Gasconade-Osage** – Although the monthly streamflow analysis at the subregion level does not point to the potential for stress or a surface water gap under current or future conditions, water stress, and the potential for water shortages have previously been identified in more localized areas of southwest Missouri, including the western portion of the Gasconade-Osage subregion. In the Little Osage subbasin, the comparison of monthly dry year and drought of record year streamflow to current withdrawals indicates the potential for supply gaps in 4 months of the year. The gaps occur from the seasonal nature of the agriculture and aquaculture/wetlands sectors, which are largely nonconsumptive uses. The Ozark and St. Francois aquifers are estimated to store a combined 138 trillion gallons of potable groundwater. Projected 2060 groundwater withdrawals of 96 MGD are 5 percent of average annual recharge from precipitation. Even though groundwater recharge greatly exceeds withdrawals and large amounts of potable groundwater are available in storage, localized stress may still occur due to over-pumping or poor quality, especially in the western counties of the subregion on the saline side of the freshwater-saline transition zone.

- **Lower Missouri** – The Missouri River and Missouri River Alluvial Aquifer are the major sources of water in this subregion. The Ozark Aquifer (south of the Missouri River) and Cambrian-Ordovician Aquifer (north of the Missouri River) are also significant groundwater sources. Although flow in the Missouri River exceeds total surface water withdrawals, surface water users in the northern and southern parts of the subregion must rely on tributaries to the Missouri. Withdrawals from the tributaries exceed median dry year flows in 5 months of the dry year and in 8 months of the drought of record year. The results suggest the potential for surface water gaps in areas of the subregion that do not have access to the Missouri River for supply, and emphasize the importance of reservoir storage, adequate and dependable Missouri River flows, interconnections with other systems, and conjunctive use of groundwater, together with other means to bridge these potential supply gaps.

- **Upper White** – The Upper White subregion has abundant surface and groundwater resources. Surface water withdrawals remain an order of magnitude below median dry year flows in any month. The relatively consistent streamflow even during dry periods is, in part, due to the thousands of springs and outlet points in the Salem Plateau portion of the subregion, which provide consistent base flow to streams. Although results of the monthly streamflow analysis at the subregion-level do not point to the potential for stress or a surface water gap under current or future conditions, the potential for shortages is a concern in growing areas such as Springfield, which sits on the drainage divide between the Upper White and Gasconade-Osage subregions. Within the subregion, the Ozark and St.

Francois aquifers are estimated to store a combined 105 trillion gallons of potable groundwater. Projected 2060 groundwater withdrawals of 435 MGD are 15 percent of average annual recharge from precipitation.

- **Neosho-Verdigris** – Comparisons of surface water withdrawals to streamflow show that withdrawals approach, but do not exceed, median dry year and drought of record year streamflow in 2 months, indicating potential for stress. Although the groundwater budget suggests that total withdrawals are less than average annual recharge to the water table, a gradual, long-term lowering of water levels has been observed in localized portions of the Ozark Aquifer in southwestern Missouri. The most severe, localized declines are primarily attributed to self-supplied residential and minor system withdrawals in northern Arkansas and agricultural (poultry) withdrawals in McDonald County (Miller and Vandike 1997). The declining water levels indicate that withdrawals from the Ozark Aquifer in this localized area have exceeded long-term recharge to the aquifer and continue to reduce the amount in storage. Similar localized declines, although not as severe, have been observed in observation wells in other parts of the subregion and suggest that future groundwater withdrawals in these areas may not be sustainable at current levels, given the continual decline in storage.

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# Section 5 Missouri's Drinking Water and Wastewater Infrastructure

## 5.1 Introduction

As described in **Section 3** of this report, water consumption statewide by major water systems is expected to increase by approximately 19 percent by 2060. To meet this future demand, there must be adequate and reliable drinking water and wastewater infrastructure throughout the state. Reliable drinking water and wastewater infrastructure is essential to human health, economic development, and preserving Missouri's waterways that serve as drinking water sources. Continued population and economic growth are reliant on the expansion and proper operation and maintenance of water and wastewater systems. Much of Missouri's water and wastewater infrastructure needs significant upgrades and repairs based on the expected design life of many existing systems and piping. Additionally, many utilities and water providers are facing the financial challenges associated with the update and repair of water and wastewater infrastructure designed and built to meet older state and federal drinking water and wastewater requirements.

### Overview of Section 5 Missouri's Drinking Water and Wastewater Infrastructure

This section of the Missouri WRP characterizes water and wastewater infrastructure throughout Missouri. Subsections are organized as follows:

- Section 5.2 Current State of Drinking Water Infrastructure – evaluates current infrastructure and future drinking water infrastructure needs statewide
- Section 5.3 Wastewater Infrastructure – evaluates current infrastructure and future wastewater infrastructure needs statewide
- Section 5.4 Drinking Water and Wastewater Rates – evaluates current water and wastewater rates, utilizing data provided by the Missouri Public Utility Alliance
- Section 5.5 Regional Water and Wastewater Infrastructure Gap Analysis – provides an overview of major regional infrastructure projects and evaluates current regional infrastructure gaps
- Section 5.6 Conclusions – provides a summary and conclusions about current infrastructure and future drinking water infrastructure needs statewide

## 5.2 Drinking Water Infrastructure

Drinking water infrastructure provides a critical public health function and is vital for promoting economic development. Public drinking water systems utilize pumps and pipes to deliver source water to a distribution or treatment facility where it is tested and, if necessary, treated to meet federal and state drinking water standards. Common water treatment methods in Missouri include coagulation, flocculation, clarification, filtration, softening, and disinfection (MoDNR 2018a). EPA has delegated primary enforcement responsibility for public drinking water systems in Missouri to MoDNR.

### 5.2.1 Current State of Drinking Water Infrastructure

Community public drinking water systems serve over 5 million customers in Missouri, approximately 88 percent of the state population (MoDNR 2016). The remaining 12 percent of the state population is served by private drinking water wells or small noncommunity systems. While more than 94 percent of the primary public water systems in Missouri utilize groundwater, approximately 64 percent of Missouri's population relies on surface water for their primary water supply.[9] MoDNR currently regulates approximately 2,700 drinking water systems statewide. Of these systems, 52 percent are community public water systems that operate year-round and serve at least 15 service connections (MoDNR 2018a). While the majority of water utilities in the state are publicly owned, approximately 27 percent of public water users are served by a private community water system (MoDNR 2019b).

MoDNR regulates over 2,700 drinking water systems statewide, which serve approximately 88 percent of the state population.

Drinking water is delivered to customers via distribution systems consisting of water mains, pump stations, and storage tanks. While water mains are long-lived assets, often lasting 80 to 100 years, the development of drinking water distribution systems in Missouri started 150 years ago, leaving many systems with components over 100 years old and in need of replacement (Metro Water Infrastructure Partnership 2014). In addition to challenges associated with aging infrastructure, utilities are often challenged by the necessity for upgrades due to changing regulations and increasing population. Investment and upkeep in this infrastructure are necessary not only for Missouri to meet current and projected future water demands, but also to promote economic development throughout the state. In contrast, depopulation can decrease revenues, thereby increasing the challenge of properly maintaining existing infrastructure.

**Aging Drinking Water Infrastructure**

In the 2018 American Society of Civil Engineers (ASCE) *Report Card for Missouri's Infrastructure*, an expert team of 28 civil engineers from across the country evaluated the major components of the state's infrastructure and provided a basis upon which residents and policymakers could discuss Missouri's status and provide guidance on continued improvements for the health, safety, and welfare of citizens and for the economic success of the state (ASCE 2018). According to the report card, investment in Missouri drinking water infrastructure continues to be a challenge. Shortfalls in investment result in systems that may experience service interruptions from main breaks, microbial contaminations, and inadequate capacities. The 2018 drinking water infrastructure grade for the State of Missouri was a C-, slightly higher than the 2017 nationwide grade of D for drinking water infrastructure[10]. According to the report, improved planning, reduced regulatory impediments, and increased funding are critical for Missouri to maintain existing facilities and ensure a safe and reliable water supply (ASCE 2018).

The ASCE Committee on America's Infrastructure assesses all relevant data and reports, consults with technical and industry experts, and assigns grades based on capacity and condition, funding, future need, operation and maintenance, public safety, resilience, and innovation.

[9] Large volume surface water use is primarily attributable to the surface water systems on the Missouri and Mississippi rivers supplying large population areas (See Section 3.3.3 for additional information).
[10] The 2018 nationwide Infrastructure Report Card is not yet available.

As with most of the nation, one of the main water infrastructure issues in Missouri is aging infrastructure. **Figure 5-1** provides the original build date of major water systems in Missouri by decade (MoDNR 2018a). While the highest percentage of systems (20 percent) were built between 1960 and 1970, nearly 25 percent were built prior to 1930. Over half of the major drinking water systems in Missouri became active prior to 1960, meaning that without repair or replacement, most original water pipes are nearing or exceeding their average expected life spans. These build dates do not represent replacements and renovations, but they do reflect the growth of the state and provide an indication of average age of systems and mains.

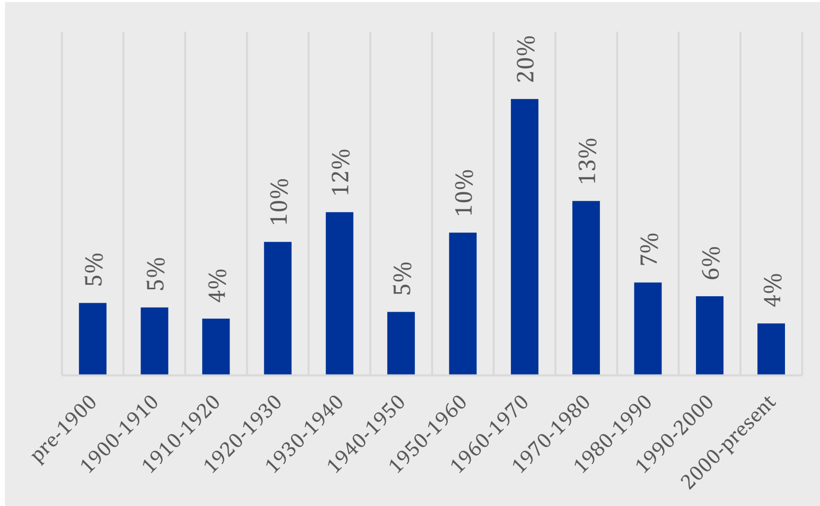


**Figure 5-1 Original Build Date of Major Water Systems in Missouri**
*Source: SDWIS Database*

> Examples of Current Drinking Water Pipe Replacement Rates
>
> - Kansas City – 1 percent per year
> - Springfield – 0.65 percent per year
> - St. Louis – 0.5 percent per year
> - Cape Girardeau – 0.3 percent per year

Proactive replacement of aging infrastructure in Missouri is generally only feasible for large systems that have adequate revenue to support a replacement program. According to the American Water Works Association (AWWA), the nationwide average replacement rate for water pipes is 0.5 percent per year (AWWA 2001). Current water pipe replacement rates for major water utilities in Missouri are generally at or above this nationwide average; however, major utility managers throughout the state agreed during technical workgroup meetings that a more aggressive replacement schedule is necessary to proactively address failing pipeline. Additionally, most small water and wastewater systems statewide find it challenging to replace any nonfailing infrastructure. During technical workgroup meetings, representatives from several small utilities expressed that they lack the funding not only to proactively manage infrastructure needs but also to meet current water quality standards and adequately address water losses. These small utilities focus instead on repair of broken pipes rather than proactive replacement.

In addition to improving pipe main replacement rates, some major utilities are working toward main break benchmarks. In 2011, the AWWA Partnership for Safe Water Distribution System Optimization Program established an annual benchmark of 15 main breaks per 100 miles of pipeline for a fully optimized distribution system (AWWA Partnership for Safe Water 2011). Kansas City has developed a prioritized replacement plan to achieve this benchmark goal. The utility currently experiences approximately 20 to 22 breaks per 100 miles, whereas prior to implementation of this plan, the utility experienced 66 main breaks per 100 miles (KC Water of Kansas City 2018).

High water loss due to aging infrastructure is a challenge for many Missouri utilities. On a biennial basis, the MoDNR Public Drinking Water Branch administers a voluntary Technical, Managerial, and Financial Capacity survey to community and nontransient, noncommunity drinking water systems. This survey is utilized in part to collect key information on water loss rates. In 2018, 45 percent of the systems that responded to the survey reported a water loss rate of 10 percent or greater. The Capacity Development Program uses data to assist in locating leaks in water lines and addressing water loss. Over a 3-year period, leak detection efforts by the program identified 195 leaks, saving drinking water systems more than 63 mgal of finished water per month.

### 5.2.2 Drinking Water Infrastructure Needs

Drinking water infrastructure needs are assessed at a statewide level through the Drinking Water Infrastructure Needs Survey and Assessment (DWINSA) (EPA 2018). The DWINSA is a nationwide survey and assessment of public water systems that is conducted every four years. The assessment allows EPA to determine total 20-year capital improvement drinking water infrastructure needs at the national and statewide level. The infrastructure need estimate determined through the DWINSA covers infrastructure needs that are eligible for the Drinking Water State Revolving Fund (DWSRF).

The most recent DWINSA was completed in 2015. According to the 2015 DWINSA report to Congress, the State of Missouri's total 20-year need for drinking water infrastructure is \$8.92 billion (\$9.48 billion in 2018 dollars). The total need is made up of five categories: transmission and distribution, treatment, storage, source, and other needs (EPA 2018). **Figure 5-2** represents the distribution of each of these categories for the State of Missouri. The *transmission and distribution* category need of \$6.3 billion includes projects for rehabilitation and the replacement of existing water mains, installing new pipe to eliminate dead end mains and the resulting stagnant water, installing new mains in areas where existing homes do not have a safe and adequate water supply, and installing or rehabilitating pumping stations to maintain adequate pressure. The source category need of \$374 million includes construction or rehabilitation of surface water intake structures, drilled wells, and/or spring collectors. The treatment category, with a statewide need of \$1.3 billion, consists of the construction, expansion, and rehabilitation of facilities to reduce contamination through treatment processes. The storage category need of \$907 million, includes projects to construct, rehabilitate, or cover finished water storage tanks, but it excludes dams and raw water reservoirs. The 5th last category, (other), encompasses any DWSRF-eligible projects that are not included in the previous four categories, such as emergency generators or systemwide supervisory control and data acquisition. Projects in this category have a need of \$30 million. **Figure 5-3** provides a comparison by category of the 2011 and 2015 DWINSA results in 2018 dollars. The latest United States government consumer price index data published was used to determine the cumulative inflation rate to adjust costs to 2018 dollars.

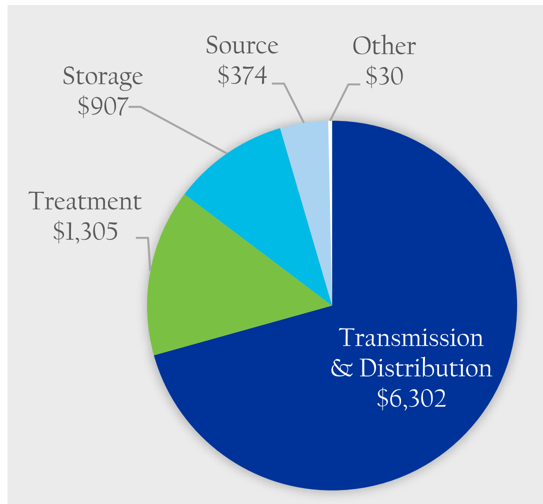


**Figure 5-2. Missouri Drinking Water Infrastructure Needs and Assessment in Millions of 2015 Dollars**
*Source: Derived from 2015 DWINSA*

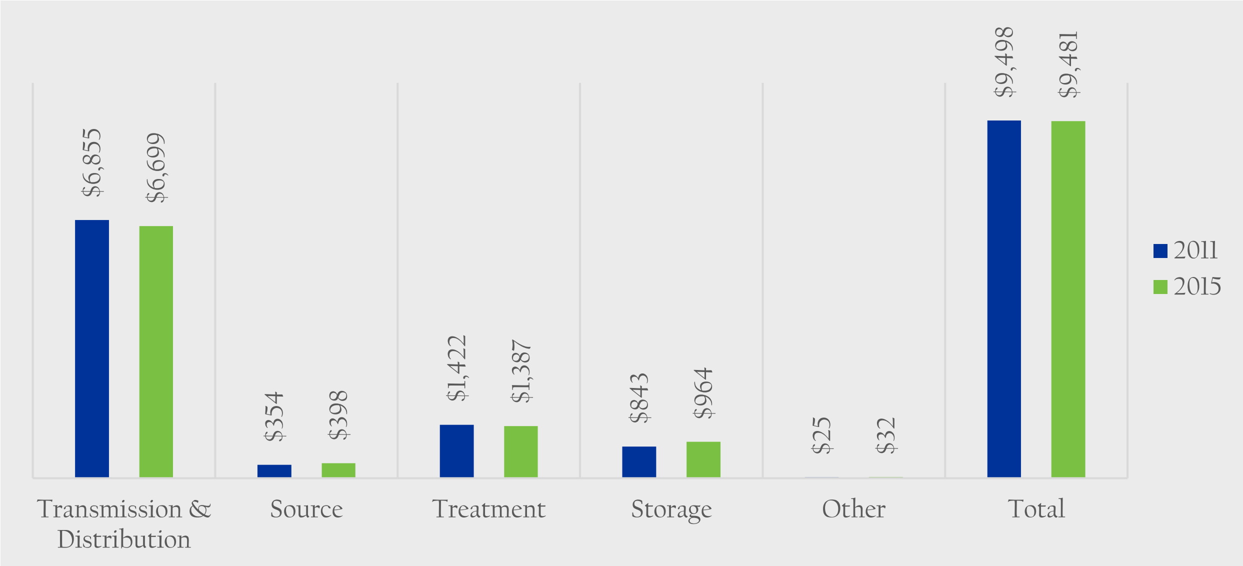


**Figure 5-3. 2011 versus 2015 Missouri DWINSA in Millions of 2018 Dollars**
*Source: Derived from the 20111 and 2015 DWINSA*

Of the 37 states that provided complete data for the DWINSA, Missouri ranks 17th on the list for total dollars needed for drinking water infrastructure improvements over the next 20 years. The 1st rank represents the highest need. **Figure 5-4** provides a geographical representation of state drinking water infrastructure needs throughout the United States, according to the 2015 DWINSA report to Congress (EPA 2018). On a per capita basis, Missouri's infrastructure needs equate to $1,489 per person, which ranks it 21st in comparison to the rest of the country.

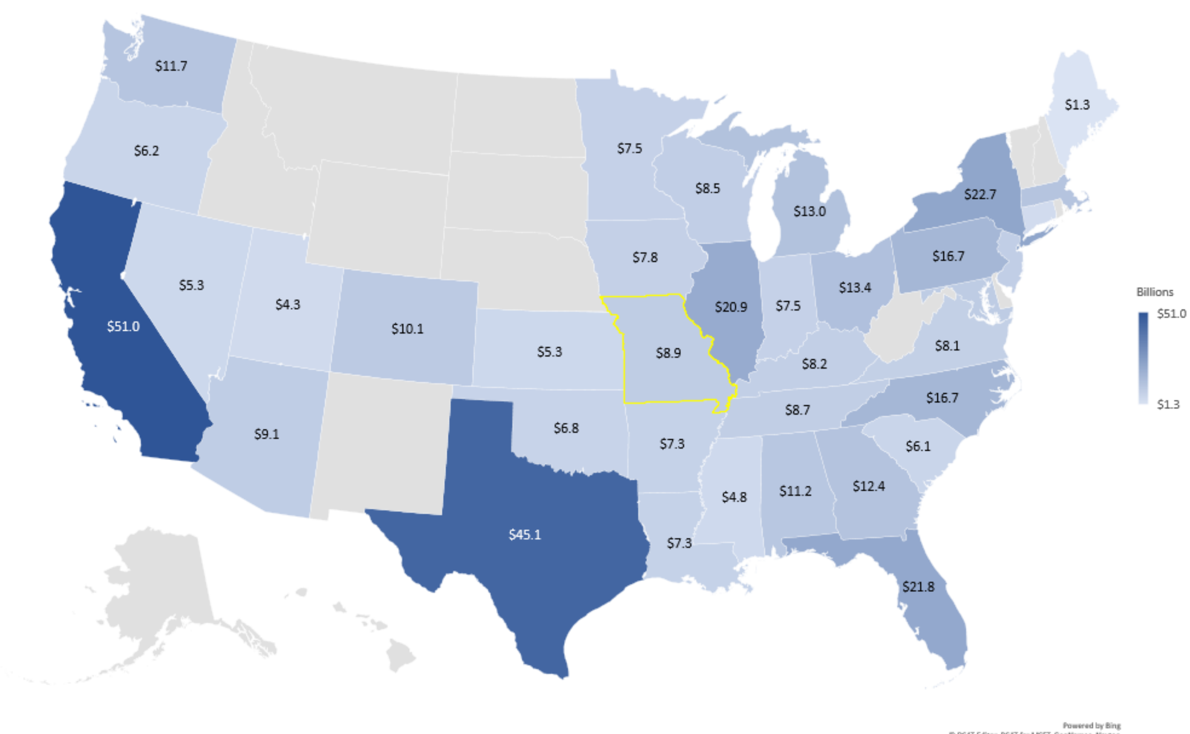


**Figure 5-4. 2015 Drinking Water Infrastructure Needs Survey and Assessment State Comparison in Billions of 2015 Dollars**
*Source: Derived from 2015 DWINSA*

Survey responses collected by MoDNR for the DWINSA list the types and categories of projects that surveyed facilities reportedly need completed. Project categories are new, expansion, replacement, or rehabilitation. Distribution projects account for approximately 41 percent of projects listed by surveyed utilities. **Tables 5-1** and **5-2** provide a breakdown of project types and categories, respectively, from the 94 Missouri drinking water facilities that completed the 2015 DWINSA survey (EPA 2018).

**Table 5-1. 2015 Missouri Drinking Water Infrastructure Needs Survey and Assessment Projects by Type**

| Type of Project | Number of Projects |
|---|---|
| Distribution | 854 |
| Storage | 392 |
| Source | 306 |
| Treatment | 278 |
| Pumping | 186 |
| Transmission | 70 |
| Other | 3 |
| **Total Number of Projects** | **2,089** |

**Table 5-2. 2015 Missouri Drinking Water Infrastructure Needs Survey and Assessment Projects by Category**

| Project Category | Number of Projects |
|---|---|
| Replacement | 1,418 |
| Rehabilitation | 610 |
| New | 56 |
| Expansion | 3 |

In addition to DWINSA results, total system capacity infrastructure need can also be assessed by individual utilities using the water demand forecast outlined in **Section 3** of this report. Water use projections by utility can be used to assess the relationship of current maximum day water demands[11] to system capacities. In the absence of local demand projections, utilities are encouraged to use the county demand and population projections provided in **Appendix B** of this report as a guideline for future growth to estimate future demands at the utility level. By comparing estimated future demands to current system capacity, utilities can estimate the need for system capacity upgrades through 2060.

## 5.3 Wastewater Infrastructure

Wastewater systems serve to route used water and other wastes from the source through pipes leading to trunk sewers, ultimately terminating at treatment plants. Following treatment, water is discharged to be reused downstream. Wastewater systems are made up of four components: collection, conveyance, treatment, and discharge. Properly functioning wastewater systems are crucial to human health and the protection of the state's waterways from pollution. Investment in and maintenance of these systems is essential to preventing untreated sewer overflows into Missouri's surface waters. Similar to drinking water infrastructure, the average age of wastewater infrastructure throughout large municipalities and small towns alike may be approaching the end of its expected life. Aging wastewater infrastructure has caused increasingly frequent leaks and failures within systems (ASCE 2018).

EPA has delegated primary enforcement responsibility for wastewater systems in Missouri to the Water Pollution Control Branch of MoDNR. Funding and programmed maintenance to wastewater utilities are essential components for proper operation, and a lack of funding and maintenance for wastewater projects can be detrimental to communities with few resources.

### 5.3.1 Current State of Wastewater Infrastructure

Wastewater is collected one of two ways in the state: in a combined stormwater and sewer system or in a sanitary sewer system. Combined sewer overflows (CSOs) and sanitary sewer overflows can occur when the capacity of the designed system is exceeded. Combined stormwater and sewer systems are no longer permitted for new construction, and several cities throughout the state are currently working on extensive

[11] Maximum day demands were calculated using 150 percent of average day production per *Minimum Design Standards for Missouri Community Water Systems* (MoDNR 2013).

sewer separation projects to separate sanitary flow from stormwater in existing infrastructure networks. This separation helps to alleviate capacity issues at downstream treatment facilities and prevent public health risks associated with CSOs.

Several utilities throughout Missouri are currently addressing infrastructure needs and making improvements to wastewater and stormwater overflows. Both Kansas City and St. Louis are currently implementing major improvements in response to EPA-issued federal mandates called consent decrees. The consent decrees require both cities to reduce sewer overflows into local streams and rivers. In Kansas City, a 2010 consent decree requires KC Water of Kansas City to spend $4.5 billion over 25 years to reduce wastewater and stormwater overflows. In response, KC Water of Kansas City is implementing a program called Smart Sewer, which will update or replace Kansas City's overall sanitary sewer system that spans nearly 318 square miles of combined and separate sewer systems (KC Water of Kansas City 2019). In St Louis, a 2012 consent decree requires the Metropolitan Sewer District of St. Louis to spend $4.7 billion over 23 years to reduce wastewater and stormwater overflows. In response, Metropolitan Sewer District of St. Louis created Project Clear, an umbrella program for a series of initiatives aimed at reducing wastewater and stormwater overflows and making general improvements to the overall water system (Metropolitan Sewer District of St. Louis 2018).

Another challenge to wastewater providers throughout the state is controlling inflow and infiltration. Infiltration occurs when rainwater or groundwater enters the sewer system through cracks or defects in the sewer pipe, whereas inflow occurs when water flows into sewer pipes from sources such as yard and area drains and roof gutters. Inflow and infiltration can create flow that exceeds pipe design capacity, leading to sewer backups in homes, overflows at manholes, and untreated sanitary discharges into streams and rivers.

A current evaluation of the state of wastewater systems in Missouri was provided in the 2018 ASCE *Report Card for Missouri's Infrastructure*. The report found that, similar to Missouri's drinking water systems, the average age of wastewater infrastructure throughout large municipalities and small towns in Missouri is nearing the end of its expected life, which may result in leaks and failures within the sewer system. For this reason, the grade assigned to wastewater and stormwater infrastructure in Missouri is a C-. According to the report, wastewater and stormwater infrastructure are minimally maintained in Missouri, and municipalities often go without repairs and routine maintenance operations until a major failure occurs (ASCE 2018).

The State of Missouri's 604(b) Statewide Wastewater Assessment provides extensive data on the current state of rural wastewater treatment systems[12]. The report, published in 2011, states that 74 percent of respondents have documented inflow and infiltration issues. Furthermore, the total cost of addressing the current wastewater needs for rural communities in Missouri is estimated to be more than $170 million (MoDNR 2011).

### 5.3.2 Wastewater Infrastructure Needs

The Clean Watersheds Needs Survey (CWNS) is a comprehensive assessment of needs conducted every 4 years by EPA in compliance with Clean Water Act (CWA) Section 516(b)(1)(B). The results generated from the survey estimate the capital investment necessary to ensure that the nation's publicly owned treatment works (POTWs) meet the water quality objectives of the CWA. The total documented POTW capital investment needs required to address water quality or water quality-related health problems represent needs for up to a 20-year period as reflected in state and local planning documentation.

[12] The State of Missouri's 604(b) Statewide Wastewater Assessment surveys all cities with a population of 5,000 or less. The survey was sent to 745 rural communities and received an approximately 40 percent response rate. Respondents were found to provide wastewater services to approximately 9 percent of the population.

According to the 2012 CWNS report, Missouri's 20-year need for clean water infrastructure is over $9.6 billion.

The State of Missouri reported a total 20-year need of $9.61 billion in the 2012 CWNS report to Congress. Missouri ranked in the top 10 states with the largest need per capita and had an increase exceeding $2.5 billion from the 2008 to the 2012 survey. The survey examines seven categories, with Missouri ranking high in most. The categories are as follows (EPA 2016):

- Secondary Wastewater Treatment
- Advanced Wastewater treatment
- Conveyance System Repair
- New Conveyance Systems
- Combined Sewer Overflow Correction
- Stormwater Management Program
- Recycled Water Distribution

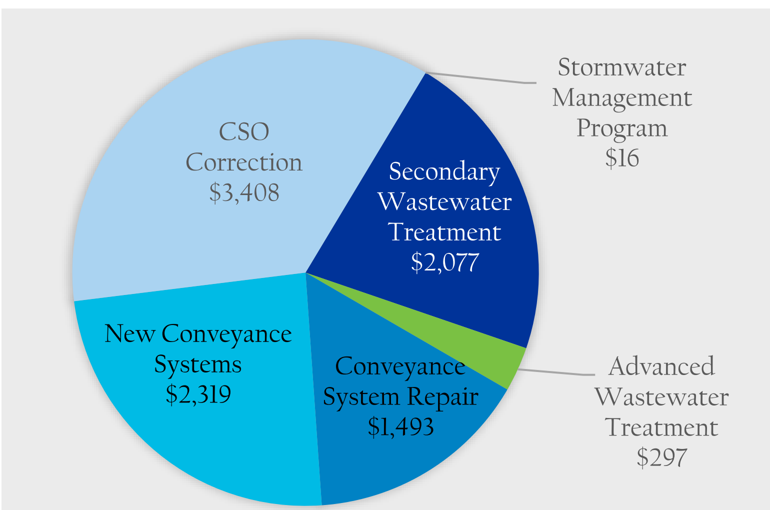


**Figure 5-5. CWNS in Millions of 2012 Dollars**
*Source: Derived from 2012 CWNS*

**Figure 5-5** provides a representation of the amount of need documented in Missouri for each category. Missouri's Secondary Wastewater Treatment need includes the capital costs for POTWs to meet secondary treatment standards, and was documented as the 4th highest in the nation at $2.1 billion. Advanced Wastewater Treatment includes capital costs for treatment plants to attain a level of treatment that is more stringent than secondary treatment. The need for this category increased by 142 percent, to $297 million, making Missouri one of 8 states with the largest percent increase since 2008. Conveyance System Repair, which includes the capital costs to rehabilitate and replace conveyance systems and has a total need of nearly $1.5 billion. The New Conveyance Systems category includes the capital costs associated with the installation of new sewer collection systems, interceptor sewers, and pumping stations. Missouri ranks 5th in the nation for New Conveyance System need, with a state need of $2.3 billion, an increase of 203 percent from the previous survey. Missouri reported a need of $3.4 billion for Combined Sewer Overflow Correction. Combined Sewer Overflow Correction includes traditional control infrastructure such as collection, storage and treatment technologies, and green infrastructure such as upland runoff techniques. The Stormwater Management Programs category includes capital costs to plan and implement structural and nonstructural measures to control stormwater. Missouri was in the list of states with the largest percent decrease (98 percent) since the previous survey, however, national need also decreased by 60 percent overall for this category, indicating a partial reason for the significant decrease was due to changes in category reporting requirements (EPA 2016). Missouri did not report any needs for the Recycled Water Distribution category. **Figure 5-6** shows a comparison of the 2008 to the 2012 survey results, both of which were converted to 2018 dollars for assessment purposes considering inflation.

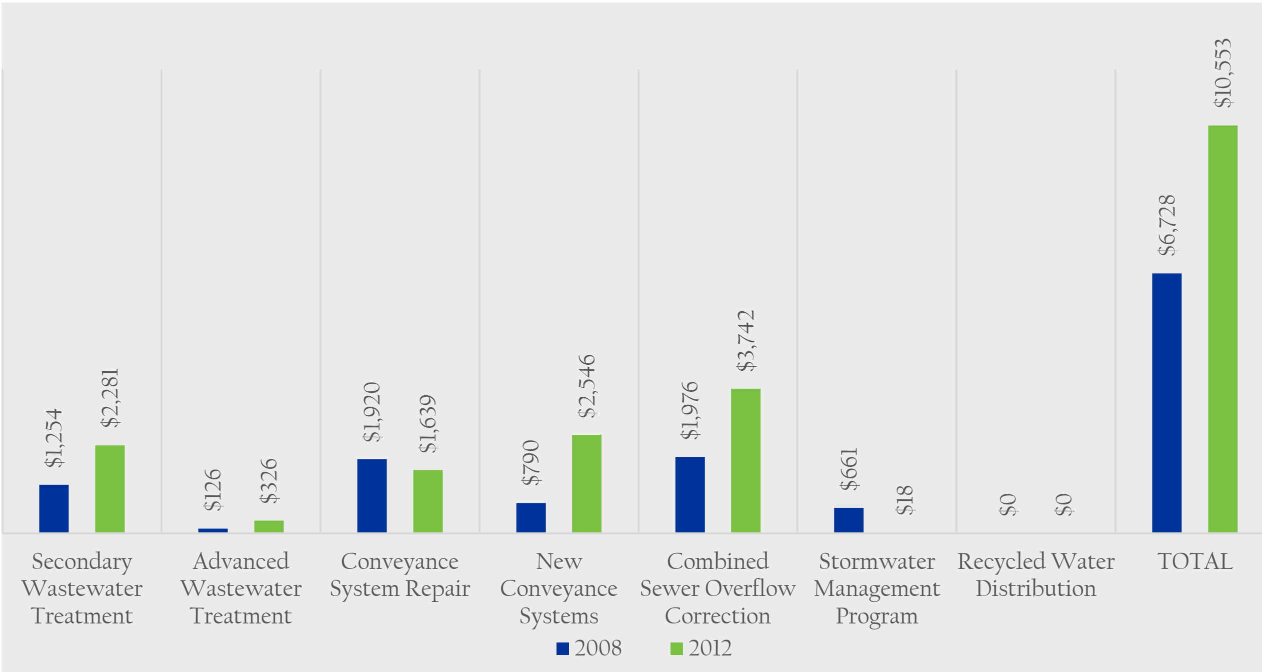


**Figure 5-6. 2008 versus 2012 CWNS Presented in Millions of 2018 Dollars**
*Source: Derived from 2008 and 2012 CWNS*

A geographical representation of total need from the CWNS throughout the country is provided in **Figure 5-7**. Compared to the rest of the country, Missouri ranks 9th on the list for total dollars needed for wastewater infrastructure improvements over the next 20 years. A rank of 1 indicates the highest need. On a per capita basis, Missouri's infrastructure needs equate to $1,605 per person, which ranks 7th in comparison to the rest of the country (EPA 2016).

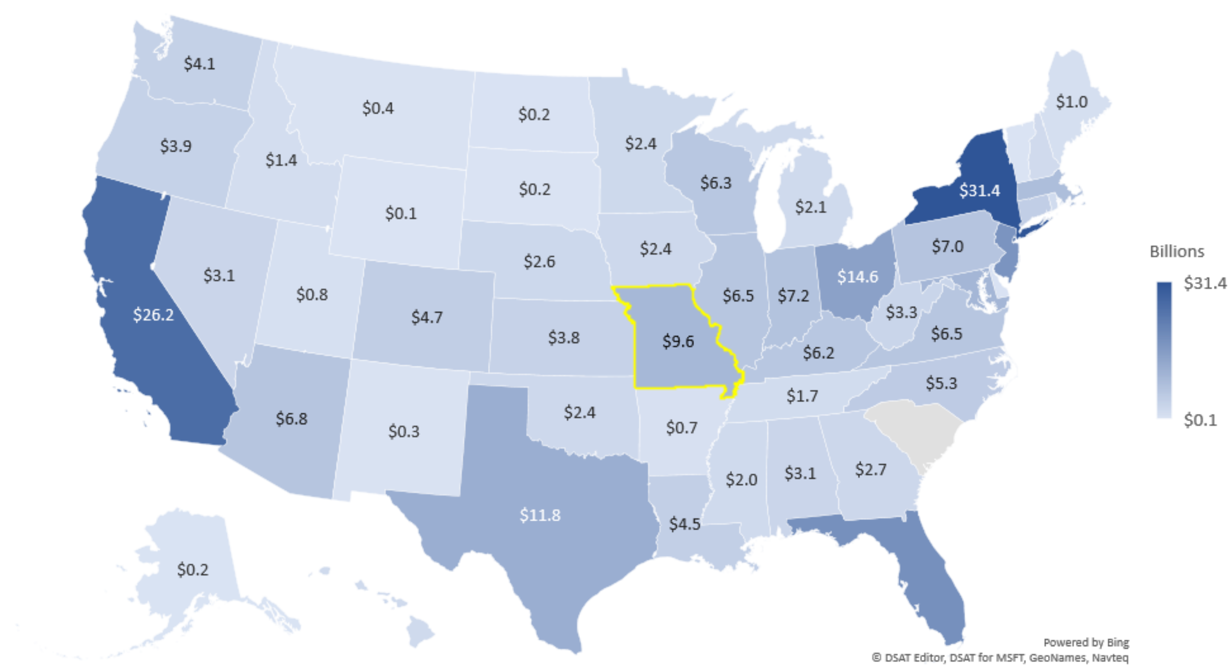


**Figure 5-7. 2012 CWNS State Comparison in Billions of 2012 Dollars**
*Source: Derived from 2012 CWNS*

The CWNS database also summarizes the state's survey results by facility. Based on the 774 wastewater treatment facilities listed in the database for Missouri, 339 completed the survey with monetary needs reported for each need category. Facilities reported needs from roughly \$34,000 to almost \$2.4 billion per facility. Those with the highest need reported extensive needs for CSO correction. The median need is approximately \$611,000 per facility.

## 5.4 Drinking Water and Wastewater Rates

Costly drinking water and wastewater infrastructure needs create challenges for utilities in balancing infrastructure investments with affordability of rates for its customer base. The Missouri Public Utility Alliance completes a biannual water and wastewater rate survey of Missouri villages, towns, and cities with populations over 100. The survey had a 96% response rate in 2018. The results of the 2018 survey were analyzed to provide a geographical representation of current water and wastewater rates throughout the state. Rates and the ratio of rates to median household income for each utility were averaged at the county level and weighted according to the population served by each reporting utility. Results for monthly water rates and wastewater rates are shown in **Figures 5-8** and **5-9**, respectively.

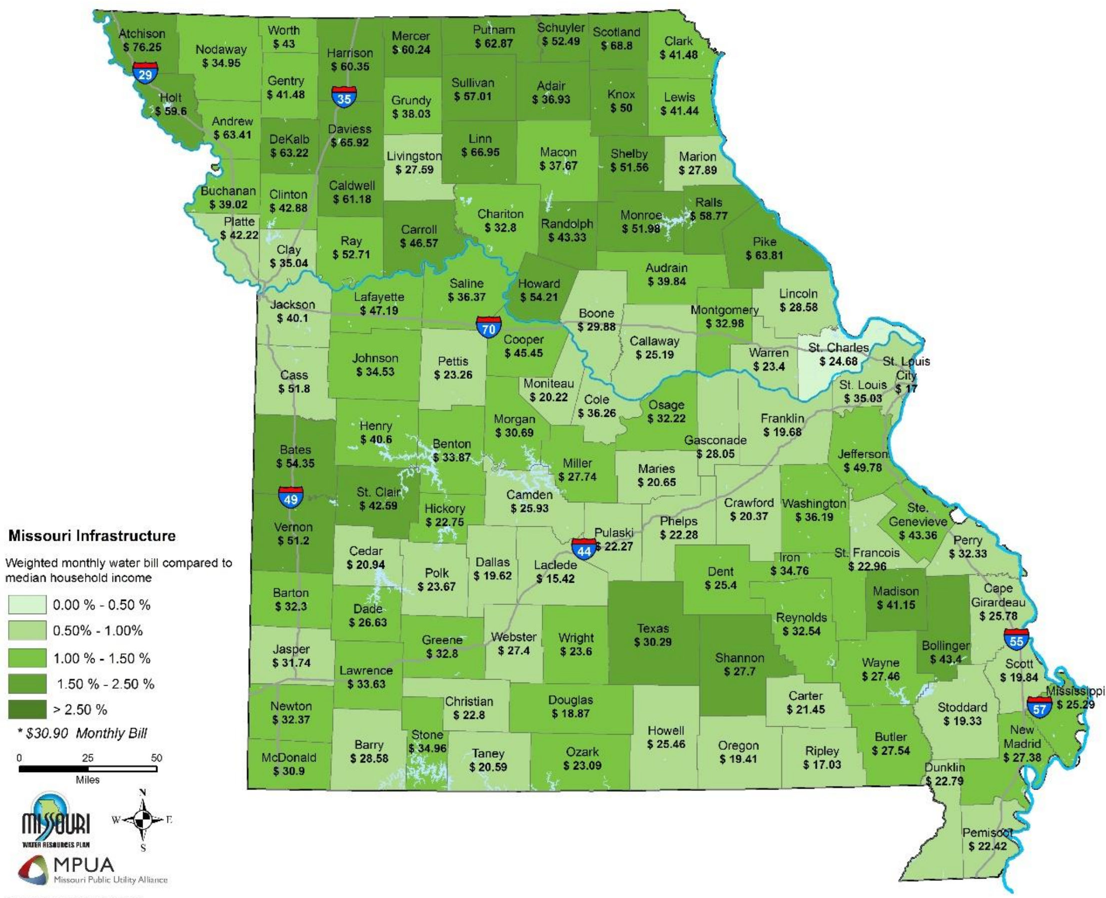


**Figure 5-8. 2018 Average Missouri Water Rates as Reported by the Missouri Public Utility Alliance**

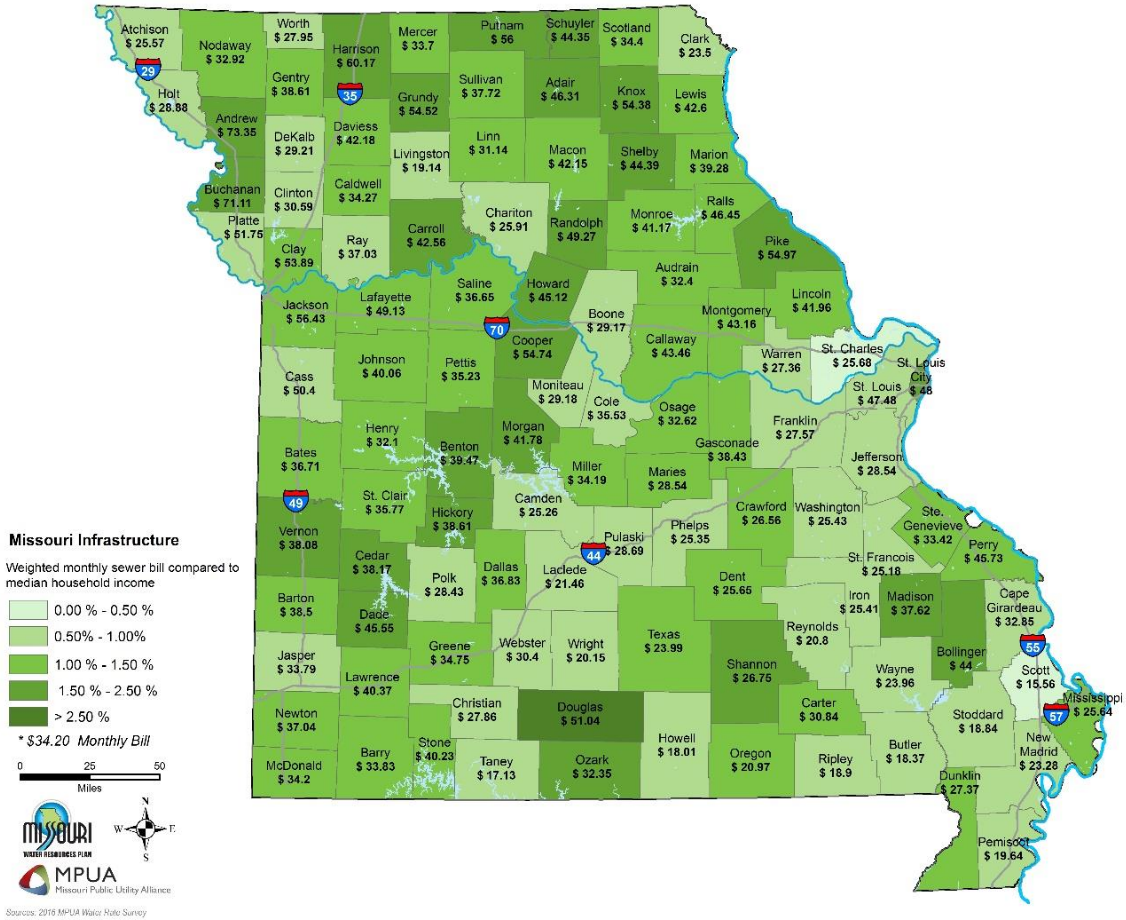


**Figure 5-9. 2018 Average Missouri Wastewater Rates as Reported by the Missouri Public Utility Alliance**

As shown in **Figures 5-8** and **5-9**, drinking water and wastewater rates are highest in several of the state's northern counties, where water and wastewater rates are a high percentage (above 2 percent in many cases) of median household income. During the technical workgroup process, utility managers expressed concerns about not only the costs associated with managing deteriorating infrastructure but also the rising costs of treating wastewater because of challenges associated with updated ammonia limits and reclassification of streams. Despite the need for significant investment in water infrastructure, utilities must also balance affordability with the need for infrastructure improvements. Affordability is defined in Section 644.145 RSMo (2015) as "*a measure of whether an individual customer or household with an income equal to or lower than the median household income for their community can pay the bill without undue hardship or unreasonable sacrifice in the essential lifestyle or spending patterns of the individual or household*." EPA guidelines state that spending under 4.5 percent of median household income for annual water and wastewater combined is considered affordable, with a general interpretation that suggests spending be under 2.5 percent for drinking water and 2.0 percent for wastewater (Bipartisan Policy Center 2017). The growing cost to repair, replace, and upgrade this infrastructure while balancing water affordability is an ongoing challenge for many Missouri water utilities.

## 5.5 Regional Water and Wastewater Infrastructure Gap Analysis

While water and wastewater utilities in Missouri face many challenges, current and future infrastructure projects will assist in bridging the gap between demands and supply while taking into account the aging nature of systems across the state. One approach to identifying and prioritizing water and wastewater infrastructure needs and projects is through an Integrated Water Resource Plan (IWRP) approach. This type of coordinated plan allows utilities to prioritize water resources projects in a manner that maximizes economic and social welfare benefits while taking ecological sustainability into account. The City of Columbia finalized an IWRP in 2017 (Columbia Water & Light Department 2017). The Springfield-Greene County Integrated Plan for the Environment is currently being developed (Springfield-Greene County 2019). These plans serve as guides for program development, budget preparation, and capital improvements planning for water systems and may serve as examples for holistic water planning for utilities statewide. Another approach is the EPA and AWWA Effective Utility Management Program. This program is designed to assist water and wastewater utility managers with identifying and prioritizing systematic changes and needs to improve utility performance. The program includes a primer, which serves as a guide or framework to help utilities identify and address projects with the greatest need, and includes reference points, keys to success, a self-assessment tool, and implementation tactics. A number of resources in support of the program are available through the partnering agencies including the AWWA, EPA, and the Water Research Foundation.

Missouri is positioned at the confluence of two of the nation's largest rivers and generally has an abundant supply of both surface and groundwater. However, several regions across the state are currently or projected to experience supply deficits, especially during drought conditions. As a result, there are several regional-scale water supply infrastructure projects in various stages of planning or development that are focused on securing adequate water supply, as shown in **Figure 5-10**. There are three major projects in northern Missouri, including two new water supply reservoirs and one pipeline. In Southwest Missouri, there are two major projects, including one new water supply reservoir and a regionalization project dependent on water supply reallocations from federal reservoirs.

### 5.5.1 East Locust Creek Reservoir (North Central Missouri Regional Water Commission)

In 2001, the North Central Missouri Regional Water Commission (NCM Commission) was formed with the goal to develop a reliable water supply for a 10-county region in North Central Missouri (Adair, Chariton, Grundy, Linn, Livingston, Macon, Mercer, Putnam, Schuyler, and Sullivan counties). The region's surface water supply is highly susceptible to droughts (Burns & McDonnell 2003). Most of the groundwater is found in deep wells that produce low yield or highly mineralized water. The usable groundwater is found in small quantities within alluvial deposits or glacial drifts. The region has had 28 water systems close in the past three decades due to inadequate reservoirs or groundwater wells and financial issues. The loss of these providers has stretched existing supplies (Allstate Consultants 2016). Additionally, communities in the region have the highest ratio of water costs to median household income in the state (NCM Commission 2019). In 2003, a feasibility study identified development of a reservoir on East Locust Creek as the most effective, least cost alternative to alleviate some of the water supply challenges in the region (Burns & McDonnell 2003).

Since the publication of the feasibility study, the NCM Commission has been working toward study of and eventual construction of the reservoir. The proposed East Locust Creek Reservoir would hold approximately 54,000 acre-feet of water at normal pool and have the capacity to provide 7 MGD of drinking water (NCM Commission 2019). Planning for the project has been funded by the citizens of Sullivan County, the current NCM Commission customers, the State of Missouri, and the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS). The total project cost is estimated to be $110 million (2019 dollars) (NCM Commission 2019).

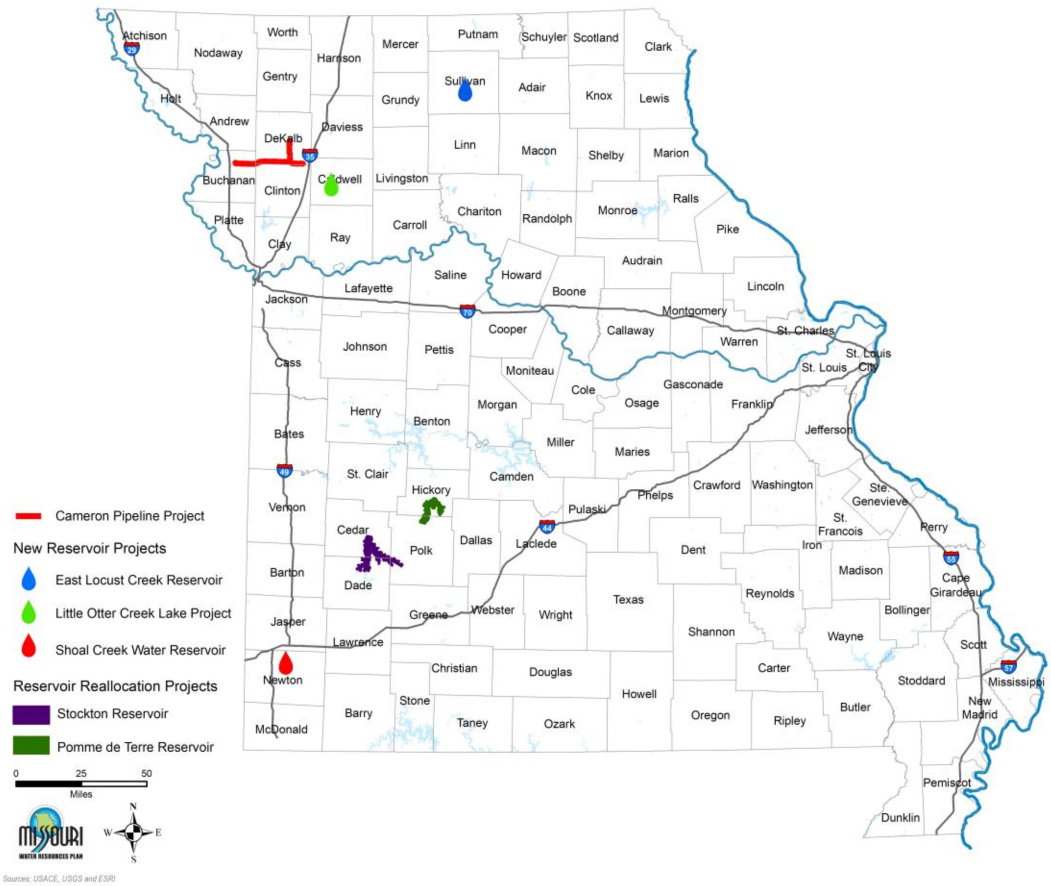


**Figure 5-10. Planned Regional Missouri Infrastructure Projects**

### 5.5.2 Little Otter Creek Lake (Caldwell County Commission)

Water supply conditions in Caldwell County have been the focus of study since the 1980s. Groundwater in the area, primarily supplied from glacial deposits and alluvial wells, is not a dependable source of supply. Many wells produce low yields that are inadequate during periods of drought, and other wells have been abandoned due to hard water that is high in manganese and expensive to treat (NRCS 2019b). Consolidation of systems in this region as occurred, with several systems now dependent on the surface water sources of other systems. The existing surface water supplies were not designed to support the county's growing population and are insufficient during periods of drought. For example, the City of Hamilton operates a drinking water reservoir that is now the raw water source for almost 25 percent of the county's population (NRCS 2019b). During the drought of 2018, Hamilton Reservoir's water levels were at a critical level of less than 2 feet above the fixed intake despite emergency restrictions imposed on customers (MoDNR 2019a).

To address these water supply challenges, the Caldwell County Commission has been working with the NRCS, landowners, USACE, and state agencies to build a multipurpose reservoir in the Little Otter Creek watershed. In addition to water supply, the reservoir will provide flood protection for 3.8 miles along Little Otter Creek and provide recreational opportunities (NRCS 2019b). The planned 344-acre reservoir would have capacity to supply a minimum of 1.2 MGD to the county's water suppliers at a cost of approximately $25 million (2019 dollars). Cost share for the project includes NRCS funding of approximately $11 million, with the additional $14 million derived from local and state sponsors including MoDNR (NRCS 2019a).

### 5.5.3 Cameron Pipeline (Great Northwest Wholesale Water Commission)

The vision for a regional water conveyance system in Northwest Missouri began more than two decades ago in response to a prolonged dry period. Representatives from a 12-county region formed a partnership aimed at developing a regional plan that would provide for a long-term and economical water supply. In 2008, this water supply partnership formed the Great Northwest Wholesale Water Commission. After detailed study of the costs and benefits of a number of potential supply alternatives, the commission is moving forward with a plan for the Cameron Pipeline (shown in **Figure 5-11**). The 36 miles of pipeline will deliver 3.1 MGD of treated water from the Missouri American Water system in St. Joseph to the towns of Cameron, Maysville, and Stewartsville (CDM Smith 2015). The three towns have a combined population of 12,000 and are projected to grow to 16,000 by 2049 (CDM Smith 2015).

The pipeline network will significantly reduce water supply risks for the area and focuses on the cities with the greatest need. The City of Cameron obtains water from three reservoirs, which are also utilized as a water supply source for Caldwell and Clinton counties. The limitations of these reservoirs pose a significant risk of the City of Cameron not meeting water supply demands during the drought of record (CDM Smith 2015). During the drought of 2018, Cameron's reservoir system declined to 36 percent of capacity (MoDNR 2019a). Maysville's water is supplied from the Willowbrook Lake system, which has significant water treatment infrastructure and operation problems that affect its reliability.

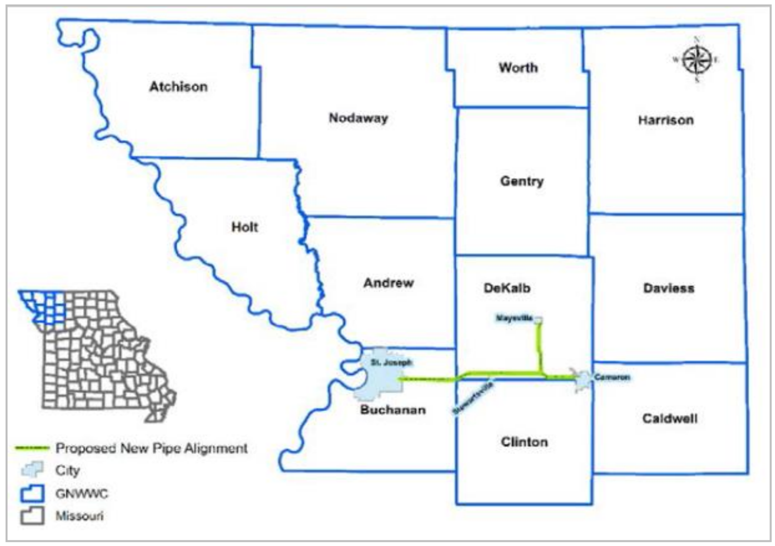

**Figure 5-11. Cameron Pipeline Project Map**

Distribution lines will parallel the two major highways in the area—U.S. Highway 36 and Missouri State Highway 33. The pipelines will cost an estimated $32.3 million (2019 dollars), which includes construction, land acquisition and easements, connection and legal fees, engineering services, and interest (CDM Smith 2019).

### 5.5.4 Southwest Missouri Water Resource Project (Southwest Missouri Regional Water)

Southwest Missouri is the fastest growing region in the state. Meeting demands for water during drought periods is a challenge for water suppliers and projected population growth in portions of the region could further exacerbate supplies. While larger communities in the region, including Springfield, Joplin, and Branson, rely primarily on surface water, the majority of the region's smaller water suppliers rely solely on groundwater. In the areas surrounding Springfield and Joplin, water is pumped from the underlying Ozark Aquifer faster than the recharge rate, which has lowered the water table. During periods of drought, Southwest Missouri is predicted to experience supply deficits (or gaps) during summer months of approximately 53 MGD by the year 2060 (CDM Smith 2014). In response to projected gaps in supply, Southwest Missouri Regional Water has a primary goal of developing additional supply sources for the 16-county region through a reallocation of water storage from Stockton Lake, Pomme de Terre Lake, and/or Table Rock Lake. Stockton Lake and Pomme de Terre Lake are active reallocation studies and potential approval of the reallocation requests would allow the purchase of annual storage to reduce the region's risk of meeting needs during drought. The reallocation study for Stockton Lake is currently in progress, with an agency decision estimated in 2021 (CDM Smith 2018). A reallocation from Stockton Lake would include an estimated minimum of 171 miles of transmission lines to connect the new intake to the member water supplies. New treatment, pumping, and storage infrastructure may also be required for this project. A reallocation study for Pomme de Terre is currently in progress.

### 5.5.5 Shoal Creek Reservoir (Missouri American Water)

As mentioned, meeting demands during drought periods is a challenge for several water suppliers in southwest Missouri. Missouri American Water has selected approximately 1,100 acres of land in Newton County for a 12-billion-gallon water storage reservoir off-channel from Shoal Creek, which has been referred to as both Shoal Creek Reservoir and Joplin Reservoir. This reservoir will address water supply shortages for the Joplin region. Missouri American is currently in the permitting process with USACE, and the project is expected to take 5 to 6 years to complete (Missouri American Water 2019). If Southwest Missouri Water Resources receives a reallocation of storage from one or more of the USACE reservoirs, water from that system could also be stored in the new reservoir (Larimore 2018).

## 5.6 Conclusions

As discussed in **Section 4** of this report, Missouri has an abundant supply of water, both in the ground and on the surface; however, aging infrastructure and regional infrastructure gaps have created a need for significant investment in water infrastructure in Missouri.

Ultimately, the biggest water and wastewater infrastructure challenge in Missouri is aging infrastructure. While increasing replacement rates is the overall solution to this problem, in many cases, these projects cannot be completed without additional funding and/or rate increases. In addition to aging infrastructure, some utilities are battling to keep up with infrastructure needs associated with rapid population growth while others struggle with declining populations and therefore declining tax bases and customers to pay for necessary infrastructure maintenance, replacement, and construction. Even with commendable infrastructure replacement rates at or above the national average and leaks and losses rates in a similar category, major utilities are struggling to secure the funds for capital spending needed to keep systems in good working order. Furthermore, small utilities are struggling to maintain existing systems and operate reactively as infrastructure repairs and replacement are required, with no available assets to address proactive replacement of aging infrastructure.

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# Section 6 Drinking Water and Wastewater Funding Options

## 6.1 Introduction

Adequate and reliable water and wastewater infrastructure are vital to public health and the prosperity of Missouri's communities. The ability to effectively develop and properly maintain critical water infrastructure is often contingent on the availability of outside funding, such as loans and grants. Funding for water and wastewater systems is available through multiple federal and state sources. Public finance sources are also available, including public bond markets, bank programs, and bond funds. Each of these programs has its own requirements, structural components, incentives, and drawbacks. Regardless of the funding method, the ability to fund needed improvements and resulting debt service is a critical element of the decision-making process for water systems' governing bodies. Balancing the demands of system maintenance and growth with the community's ability to pay is often the most difficult challenge for a governing body.

There is currently a need in Missouri for funding for water and wastewater infrastructure projects. It is estimated that the current needs for drinking water projects total $8.9 billion while wastewater needs are $9.6 billion (EPA 2018, 2016).

### Overview of Section 6 Drinking Water and Wastewater Funding Options

This section of the Missouri WRP characterizes water and wastewater infrastructure funding opportunities available in Missouri. Subsections are organized according to the source of funding opportunities, as follows:

- Section 6.2 Federal Assistance for Water Infrastructure – provides a summary of the federal programs that are available to provide funding for water and wastewater utilities in Missouri.
- Section 6.3 State Assistance for Water Infrastructure – provides a summary of the state programs that are available to provide funding for water and wastewater utilities in Missouri.
- Section 6.4 Private Assistance for Water Infrastructure – provides a summary of the private companies and nonprofit foundations that are available to provide funding for water and wastewater utilities in Missouri.

## 6.2 Federal Assistance for Water Infrastructure

### 6.2.1 Municipal Bonds

Tax-exempt municipal bonds have been the primary funding mechanism for water infrastructure improvements nationwide since 1913, when the Revenue Act first codified exemption of interest on municipal bonds from federal income tax. Municipal bonds are loans issued by government entities to fund capital projects. Because bonds' interest earnings are exempt from federal income tax, communities are able to borrow money for infrastructure needs at a low borrowing rate, saving millions of dollars annually for local water ratepayers. Nationwide in 2016, communities issued nearly $38 billion in municipal bonds to pay for sewer, sanitation, and water infrastructure projects (National Association of Clean Water Agencies [NACWA] 2017).

In 2016, communities across Missouri issued $485 million in municipal bonds to fund improvements to drinking water and wastewater infrastructure. The income tax exemption on interest on this $485 million allows these communities to offer low interest rates, resulting in a savings of an additional $206 million that would be incurred based on basic bond rates over their payback periods at a cost to Missouri cities and towns (NACWA 2016).

### 6.2.2 U.S. Economic Development Administration

The U.S. Economic Development Administration (EDA) offers two primary programs that provide funding for the development of water and wastewater infrastructure in Missouri: the Public Works Program and the Economic Adjustment Assistance Program.

*Public Works Program*

The EDA's Public Works Program aids distressed communities by providing funding for existing physical infrastructure improvements and expansions. The Program supports the acquisition or development of land and infrastructure improvements needed to attract new industry, encourage business expansion, diversify local economies, and generate or retain long-term, private sector jobs and investments (EDA 2012). Funding from the EDA Public Works Program has been used to fund replacement of aging and unreliable water infrastructure in cases where the project will allow for continued business momentum and job creation in the area (EDA 2017).

*Economic Adjustment Assistance Program*

The Economic Adjustment Assistance Program provides assistance in regions experiencing adverse economic changes. This program offers technical, planning, and public works and infrastructure assistance for projects in communities experiencing adverse economic challenges. Implementation grants are offered through the program for infrastructure improvements demonstrating an improvement in regional economic development. Funded activities include site acquisition, site preparation, construction, rehabilitation, and equipping of facilities (EDA 2019).

Additionally, EDA provides planning and local assistance programs that help eligible recipients develop economic plans and studies. These services can be utilized for water and wastewater planning.

### 6.2.3 U.S. Environmental Protection Agency

*Water Infrastructure Finance and Innovation Act*

In 2014, EPA established the Water Infrastructure Finance and Innovation Act (WIFIA) as a federal credit program for eligible water and wastewater infrastructure projects. The WIFIA program provides long-term, low-cost, supplemental loans for regionally and nationally significant water infrastructure projects. WIFIA loans can be combined with various funding sources and offer a single fixed interest rate equal to the United States Treasury rate of a similar maturity. The minimum project size is $20 million for large communities and $5 million for small communities (population 25,000 or less). WIFIA can fund up to 49 percent of the eligible project costs while total federal assistance may not exceed 80 percent of a project's eligible costs. Both development and implementation activities for eligible projects are funded under the program. Eligible borrowers include local, state, tribal, and federal entities; partnerships and joint ventures; corporations and trusts; and Clean Water State Revolving Fund (CWSRF) and Drinking Water State Revolving Fund (DWSRF) program recipients (EPA 2019).

Eligible projects include:

- Projects eligible for the CWSRF, notwithstanding the public ownership clause
- Projects eligible for the DWSRF
- Enhanced energy efficiency projects at drinking water and wastewater facilities
- Brackish or seawater desalination, aquifer recharge, alternative water supply, and water recycling projects
- Drought prevention, reduction, or mitigation projects
- Acquisition of property if it is integral to the project or will mitigate the environmental impact of a project

> The CWSRF and DWSRF programs offer grants and low-interest financing to construct drinking water, wastewater, and stormwater projects (further discussed in **Section 6.2**).

- A combination of projects secured by a common security pledge or submitted under one application by a state revolving fund program

### 6.2.4 U.S. Department of Agriculture Rural Development

USDA Rural Development is a federal agency that offers loans, grants, loan guarantees, and technical assistance in rural areas and small towns in an effort to encourage economic development. USDA Rural Development provides an extensive list of services and programs to support rural development, many of which are specific to communities and nonprofits. Programs to highlight that support the development of water infrastructure include Rural Business Development Grants, Water & Waste Disposal Loan & Grant Program, Water & Waste Disposal Loan Guarantees, Emergency-Community Water Assistance Grants, and Special Evaluation Assistance for Rural Communities and Households. Though infrastructure is a necessity for water systems, the importance of technical assistance/training cannot be overlooked. While not discussed in this document, it is important to note that the USDA Rural Development agency offers two programs—Solid Waste Management Grants and Technical Assistance/Training/Circuit Rider—meant to assist communities in training. The USDA Rural Development website provides a complete overview of the programs and services offered (USDA 2019a).

*Water and Wastewater Disposal Loans and Grants*

USDA offers loans and grants to households and businesses in eligible rural areas to provide financing for water, sanitary sewage, solid waste disposal, and stormwater infrastructure through the Water & Wastewater Disposal Loan & Grant Program. This program offers assistance to qualified applicants who cannot otherwise obtain commercial credit on reasonable terms. Loans are offered with a term limit of 35 years, except for nonprofit corporations, which may borrow for up to 40 years. Loan interest rates are based on the economic health of the community or entity, determined by the median household income of the service area and need for the project by health or sanitary standards. Loan interest rates are designated as poverty, intermediate, or market (USDA 2019b).

Eligible fund applicants include public bodies such as municipalities (cities, towns, and villages), counties, and special purpose districts (water districts and sewer districts); nonprofit corporations; and federally recognized Indian tribes. Loans and/or grants are not made to municipalities with a population of more than 10,000, and municipalities with a population of less than 5,500 will be given priority.

Projects eligible for funds include:

- Drinking water sourcing, treatment, storage, and distribution
- Sewer collection, disposal, and closure
- Solid waste collection, disposal, and closure
- Stormwater collection, transmission, and disposal (USDA 2019b)

Water and waste disposal grant funds may be available for up to 75 percent of the development cost of a project and are considered only after a determination is made on the maximum loan amount the community can afford while maintaining reasonable user rates. Grants may be used to supplement other funds borrowed or furnished by applicants for project costs and may be combined with USDA loans (USDA 2019b).

*Water and Wastewater Disposal Loan Guarantees*

USDA offers guarantees on loans to construct or improve drinking water, sanitary sewer, solid waste disposal and stormwater infrastructure. Through this program, the USDA assists towns and rural areas that may otherwise be unable to secure a loan by assuming the debt obligation for the loan (typically 90 percent of the loan amount) in the event that the borrower defaults. In order to apply, the town or rural area must have a population of 10,000 or less (USDA 2019c).

*Emergency-Community Water Assistance Grants*

USDA also administers the Emergency-Community Water Assistance Grant program, which is designed to assist rural communities in obtaining or maintaining adequate water supply following a significant decline in quality or quantity of drinking water because of an emergency that threatens the availability of safe and reliable drinking water. Eligible projects must service a rural area with a population of 10,000 or less that has a median household income not in excess of the statewide nonmetropolitan median household income (USDA 2019d).

*Special Evaluation Assistance for Rural Communities and Households*

The Special Evaluation Assistance for Rural Communities and Households program, also referred to as SEARCH, assists rural, financially distressed communities with populations of 2,500 or less with feasibility studies, design, and technical assistance on water or waste disposal projects. To be considered financially distressed, the area or community must have a median household income below the poverty line or below 80 percent of the statewide nonmetropolitan median household income (USDA 2019e).

*Rural Business Development Grants*

Rural business development grants are competitive grants offered through USDA to rural areas or towns "outside the urbanized periphery of any city with a population of 50,000 or more" (USDA 2019f). Applications compete at the state office level and are evaluated based on factors such as job creation, percent of nonfederal funding committed, and economic need. There is no cost sharing requirement, and grants generally range from $10,000 to $500,000 with no established maximum grant amount (USDA 2019f).

### 6.2.5 U.S. Army Corps of Engineers

*Planning Assistance to States*

USACE can provide states, local governments, and other nonfederal entities assistance in the development of comprehensive plans for the development, utilization, and conservation of water resources. Funds under this program are cost shared on a 50 percent federal, 50 percent nonfederal basis, and cannot be used for design or construction. In recent years the program has funded several projects in Missouri focused on water supply and demand, which may precede water supply expansions or reallocations (USACE 2019).

### 6.2.6 Delta Regional Authority

Southeastern Missouri is part of the Delta Regional Authority (DRA), which was established in 2000 and serves 252 counties and parishes within the Mississippi River Delta region. DRA's flagship grant program provides funding for projects within the service region aimed at strengthening the Delta economy. Funds are provided through States' Economic Development Assistance Program. In 2019, DRA invested over $300,000 in Missouri projects for water system expansion and improvements. All projects are developed in coordination with Local Development Districts, which assist to review projects for eligibility (DRA 2019).

## 6.3 State Assistance for Water Infrastructure

### 6.3.1 Missouri Department of Natural Resources

MoDNR administers low-interest loans and grants to municipalities, counties, public water and public sewer districts, and political subdivisions for wastewater and drinking water infrastructure projects. Privately owned and not-for-profit facilities may also apply for loans for certain types of projects. MoDNR's Financial Assistance Center includes a team of engineers, project coordinators, and administrative staff who assist Missouri communities in planning and funding water, wastewater, and stormwater infrastructure projects.

*Drinking Water State Revolving Fund*

Congress established the DWSRF in the 1996 amendments to the Safe Drinking Water Act. The program is a federal-state partnership aimed at ensuring that communities have safe drinking water by providing low interest loans and grants to eligible recipients for drinking water infrastructure projects. Congress appropriates funding for the DWSRF that is then awarded to states by EPA based on the results of the most recent Drinking Water Infrastructure Needs Survey and Assessment, or DWINSA, which is covered in detail in **Section 5.2.2**. Missouri provides a 20 percent match to the federal grants.

MoDNR has received requests for 20 DWSRF projects, totaling more than $61 million for fiscal year 2019.

Eligible projects for DWSRF funding are those that are needed to construct new infrastructure or to replace, rehabilitate, expand, or upgrade existing infrastructure to allow the water system to provide existing customers with safe drinking water. Projects ineligible for DWSRF funding are those that substantially accommodate future growth, are driven by fire protection needs, are for source water protection, or benefit a raw water reservoir or dam-related need. Projects outside of capital needs or that do not address the public health goals of the Safe Drinking Water Act are also ineligible for DWSRF funding.

DWSRF grants are awarded with priority given to disadvantaged communities. Disadvantaged communities are those with a population of 3,300 or less with average drinking water rates of at least 2 percent of median household income. Additionally, the median household income of the service area must be at or below 75 percent of the state average median household income. As funding is available, disadvantaged communities may be awarded a grant up to 75 percent of the project costs, with a maximum amount of $2 million (MoDNR 2019a).

MoDNR has received requests for 39 CWSRF projects, totaling more than $296 million for fiscal year 2019.

*Clean Water State Revolving Fund*

The CWSRF was established by the 1987 amendments to the CWA as a financial assistance program for a range of wastewater infrastructure projects. The program is a federal-state partnership between EPA and the states that replaced EPA's Construction Grants program. Similar to the DWSRF program, grants are provided by EPA, and the state of Missouri contributes an additional 20 percent to match the federal grants. The program provides low interest loans and grants to eligible recipients for wastewater and stormwater infrastructure projects.

There are 11 types of projects eligible to receive CWSRF assistance:

- Construction of publicly owned treatment works
- Nonpoint source pollution management programs
- National estuary program projects
- Decentralized wastewater treatment systems
- Stormwater
- Water conservation/efficiency/reuse
- Watershed pilot projects
- Energy efficiency
- Water reuse
- Security measures at publicly owned treatment works
- Technical assistance

Funding from the CWSRF is available in various forms, including grants, loans, the purchase or refinance of debt, guarantees and insurance, guarantees of State Revolving Fund (SRF) revenue debt, loan guarantees, additional subsidization, and earned interest.

CWSRF affordability grants with loans may be available to communities with populations of 10,000 or less. Eligible applicants are those communities that would have difficulty financing projects without additional subsidization. As funding is available, eligible communities may be awarded a grant up to 50 percent of the eligible project costs, with a maximum grant of $2 million. Additionally, CWSRF regionalization incentive grants are currently under development and will be available for municipalities connecting small public or private systems, with a priority given for enforcement connections (MoDNR 2019b).

*Small Borrower Loan Program*

Under the Small Borrower Loan Program, qualifying communities or public water districts with a population or service area of less than 1,000 may be considered for a direct loan for drinking water or wastewater system improvements for up to $100,000, with a maximum 20-year repayment term (MoDNR 2019c).

*Rural Sewer Grants*

MoDNR's rural sewer grant program offers two types of grants that can be used for wastewater construction projects:

- Collection for Unsewered Areas Grants
- Special Needs Grants

The Collection for Unsewered Areas Grants may be used to fund connection of homes and businesses currently served by nonpermitted systems such as septic tanks to a central wastewater treatment system. Special Needs Grants are used to fund the additional costs of meeting higher EPA or MoDNR standards for wastewater treatment. Entities eligible for these grants include public sewer districts, public water districts, and communities with populations of less than 10,000. The maximum grant amount is the lesser of 50 percent of the eligible project cost or $3,000 per service connection. Grants are capped at $500,000 (MoDNR 2019d).

Missouri DNR Special Needs Grants have been used to fund additional costs of upgrades to meet ammonia limits and disinfection requirements.

*Small Community Engineering Assistance Program*

MoDNR offers grants through the Small Community Engineering Assistance Program for municipalities, counties, public sewer or water districts, political subdivisions, or instrumentalities of the state with populations of less than 10,000. This program assists small communities making wastewater treatment and collection system improvements by providing funding for wastewater engineering costs incurred in preparation of a facility plan. Eligible communities may receive an 80 percent grant with a 20 percent recipient match while disadvantaged communities may be eligible to receive up to a 90 percent grant with a 10 percent recipient match, not to exceed $50,000. Eligible costs are those that are directly incurred in the development of a facility plan (MoDNR 2019d).

*Drinking Water Engineering Report Services Grants*

Community water systems serving populations of 3,300 or less may be eligible for a Drinking Water Engineering Report Services Grant. This funding helps community water systems create an engineering report. Engineering reports help systems achieve and maintain technical, managerial, and financial capacity and compliance with drinking water regulations. The grant pays up to 80 percent of costs up to a maximum of

$20,000, and disadvantaged communities can receive up to 100 percent of costs up to a maximum of $25,000. Communities with populations greater than 3,300 may be considered if they will provide benefit to small systems through regionalization or consolidation (MoDNR 2019e).

*Missouri Multipurpose Water Resource Program Fund*

The Missouri Multipurpose Water Resource Program Fund offered by MoDNR was established in 2016. The program focuses on funding projects that cannot meet full funding needs through DWSRF or similar programs (described above), particularly those that provide a long-term, reliable public water supply, treatment, or transmission facility in an area that exhibits significant need. Funds are available to any political subdivision of the state or wholesale water district, and require submission of a project plan to MoDNR. Planning and feasibility studies are eligible for grants with cost share. Construction projects are eligible for loans, and sponsors for these projects must propose a schedule to remit contributions back to the fund (Revised Statutes of Missouri 2019).

### 6.3.2 Environmental Improvement and Energy Resources Authority

The Environmental Improvement and Energy Resources Authority (EIERA), which was established by the Missouri General Assembly in 1972, is a quasi-governmental environmental finance agency that is administratively assigned to MoDNR. The EIERA provides financing for planning, design and construction of drinking water and wastewater systems, and nonpoint source facilities. Missouri SRF bonds are purchased and resold nationally by the EIERA. The EIERA has sold more than $2.67 billion in bonds through the SRF to support residents with water and wastewater infrastructure needs (EIERA 2016).

### 6.3.3 Missouri Development Finance Board

Initially established in 1982, the Missouri Development Finance Board is composed of 12 members who are tasked with administering 15 different programs in accordance with the Revised Statutes of Missouri Sections 100.250 to 100.297 (Missouri Development Finance Board 2010). The following describes two programs relevant to water infrastructure.

*Missouri Infrastructure Development Opportunities Commission Program*

The Missouri Infrastructure Development Opportunities Commission Program is authorized to provide long-term interest rate loans to local political subdivisions, including public sewer and waste districts. Rural communities with populations up to 5,000 and rural districts that have a financial hardship pertaining to their infrastructure project and are unable to obtain financing elsewhere are eligible to request loans between $25,000 and $150,000 for water and wastewater infrastructure projects (Missouri Development Finance Board 2019a).

*Public Entity Loan Program*

The Public Entity Loan Program provides loans to finance general public infrastructure improvements and economic development projects. The loans are funded by the issuance of individually structured tax-exempt revenue bonds by the Board, tailored to meet the specific needs of each public entity. The minimum loan amount is $1 million, with no cap on the maximum amount. Eligibility for this program is determined based on the credit of the applicant. Lower interest rates (partial credit enhancements) are possible for projects that are considered to have "substantial impacts to the state" (Missouri Development Finance Board 2019b).

### 6.3.4 Missouri Department of Economic Development

*Community Block Development Grants*

The Missouri Department of Economic Development offers Community Development Block Grants for water and wastewater programs to Missouri communities to develop a greater capacity for growth, address health and safety concerns, and improve local facilities. The Community Development Block Grants program aids communities in establishing or improving their local water or sewer system. These grants may be used for the construction of sewer treatment and collection and water treatment and distribution projects for publicly owned systems. Construction of new water or sewer systems or expansion of existing systems that have substantiated health concerns are prioritized over other applicants. To be eligible for this grant, project beneficiaries must be at least 51 percent low-to-moderate income, with a total cost of $750,000, $5,000 per household, or $7,500 per household if serving under 100 households, whichever is less (Missouri Department of Economic Development 2019).

## 6.4 Private Assistance for Water Infrastructure

### 6.4.1 CoBank

CoBank offers rural water and wastewater loans for water and wastewater nonprofit associations, municipalities, and investor-owned utility companies. CoBank also offers a streamlined refinance program to rural water and wastewater providers. This streamlined process is for refinancing existing USDA Rural Development loans. Loans refinanced under the program offer benefits, including low interest rates, simple credit application packets, flexible structures that reduce payments or shorten maturity, streamlined approval and closing processes, and patronage refunds (CoBank 2019).

### 6.4.2 National Rural Water Association

*Rural Water Loan Fund*

The National Rural Water Association administers the Rural Water Loan Fund, which provides low-cost loans for small water and wastewater utilities. These loans offer below market interest rates with a maximum repayment period of 10 years, with loan amounts not to exceed $100,000 or 75 percent of the total project cost, whichever is less. Eligible systems must be public entities (municipalities, counties, special purpose districts, Native American tribes, nonprofit corporations, and cooperatives) serving up to 10,000 people or public entities in rural areas not subject to population limits. Emergency loans consist of a 90-day no-interest loan, with an immediate turnaround on applications (National Rural Water Association 2019). The Rural Water Loan Fund was established through a grant from USDA's Rural Utilities Service Agency. Repaid loans replenish the fund and make new loans. Projects eligible for these funds include:

- Predevelopment (planning) costs for infrastructure projects
- Replacement equipment, system upgrades, maintenance, and small capital projects
- Energy efficiency projects to lower costs and improve system sustainability
- Disaster recovery or other emergency projects (National Rural Water Association 2019)

### 6.4.3 Additional Nonprofit Foundations

In addition to federal and state resources, several nonprofit foundations offer funding for water infrastructure. EPA lists five nonprofit foundations that have provided funding for water infrastructure (EPA 2019b):

- The Johnson Foundation at Wingspread
- Rockefeller Foundation
- Ford Foundation
- Walton Family Foundation
- Pisces Foundation

## 6.5 Summary of Funding Opportunities for Water Infrastructure

A summary of federal and state funding opportunities for water infrastructure is shown in **Table 6-1**.

**Table 6-1. Federal and State Water Infrastructure Assistance**

| Organization | Program | Purpose | Type of Funding |
|---|---|---|---|
| Federal Municipal Bonds | Tax Exempt Municipal Bonds | The interest paid on these government-issued loans is exempt from federal taxes, and in some cases, state and local taxes. | Loan |
| U.S. Economic Development Administration | Public Works Program | This program focuses on revitalization of distressed communities through funding public works upgrades and/or expansions. | Grant with cost share or matching requirement |
| | Economic Adjustment Assistance Program | This program offers technical, planning, and public works and infrastructure assistance for projects to communities experiencing economic challenges. | Grant with cost share or matching requirement |
| US Environmental Protection Agency | Water Infrastructure Finance and Innovation Act | This program provides long-term, low-cost supplemental loans for regional and national water infrastructure projects. | Loan |
| US Department of Agriculture Rural Development | Water and Wastewater Disposal Loans and Grants | This program offers assistance to applicants who cannot otherwise obtain commercial credit on reasonable terms. Loans are available to municipalities with populations of less than 10,000, and municipalities with populations of less than 5,500 are given priority. Grants may be available. | Loan and grant with cost share or matching requirement |
| | Water and Wastewater Disposal Loan Guarantees | Through this program, the USDA assists towns and rural areas that may otherwise be unable to secure a loan by assuming the debt obligation for the loan (typically 90 percent) in the event that the borrower defaults. In order to apply, the town or rural area must have a population of 10,000 or less. | Loan guarantee |
| | Emergency Community Water Assistance Grants | This program is designed to assist rural communities in maintaining or obtaining adequate water supply following an emergency. | Grant |
| | Special Evaluation Assistance for Rural Communities and Households | This program assists rural, financially distressed communities with populations of 2,500 or less with feasibility studies, design, and technical assistance on water projects. | Grant |
| | Rural Business Development Grants | Rural business development grants are competitive grants offered through the USDA to rural areas or towns outside the urbanized periphery of any city with a population of 50,000 or more. | Grant |
| US Army Corps of Engineers | Planning Assistance to States | USACE can provide local governments, states, and other nonfederal entities assistance in the development of comprehensive plans for the development, utilization, and conservation of water resources. | Cost shared on a 50 percent federal, 50 percent nonfederal basis |

| Organization | Program | Purpose | Type of Funding |
|---|---|---|---|
| Delta Regional Authority | States' Economic Development Assistance Program | This flagship grant program provides funding for projects within the service region (portions of southeastern Missouri) aimed at strengthening the Delta economy. Projects may include water system expansion and improvement. | Grant |
| Missouri Department of Natural Resources | Drinking Water State Revolving Fund | Eligible projects for funding are those that are needed to construct new infrastructure or to replace, rehabilitate, or expand/upgrade existing infrastructure to allow the water system to provide existing customers with safe drinking water. | Loan and grant with cost share or matching requirement |
| | Clean Water State Revolving Fund | Funding for wastewater and stormwater infrastructure projects is available in various forms including grants, loans, the purchase or refinance of debt, guarantees and insurance, guarantees of SRF revenue debt, loan guarantees, additional subsidization, and earned interest. | Loan and grant with cost share or matching requirement |
| | Small Borrower Loan Program | Under this program, qualifying communities or public water districts with a population or service area of less than 1,000 may be considered for a direct loan for drinking water or wastewater system improvements for up to $100,000. | Loan |
| | Rural Sewer Grants | Grants may be used to fund connection of homes and businesses currently served by nonpermitted systems, such as septic tanks, to a central wastewater treatment system. Additional grants are used to fund the additional costs of meeting higher EPA or MoDNR standards for wastewater treatment. Entities eligible for these grants include public sewer districts, public water districts, and communities with populations of less than 10,000. | Grant with a 50 percent cost share or matching requirement |
| | Small Community Engineering Assistance Program | This program assists small communities with populations of less than 10,000 make wastewater treatment and collection system improvements by providing funding for wastewater engineering costs incurred in preparation of a facility plan. | Grant with a 10 to 20 percent cost share or matching requirement |
| | Drinking Water Engineering Report Services Grants | This funding helps community water systems serving populations of 3,300 or less create an engineering report. | Grant with 20 percent cost share; disadvantaged communities may receive up to 100 percent of costs |

| Organization | Program | Purpose | Type of Funding |
|---|---|---|---|
| | Missouri Multipurpose Water Resource Fund | The program focuses on funding projects that do not qualify for the DWSRF, particularly those that provide a long-term, reliable public water supply, treatment, or transmission facility in an area that exhibits significant need. | Grant with cost share for planning and feasibility studies; Loans for construction projects |
| Environmental Improvement and Energy Resources Authority (EIERA) | SRF Bond Program | This organization provides financing for planning, design, and construction of drinking water and wastewater systems, and nonpoint source facilities. Missouri SRF bonds are purchased and resold nationally by the EIERA. | Loan |
| Missouri Development Finance Board | Missouri Infrastructure Development Opportunities Commission Program | This program provides loans to local political subdivisions including public sewer and waste districts. Rural communities with populations up to 5,000 and rural districts that have a financial hardship pertaining to their infrastructure project and are unable to obtain financing elsewhere are eligible to request loans between $25,000 and $150,000 for water and wastewater infrastructure projects. | Loan |
| | Public Entity Loan Program | This program provides loans to finance general public infrastructure improvements and economic development projects. The minimum loan amount is $1 million, with no cap on the maximum amount. | Loan |

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# Section 7 Developing Options for Future Water Needs

## 7.1 Introduction

While Missouri has a large supply of water overall, it is not always where it is needed, found when it is needed, or of a usable quality. As discussed in **Section 5**, a portion of Missouri's immediate water supply needs can be addressed through projects and processes that are currently being pursued by local and regional water providers. As new water supply needs or challenges emerge, there are numerous and diverse options available to water providers and users that can be implemented independently or in combination to meet these needs. This section explores the water supply options for the two primary sectors of water demand to which they apply—municipal & industrial (M&I) and agricultural.

### Overview of Section 7 Developing Options for Future Water Needs

This section discusses options for meeting future water supply needs and their advantages and disadvantages. Subsections are organized as follows:

- Section 7.2 Municipal and Industrial Options – presents M&I options, including additional surface water storage, conveyance, enhanced water treatment, water reuse, expanded conservation, conjunctive use, system redundancy, and regionalization.
- Section 7.3 Agricultural Options – presents agricultural options, including additional storage, conveyance, conjunctive use, system efficiencies, recycled water, expanded groundwater use, and surface impoundments.

## 7.2 Municipal and Industrial Options

Options to address future M&I water needs fall under one of the following categories, which are described in detail in the following subsections:

- Additional surface water storage
- Conveyance
- Enhanced water treatment
- Water reuse
- Expanded conservation
- Conjunctive use of groundwater and surface water
- System redundancy
- Regionalization

### 7.2.1 Additional Surface Water Storage

Surface water storage projects capture and store water for future use. Additional storage can be achieved by constructing new reservoirs; expanding the capacity of existing reservoirs through enlargement, removal of sediment, or repair; and using existing storage in reservoirs that is either intended for M&I water supply or for other purposes.

#### New Storage

New storage projects include the construction of on-channel or off-channel reservoirs. Off-channel reservoirs require diversion or pumping facilities from a river or stream to deliver the diverted water to a reservoir. On-channel reservoirs are constructed by building a dam across the main channel of a stream and allowing that stream and its tributaries to fill the newly created reservoir. The economic feasibility of new reservoirs is determined by comparing the benefits of the storage project with the costs associated with construction, mitigation, annual operation and maintenance, and impacts to property and natural resources. Other factors that contribute to reservoir viability include suitable water quality, ability to meet demand during a drought of record (firm yield), proximity to water users or conveyance distance, suitability of dam sites, sedimentation load, presence of endangered or threatened species, and cultural resources that might be impacted.

There are several potential benefits realized by developing new storage projects. In areas where the quality or quantity of groundwater limits its use and streamflow is susceptible to droughts, surface water reservoirs provide critical drought resiliency by capturing water during high-flow periods and storing it for use. Systems utilizing a reservoir in tandem with another water source (e.g., groundwater, additional surface water) reduce the risk of supply shortfalls as the risks of water quality issues, supply shortages, and infrastructure failures are spread among the water supply sources. Reservoirs may also create new opportunities for recreation, flood control, wildlife habitat, and hydropower generation. When assessed over the lifespan of the reservoir, constructing a new reservoir offers a long-term, sustainable solution to water supply challenges.

Possible trade-offs associated with developing new storage projects include impacts to the environment and cultural resources, and loss of stream recreational opportunities, agricultural resources, and property. Initial capital costs can be higher compared to other water supply options. Permitting and mitigation can be considerably more expensive and lengthier than other water supply options and have an uncertain outcome. Sedimentation rates may impact the useful life of the reservoir.

**New Reservoirs Planned in Missouri**

There are three new reservoir projects currently in the planning process in Missouri: East Locust Creek Reservoir in Sullivan County, Little Otter Creek Lake in Caldwell County, and the Missouri American Water reservoir near Joplin. Each is aimed at establishing an additional reliable source of supply to address water shortages, especially in cases of severe drought. East Locust Creek Reservoir will provide up to 7 MGD of water supply and is estimated to cost $110 million (North Central Missouri Regional Water Commission 2019). Little Otter Creek Lake will provide 1.2 MGD of water supply at a cost of $25 million (NRCS 2019). Missouri American Water's reservoir project is still in the early phases of planning, but a site within the Shoal Creek watershed has been identified. More details on these planned reservoirs can be found in Section 5.

### Expansion of Existing Storage Facilities

Storage in existing reservoirs can be increased by raising dams and spillways or by removing sediment that has accumulated in a reservoir. Costs associated with raising a dam and spillway include construction, impacts to environmental and cultural resources that will be flooded, and loss of property adjacent to the reservoir.

Over time, sedimentation can impact reservoir storage capacity, water supply yield, water quality, and access to water intake structures. Streams and rivers carry suspended sediment and larger solids that eventually settle to the channel bottom near the head of the reservoir or further down the reservoir. Off-channel reservoirs can experience similar problems, as the pumped water contains suspended solids. The sedimentation rate for a reservoir varies by basin and is dependent on soil type, land slopes, plant cover, land use, and rainfall characteristics. The most common approaches to removing sediment that has already accumulated are conventional wet mechanical dredging or dry excavation. The removed sediments can be disposed of through land-application or landfills, the latter of which greatly increases costs. Hydraulic dredging further requires construction of a disposal basin large enough to hold the water slurry for enough time that the solids settle, and clean water is returned to the reservoir. As a critical cost-effective factor, the composition of the sediment must be tested to determine if contaminants are present and can be removed. Dredging costs are typically expressed in dollar cost per cubic yard removed, and depend upon the dredging type, disposal options, and sediment quality. Recently, dredging occurred at the John Redmond Reservoir in eastern Kansas. Dredging the reservoir occurred at a cost of $6 per cubic yard, which included permitting, engineering and design, construction, dredging, lease payments, and land reclamation (USACE 2017).

Expanding existing storage facilities does not diversify water sources and the risks of mechanical failures or water quality problems are not reduced. Permitting and mitigation, though typically less difficult than that for new storage, can still be expensive and lengthy, with uncertain outcomes.

An additional option is to extend the useful life of the reservoir through sediment management methods. Common approaches include watershed management, enhancing or constructing wetlands, upstream sediment traps, sluicing, sediment bypass, and hydrosuction bypass (Utah Division of Water Resources 2010).

### Storage from U.S. Army Corps of Engineers Reservoirs (USACE)

USACE manages the operation of 11 federal reservoirs that fall entirely or partially within Missouri. These reservoirs either currently store water for M&I use or have the potential to in the future. Some of these lakes had water supply as an original authorized purpose, some had it added after the original authorization, and still others do not currently have a water supply authorization but have the ability to provide water supply. The process of seeking water supply storage in a USACE reservoir can be complex, depending upon its unique operational circumstances, but can lead to a long-term, dependable water supply.

**Authorized Reservoir Purpose**

USACE reservoirs are generally authorized for up to eight purposes: flood control, navigation, hydroelectric power, irrigation, M&I water supply, water quality, fish/wildlife, and recreation. Specific project authorizations, either initially authorized or passed after construction, are found in a variety of federal laws but are most commonly found in a series of Flood Control acts passed by Congress since 1870. Recent authorizations have been contained in a series of Water Resources Development acts.

Storage is generally already allocated at USACE reservoirs. Of the storage allocated for water supply, if any, all or a portion of that storage can be already under contract or available for contract. In circumstances where no additional water supply storage is available for contract and an entity desires to obtain more for M&I use, a process called reallocation is necessary to change storage from an existing purpose to water supply. The reallocated storage must come from the various pools within the reservoir and sometimes from storage allocated to another authorized purpose. The primary sources of reallocated storage for water supply include flood control, multipurpose (conservation), and inactive pools (USACE 2015). While the responsibility of securing water supply is the primary responsibility of local and state governments, the Water Supply Act of 1958, as amended (Public Law 85-500, Title III), allowed the federal government to cooperate and support local efforts by providing USACE with the authority to include M&I water storage in reservoir projects and reallocate storage in existing projects for M&I use. For any reallocation that may have a significant impact to an authorized purpose, or which would involve major structural or operational changes, congressional approval is required. Otherwise, approval levels vary depending on the amount of storage being considered for reallocation.

Typical sponsors for M&I storage contracts include states, water supply commissions, counties, cities, and industries. Reallocation requests from sponsors require detailed study to understand the trade-offs and potential impacts of the federal action. If the storage is already allocated, for example to hydropower or water quality, or if the request for water supply storage will require changes to the flood control storage (meaning a pool raise), these impacts must be studied and documented. Ultimately, if approved, the reallocated storage is available for purchase via a water supply agreement between USACE and sponsors that defines the amount of water supply storage available for use; the payment for that storage space; and the user's responsibility for a portion of the annual joint-use operations and maintenance, rehabilitation, repair, and replacement costs.

**Table 7-1** provides a summary of the water supply authorizations, allocations, and contractual amounts for reservoirs that fall partially or entirely within Missouri. Of the 11 reservoirs, there are seven contained entirely and two that fall partially within Missouri that have water supply storage as an authorized purpose. These seven reservoirs have a combined total storage space allocated to water supply of over 205,000 acre-feet (USACE 2015). These projects include Mark Twain (Clarence Cannon), Harry S Truman, Long Branch, Smithville, Stockton, Bull Shoals, and Norfork. Long Branch and Smithville have 20,000 and 75,700 acre-feet of water supply storage space currently available for contract, respectively (USACE 2015). The 13,750 acre-feet of water supply storage under future contract at Mark Twain was purchased by the State of Missouri and remains available for M&I use. In addition, there are numerous USACE reservoirs that lie completely or partially within Missouri that do not have water supply as an authorized purpose but have the potential to supply M&I water. Several of these reservoirs, located in the southwestern quarter of Missouri, were identified by USACE has having a high potential to meet M&I water supply through an allocation in the future (USACE 2016).

**Table 7-1. USACE Reservoirs as Water Supply Sources in Missouri**

| Lake | USACE District | Gross Storage (acre-feet) | Originally Authorized for Water Supply Storage/or Reallocated Storage | Water Supply Storage (acre-feet) | | | |
|---|---|---|---|---|---|---|---|
| | | | | Total Allocated | Present Under Contract | Future Under Contract | Not Under Contract |
| Bull Shoals[1] | Little Rock | 6,013,000 | Original | 12,613 | 12,613 | 0 | 0 |
| Clearwater Lake | Little Rock | 911,150 | Not Applicable | Not Applicable | | | |
| Harry S Truman Reservoir | Kansas City | 5,187,032 | Reallocated | 1,000 | 674 | 0 | 326 |
| Long Branch Lake | Kansas City | 64,516 | Original | 24,400 | 4,400 | 0 | 20,000 |
| Mark Twain Lake (Clarence Cannon) | St. Louis | 1,428,000 | Original | 20,000 | 6,250 | 13,750 | 0 |
| Norfork[1] | Little Rock | 2,108,700 | Reallocated | 2,400 | 2,400 | 0 | 0 |
| Pomme de Terre Lake | Kansas City | 644,177 | Not Applicable | Not Applicable | | | |
| Smithville Lake | Kansas City | 243,443 | Original | 95,200 | 4,650 | 14,850 | 75,700 |
| Stockton Lake | Kansas City | 1,650,953 | Reallocated | 50,000 | 50,000 | 0 | 0 |
| Table Rock Lake | Little Rock | 4,075,000 | Not Applicable | Not Applicable | | | |
| Wappapello Lake | St. Louis | 582,200 | Not Applicable | Not Applicable | | | |

*Source: USACE 2015*

[1] A small portion of the lake is in Missouri.

Engineer Regulation 1105-2-100, the *Planning Guidance Notebook*, provides the overall direction by which USACE Civil Works projects are formulated, evaluated, and selected, and defines how to calculate the cost of storage for a sponsor contract (USACE 2000). The cost of reallocated storage is based on the highest of the following costs: (1) updated cost of storage, (2) benefits forgone, (3) revenues foregone, or (4) replacement costs. Reallocation requires the quantification of loss to current authorized purposes. A large portion of the reallocation costs, for example, could be compensating other users such as hydroelectric producers for revenues lost due to reallocation. Outside of this calculation, the sponsor may incur financial costs for the feasibility study and is solely responsible for any costs associated with conveyance or mitigation costs that are identified by the reallocation study.

The complexity of reallocation requests depends upon the amount of storage requested and impacts to human and natural resources, infrastructure, recreation, cultural resources, and USACE reservoir operations. Agency decisions must comply with the National Environmental Policy Act, Endangered Species Act, and other pertinent environmental laws and executive orders. A reallocation feasibility study requires preparation of either an Environmental Assessment or Environmental Impact Statement to identify potential environmental impacts that might result from the reallocation. If environmental resources are impacted, mitigation is required, which increases costs to the user. Reallocation requests that will result in significant impacts to the authorized storage or major structural or operation changes requires congressional approval. Dam safety issues must be taken into consideration and may prevent a reallocation request from being approved if identified issues are not resolved.

**Reallocation Under Study in Southwest Missouri**

The Tri-State Water Resources Coalition (SWMO Water) is exploring water supply solutions for several communities in southwest Missouri that are facing rapid population growth, declining groundwater levels, and cyclical drought. Stockton, Pomme de Terre, and Table Rock lakes have been identified as priority options for obtaining additional water supply. Reallocation studies are underway for Stockton and Pomme de Terre. Preliminary modeling results indicate that a reallocation at Stockton Lake is a likely sustainable and cost-effective option for a portion of the projected demand (CDM Smith 2017). Future studies will focus on supply options for the remaining projected demand, potentially from Pomme de Terre or Table Rock lakes.

While obtaining M&I water supply from a USACE reservoir can be economically feasible and beneficial, a reallocation study requires assessment of other reasonable alternatives to ensure that the reallocation of storage is a cost-effective solution in comparison to other water supply alternatives. The impacts to natural resources and the environment, and the loss of land for other uses that is associated with new reservoir construction will be avoided because an existing reservoir is used. Permitting may be less challenging when compared to construction of a new storage reservoir, and mitigation requirements may be avoided. Additionally, USACE manages operation of the reservoir, which can be beneficial compared to building a new reservoir that must be maintained and operated by the water supplier. Entities that would like to explore the possibility of obtaining water supply storage from a USACE reservoir should submit a formal request to the District responsible for the reservoir.

### 7.2.2 Conveyance

Conveyance refers to moving water from one location to another. Conveyance systems transport source water to a treatment plant and treated potable water to consumers, connect one system to another, move municipal or industrial wastewater to treatment plants, and deliver treated wastewater to a water body. This section refers to pipelines that connect communities for drought and emergency connections and pipelines that bring water from a reliable water source, such as a river or reservoir, to where the water is needed.

Transportation of water by pipeline reduces water loss from evaporation and seepage compared to open-channel methods. Larger-diameter pipelines can be used to convey water over large distances, while smaller-diameter pipelines can be used to provide individual supplies at the point of use. Pipelines and canals, whether operated by gravity or a pumping system, require regular maintenance, repair, and periodic upgrades. Long-distance conveyance systems can have high energy costs and could be affected by natural disasters such as earthquakes or floods. Problems with water leaks, pumps, and storage facilities can result in interruption of services to customers.

There are several benefits of pipeline conveyance systems. Large quantities of water can be transported without degradation in water quality or significant water losses. In areas where water supplies are limited or are not of usable quality, pipelines can be used to move water over large distances from areas with sufficient, reliable supply to the areas where the water is needed. Industry and agriculture can be situated where water is otherwise unavailable if economic factors are favorable. Pipelines that connect water systems and create regional systems improve water reliability and resiliency for the connected systems

### 7.2.3 Enhanced Water Treatment

**Pipeline to Supply the Northwest**

The Great Northwest Wholesale Water Commission is currently designing a new water distribution system that will deliver 3.1 MGD of finished water from the Missouri American Water system at St. Joseph to the cities of Cameron, Stewartsville, and Maysville. This plan includes construction of approximately 18 miles of 18-inch-diameter pipe, 10 miles of 16-inch-diameter pipe, and 8 miles of 6-inch-diameter pipe, as well as two water storage tanks and a pump station. Overall, this project is anticipated to cost approximately $32.3 million (2019 dollars) and will meet the needs of a projected population of nearly 16,000 in 2049 (CDM Smith 2015, 2019).

As new water supply challenges emerge, implementing enhancements to traditional water treatment methods may be an option to help meet water supply needs. For example, in much of northern Missouri, groundwater is highly mineralized and not suitable for most uses without enhanced treatment. The addition of an enhanced treatment process, while more expensive than conventional methods, may be evaluated as an alternative to conveyance or developing new supply sources.

#### Surface Water

Surface water quality can be highly variable from one water body to another due to variations in land use, population, and source (e.g., springs versus runoff). Treatment options can range from relatively simple to complex depending on the surface water source and potential pollution sources.

Conventional surface water treatment technologies such as coagulation, flocculation, clarification, and filtration remove suspended solids, pathogens, and chemicals causing taste and odor issues. Pesticides, radiologicals, cyanotoxins, and high concentrations of aesthetic constituents such as metals or nutrients require more complex treatment technology. Enhanced coagulation, lime softening, ozone, ultraviolet (UV), and the use of granular activated carbon (GAC) adsorption are higher-level treatment options that may be required if source water quality is poor. Nanofiltration, ultrafiltration, reverse osmosis (RO), and other advanced treatment options are also available when dealing with contaminants that are resistant to adsorption. Some of these treatment techniques concentrate contaminants into liquid or solid wastes that may require further treatment, off-site disposal, or in specific cases, reactivation (for GAC and some adsorptive media or resins). **Table 7-2** shows the general effectiveness of water treatment types on various contaminants and contaminant categories.

**Table 7-2. Treatment Type Effectiveness on Various Contaminants and Contaminant Categories**

| Treatment Type | Treatment Type Effectiveness | | | | | | |
|---|---|---|---|---|---|---|---|
| | Pathogens | TOC[1] | TSS[2] and Turbidity | Salinity | Hardness | Nutrients/ Taste and Odor | Emerging Contaminants |
| Direct Filtration | LOW | LOW | LOW | LOW | LOW | LOW | LOW |
| Conventional | MED | MED | MED | LOW | LOW | LOW | LOW |
| Conventional + Enhanced Coagulation | MED | MED-HIGH | MED-HIGH | LOW | LOW | LOW | LOW |
| Conventional + Lime Softening | MED | MED-HIGH | MED-HIGH | LOW | HIGH | LOW | LOW |
| Conventional + Ozone/UV | MED-HIGH | MED-HIGH | MED-HIGH | LOW | LOW | MED-HIGH | MED-HIGH |
| Conventional + GAC | MED | MED-HIGH | MED-HIGH | LOW | LOW | MED-HIGH | MED-HIGH |
| Conventional + Membranes | MED-HIGH | MED-HIGH | MED-HIGH | LOW | LOW | LOW | LOW |
| Conventional + Nanofiltration/RO | MED-HIGH | MED-HIGH | MED-HIGH | MED-HIGH | MED-HIGH | MED-HIGH | MED-HIGH |

[1] Total organic carbon
[2] Total suspended solids

Surface water quality is influenced by watershed conditions. Precipitation runoff may carry contaminants into the water from the surrounding watershed. Land disturbance activities increase the contaminants that can be moved by runoff, and impervious surfaces associated with development can increase runoff and reduce absorption of water into the ground. Additionally, as populations continue to grow in Missouri, stormwater and wastewater have the potential to have greater impacts, and the need for source water protection will become more critical. Efforts that protect source waters from contamination will help reduce the need for more complex and costly water treatment technologies. Maintaining permeable surfaces and natural areas, and implementing stormwater best management practices (BMPs) that reduce runoff can help protect source waters from adverse water quality impacts.

## Groundwater

Treatment of groundwater can be relatively simple or complex due to variations in Missouri's groundwater aquifers. Pristine groundwater that is free of pathogens and contaminants (natural or man-made) requires only minimal, if any, treatment. However, varying concentrations of natural or synthetic organic and inorganic constituents can cause problems in drinking water supplies that range from minor aesthetic issues to chronic or acute health risks. Contamination to groundwater can result from natural sources and from human activities. Natural contaminant sources include the geologic formation where groundwater resides and may contribute inorganics (e.g., arsenic or high levels of iron and manganese), radionuclides (e.g., alpha particles and radium), and high levels of total dissolved solids, sulfate, chlorides, and other constituents that make the water unusable for most purposes without treatment. Failing septic systems, leaking waste lagoons, over-application of herbicides and pesticides, and chemical spills are examples of human activities that may contaminate groundwater supplies. Wellhead protection efforts, which are aimed at preventing contamination to groundwater that feeds a water supply well, help reduce the need for more complex and costly water treatment.

The presence of man-made contaminants from agricultural, industrial, or municipal sources can include pathogens, organics, metals, and other chemicals. Whether natural or man-made, these contaminants necessitate additional treatment. Combinations of contaminants can result in complex treatment facilities with multiple processes, and multiple liquid and/or solid residuals that must be properly disposed.

Common treatment technologies for high- and moderate-quality groundwater are generally limited to disinfection, basic filtration, corrosion control, oxidation, and water softening. High concentrations of aesthetic constituents or the presence of regulated contaminants that present health risks require higher levels of treatment, such as advanced disinfection, oxidation, air stripping, filtration, softening, ion exchange, and the use of activated carbon. High salinity levels and contaminants resistant to oxidation and adsorption can require enhanced filtration, RO, electrodialysis reversal, or other advanced treatment. Some of these treatment techniques concentrate the contaminants into liquid or solid wastes, which can require further treatment, off-site disposal, or in specific cases, reactivation (for GAC and some adsorptive media or resins). In much of northern Missouri, deep bedrock groundwater is highly mineralized and would require an advanced treatment process such as RO for use as a public water supply. In Missouri, no communities currently use an advanced treatment process such as RO to treat highly mineralized water. In some coastal areas of the United States, brackish waters are effectively treated using RO; however, as salinity increases, the economic feasibility of RO treatment decreases because of high energy cost and low recovery of potable water.

The quality of groundwater and yield from Missouri's aquifers are highly variable. High concentrations of private, municipal, and industrial wells are found in the Ozarks region because of the large volume of groundwater available and relatively high quality. In other regions, such as in northwestern Missouri, the highly mineralized bedrock groundwater presents challenges for treatment and is seldom used. The alluvial aquifers along the Missouri and Mississippi rivers as well as the buried glacial channels in northern Missouri are both productive and suitable for agriculture and M&I uses with appropriate treatment.

Groundwater wells for drinking water can range in capacity from less than 10 gpm to several MGD. In some cases, a drinking water system may incorporate multiple wells to increase overall capacity. If wells are spaced miles apart from one another, treatment at each well-head may be the most cost effective. When wells are clustered closely, water may be pumped from each well to a central treatment plant.

### 7.2.4 Water Reuse

Water reuse is the process of reusing treated wastewater for beneficial purposes. Drivers such as population growth, water supply limitations, changing climate and weather patterns, increasingly stringent discharge regulations, and shifting societal views towards resource recovery have led states to evaluate water reuse as an alternative water supply for a variety of applications (EPA 2012). Because municipal wastewater generation averages approximately 75 GPCD and remains fairly constant throughout the year, water reuse can become a steady source of supply not subject to weather variations (EPA 2012). Reuse can be expensive but more cost effective than developing additional water supplies.

Water reuse can be divided into two categories: potable and nonpotable. Each category and further specific end use have distinct treatment requirements and infrastructure needs. These treatment requirements are developed at the state government level, although Environmental Protection Agency (EPA) does have recommended guidelines for nonpotable reuse. Currently, there is no provision in the Missouri safe drinking water regulations or minimum design standards for community water systems regarding water reuse.

#### Nonpotable Reuse

Nonpotable (not used for drinking water) reuse refers to treated wastewater that can be distributed to urban and rural customers for nonpotable uses such as landscape irrigation, golf course and recreation field irrigation, food crop or nonfood crop irrigation, wetland replenishment, cooling tower cycling, industrial process water; and other uses. This category of reuse is sometimes referred to as recycled water or purple pipe because of the pipe color used to distinguish it from other pipes in the treatment facility and/or distribution system. To meet nonpotable standards and ensure safety, the effluent may undergo additional treatment such as filtration and disinfection to remove contaminants and particulates, depending upon the nonpotable end use and individual state regulations.

In the broader Midwest region, water reuse practices are site-specific and driven by factors such as water quality, water quantity, sustainable economic growth, and environmental stewardship (EPA 2012). As an example, the City of Columbia and the MDC partnered to deliver treated wastewater from the city facility to 1,100 acres of wetlands at the Eagle Bluffs Conservation Area (MDC 2019) providing a constant supply of water to the reconstructed wetlands and reducing the amount of water taken from the Missouri River to maintain them. Additionally, KC Water of Kansas City is considering nonpotable reuse for select industrial users.

**Kansas City Considering Nonpotable Reuse**

In 2019, KC Water completed a study to evaluate the feasibility of providing treated wastewater from its six wastewater treatment plants to industrial and agricultural customers (Black & Veatch 2019). The study identified and examined potential customers, evaluated treatment technologies and distribution needs, and estimated the cost of service for a reuse system at the Blue River Wastewater Treatment Plant—the utility's largest plant. The study concluded that the rates that would need to be charged to the two potential major industrial end users to cover capital and operating costs would be less than their existing water rates, making a reuse system financially feasible and potentially attractive to customers.

Cost-effectiveness for nonpotable reuse is dependent primarily upon the location and level of treatment required by the end user and is often compared to the next least-cost option. Systems that distribute nonpotable reused water must also consider the cost of conveyance that must be kept separate from potable water lines. To be feasible, wastewater plants typically need to be near the location of the demands. In addition, seasonal demands like irrigation may necessitate water storage so that water year-round can be captured for use. Application of reuse water for food crops can be complicated and is only cost-effective in regions where water supplies are highly limited. In the case of processed food crops, or nonfood crops such as seed crops, industrial crops (e.g., corn for ethanol, soybeans for biodiesel), and orchard crops, irrigation with reuse water is far less complicated and may be more readily accepted by the agricultural community (EPA 2012).

An obvious benefit of nonpotable reuse is the conservation of fresh water sources and potable water. Further, nonpotable reuse is a reliable source of water because urban wastewater collection stays relatively constant throughout the year and over time, in comparison to water supply sources reliant upon precipitation and subject to drought, evaporation, and climate variability. Additionally, nonpotable reuse can be a tool in addressing both water supply and wastewater disposal needs. In the United States, nonpotable reuse has grown in response to rigorous and costly requirements to remove nutrients from effluent discharge to surface waters (EPA 2012). By eliminating or reducing effluent discharge, a municipality may be able to avoid or reduce the need for costly nutrient removal processes. Nonpotable reuse may be a cost-effective option in communities facing difficulty meeting stream discharge limits. The benefits can be even more pronounced if the community is also facing water supply limitations.

Another benefit is that reuse may have less of an environmental impact than a new water supply project. Reducing effluent discharges generally reduces the adverse impacts to the receiving waters. For irrigation applications, salts and nutrients in reclaimed water must be considered and might require special management practices.

### Potable Reuse

Potable reuse involves the introduction of highly treated wastewater, either indirectly or directly, into the municipal drinking water supply. Indirect potable reuse involves the discharge of treated wastewater into an environmental buffer such as a river, stream, wetland, or reservoir prior to conventional or advanced water treatment. Direct potable reuse is a closed loop where highly treated wastewater is not discharged into the environment but is instead redirected back into the municipal water supply after undergoing advanced treatment. Direct potable reuse may involve retention in an engineered storage buffer and is often blended with other water sources before final treatment (EPA 2017). Potable reuse requires a high level of operator training. Direct potable reuse schemes have shorter response times, and therefore, it is important to implement real-time monitoring and process control strategies. Potable reuse is not currently regulated at the federal level; however, the CWA and Safe Drinking Water Act provide the core statutory requirements relevant to potable reuse (EPA 2017). States are responsible for setting specific potable reuse regulations and requirements, akin to nonpotable reuse.

Communities facing water supply challenges, such as drought, are increasingly likely to adopt potable reuse as a cost-effective strategy. Advancements in technology, paired with a further understanding of protocols to protect public health, have resulted in multiple successful potable reuse installations, notably in Big Springs and Wichita Falls in Texas, and Gwinnett County in Georgia. The costs can be high due to the complex infrastructure required, but potable reuse can be cost effective if the cost of developing alternative water sources is also high (EPA 2012). Similar to nonpotable reuse, costs are hard to generalize and are best evaluated using a triple-bottom-line analysis where the social, environmental, and financial tradeoffs are considered. Public perception of potable reuse has historically been an obstacle but research over the past decade has shed light on successful ways to communicate transparently to the public, using consistent terminology and emphasizing the purity of the final product water. Comprehensive public perception programs are important and have proven successful when appropriately executed.

## 7.2.5 Expanded Water Conservation

M&I water conservation programs improve water use efficiency and decrease water consumption. Water savings occur through the replacement of water fixtures with more efficient fittings (e.g., showerheads, toilets, landscape irrigation controls, cooling towers), changes in customer behaviors (e.g., reduced showering time, optimized irrigation schedules, optimized maintenance schedules), and reduction in water losses in conveyance and distribution systems. Reducing water loss is a major component to achieving and maintaining technical, managerial, and financial capacity. This is generally accomplished through the implementation of a water loss control program in which real and apparent losses are identified, quantified, and managed. Identification of water loss may include reviewing sales records, monitoring flows, performing visual inspections of the distribution system, and using leak detection equipment. Promptly repairing leaks can result in long-term savings for utilities in recovered water and reduced operating expenses associated with energy and chemical usage. In some cases, water loss control programs can even serve as a short term solution for utilities experiencing increasing demands or source water limitations.

The effects of conservation on water demand are the result of both passive and active water conservation measures. Passive savings refer to water conservation achievements from plumbing codes and are called such because water utilities do not actively fund and implement the programs that produce these savings. Active savings refer to programs funded and implemented by a water provider or other entity.

Passive water conservation savings are the direct result of state and federal plumbing code changes mandating the efficiency of plumbing fixtures available on the market. Prior to 1980, most toilets used 5.0 gallons per flush (gpf). After 1980, most new toilets used 3.5 gpf due to industry-driven changes. In 1994, as a result of the U.S. Energy Policy Act (Energy Act) of 1992, national plumbing codes mandated a maximum flush rate of 1.6

gpf for toilets sold. Standards were also set for faucets (2.5 gallons per minute [gpm]), showerheads (2.5 gpm), and urinals (1.0 gpf). Gradual increases in efficiency from the Energy Act are still being achieved but are expected to reach full potential by 2026, when older fixtures are estimated to be fully replaced (Vickers 1993).

Many states, such as California, Georgia, Texas, Colorado, Nevada, Iowa, and Washington, have adopted statewide high efficiency plumbing codes and standards that exceed the 1992 Energy Act (National Conference of State Legislatures 2019). Additionally, many counties and cities throughout the United States have adopted codes or ordinances that require more efficient plumbing standards. Mandating minimum plumbing and building code requirements can be a key avenue to advancing water efficiency in indoor plumbing fixtures. While implementing and enforcing new plumbing requirements can be a laborious task for cities, counties, and states, once in place, significant water savings are possible for decades into the future.

Active water conservation includes measures and programs undertaken by M&I water providers to reduce the amount of water consumed by their customers or within their system. Active measures include rebate or giveaway programs to replace older water fixtures, pricing structures that incentivize conservation, efforts to reduce water loss and leaks, water conservation education, and ordinances that reduce indoor or outdoor use. While customer adoptability and acceptance can pose challenges to implementing successful water conservation programs, resources are available from EPA and the American Water Works Association (AWWA) to assist water utilities in developing and implementing water conservation strategies and programs.

Water conservation measures have various levels of implementation, adoptability, and cost-effectiveness. Measures available to M&I water providers fall along a spectrum ranging from basic to highly advanced. As water supplies or infrastructure become constrained, M&I water providers can implement water conservation strategies as a means of reducing demand, stretching supplies, and delaying infrastructure expansions. The list that follows summarizes five generalized levels of water conservation applicable to Missouri water providers. Each level is progressively more advanced. Passive conservation is included as Level 1 to highlight programs that move beyond these savings and where passive savings fall along the spectrum.

- **Level 1, Passive Conservation**: This level consists of water savings that result from the impacts of the existing federal plumbing codes. These savings occur as new developments and remodeled buildings become more water efficient over time.
- **Level 2, Basic Conservation:** This level of conservation consists of programs for metering and leak detection.
- **Level 3, Moderate Conservation:** This level of conservation typically includes programs for metering and leak detection, education, rebates for water-efficient fixtures, and a rate structure that promotes efficient water use.
- **Level 4, Advanced Conservation:** This level of conservation typically includes programs above and beyond moderate conservation, including rebates for irrigation sensors and controllers, submetering of master-metered properties, ordinances aimed at limiting lawn irrigation, and/or cooling tower efficiency programs.
- **Level 5, Aggressive Conservation:** This level of conservation consists of programs that are more difficult to implement but have potential for significant water savings. These measures generally require intragovernmental coordination and high customer acceptance.

**Table 7-3** includes examples of water conservation measures or activities associated with each level. For each measure, information is provided on potential savings achievable and relative costs. The conservation savings and relative costs are rough estimates and will vary depending on the makeup of factors such as the system, customer base, and weather. Program savings are influenced by the level of participation.

**Table 7-3. Conservation Measures by Level with Potential Water Use Reductions**

| Level | Example Programs/Activities | Typical Water Use Reductions for Targeted End Uses | Relative Cost Range | Notes/Citations |
|---|---|---|---|---|
| Level 1, Passive | Replacement of inefficient fixtures with those that meet 1992 Energy Act standards | 2.5–6% | $ | Savings dependent on age of housing stock |
| Level 2, Basic | Metering of customers; submetering of multifamily or mobile home parks | up to 20% | $$ | Inman and Jeffery 2006 |
| | Utility-side leak detection and water loss reduction | 5–20% | $-$$ | Savings dependent on utility system losses; investment dependent on the alternative cost of water supply |
| Level 3, Moderate | All of the above (Level 2) | | | |
| | Education campaigns | 1–5% | $ | AWWA M52 Manual (AWWA 2017) |
| | Rebates for high-efficiency toilets | 63% | $ | AWWA M52 Manual |
| | Rebates for high-efficiency washing machines | 34% | $ | AWWA M52 Manual |
| | Indoor audits for top commercial/industrial users | 5% | $ | AWWA M52 Manual |
| | Residential landscape audits | 10% | $ | AWWA M52 Manual |
| | Commercial landscape audits | 15% | $ | AWWA M52 Manual |
| | Conservation-based rate structure | 15% | $ | AWWA M52 Manual |
| | Rebates for efficient pre-rinse spray valves for food service | 20–60% | $ | Dependent on existing flow rate and replacement fixture rate (California Urban Water Conservation Council 2016) |
| Level 4, Advanced | All of the above (Level 3) | | | |
| | Weather-based irrigation controller or other irrigation system efficiency improvement incentives | 10% | $ | Diamond 2003 |
| | Submetering of master-metered properties | 15% | $$ | AWWA M52 Manual |
| | Ordinance to restrict time of day/week landscape sprinkling | 5–11% | $ | 2-day-per-week allowance typical (Texas Living Waters 2019) |
| | Ordinance eliminating single-pass cooling | varies | $ | Dependent on cooling tower makeup; single-pass cooling systems reductions significant |
| Level 5, Aggressive | All of the above (Level 4) | | | |
| | Waterless or low-gpf urinals in commercial/institutional/industrial establishments | 50–99% | $ | |
| | Greywater collection system incentives for residential new construction | 27–38% | $$$$ | Dependent on housing water use characteristics; Yu et al. 2015 |
| | Advanced-metering infrastructure with customer feedback on water use and rapid customer leak detection | 4–10% | $$ | Mitchell and Chesnutt 2013, City of Corona (California) 2012 |
| | Turf replacement or landscape transformation incentives and/or restrictions | 25% | $$ | AWWA M52 Manual |

Emergency conservation programs and short-term drought restrictions are not included among the water conservation activities and measures provided in **Table 7-3**. During periods of drought or supply shortages, entities responsible for supplying water often request voluntary demand reductions or mandatory water use restrictions. This type of demand modification usually involves drastic but temporary behavioral changes, such as restrictions on lawn irrigation, the use and filling of swimming pools, and nonessential high-water-use businesses such as car washes. In the absence of restrictions or requests to reduce use, water demands can increase significantly during drought, further stressing supplies.

### 7.2.6 Conjunctive Use of Surface Water and Groundwater

Conjunctive use of surface water and groundwater can maximize the benefits and reliability of both surface water and groundwater sources of supply. In its simplest form, conjunctive use involves a water provider using both surface water and groundwater sources to meet demands. Surface water is typically used when surface supplies are ample, such as during average to above-average runoff conditions. When surface water supplies are limited, groundwater supplies are used to help meet demands. In the future, conjunctive use may become an important option to help mitigate the impacts of pronounced and extended droughts and other water shortages.

Currently, about 3 percent (42 of 1,426) of Missouri's community water systems rely on both surface and groundwater, either of their own supply or purchased to meet demands (MoDNR 2016). The larger of these systems include Kansas City, Springfield, Lee's Summit, St. Charles, Blue Springs, St. Peters, and Missouri American Joplin.

In the context of water supply, aquifers can be categorized as being renewable or nonrenewable. Aquifers that are adjacent to rivers in alluvial floodplain deposits usually have a hydrologic interaction with those rivers and dynamically get water from or discharge water to the rivers throughout their reaches. Aquifers of this type are usually unconfined aquifers that are relatively shallow. They are considered to be a renewable source of water since they replenished by mechanisms such as infiltration of surface water and to a lesser extent precipitation. South of the Missouri River, where most groundwater use in the state occurs, the aquifers are generally considered renewable. Recharge from precipitation and rivers continues at a rate that is sufficient to prevent large-scale declines in water levels. Renewable aquifers include the Ozark, St. Francois, and Springfield Plateau aquifers; the alluvial aquifers along the major rivers; and the McNairy Aquifer in the southeastern lowlands.

**Aquifer Storage and Recovery**

Conjunctive use may also include the practice of storing surface water in an aquifer for later use. Bedrock aquifers can be used in a conjunctive use water supply operation by serving as a water storage bank. Deposits are made in times of surface water supply surplus and withdrawals occur when available surface water supply falls short of demand. This technique is often referred to as aquifer storage and recovery (ASR). ASR requires careful planning and evaluation to confirm that the treated surface water is compatible with the bedrock formations and no reactions occur that compromise the quality of both the native and stored water. By storing surface water in the ground, there is no additional evaporative water loss compared to surface water storage; however, it is also important to consider that all the surface water stored in the aquifer may not be recoverable.

For ASR to work, groundwater supplies must be of adequate quality. Many areas of northern Missouri are highly mineralized and would not be suitable for storing excess surface water. Although ASR has been tried in Missouri, it is not currently used.

Nonrenewable aquifers are generally not replenished from renewable sources such as rivers or from infiltration of rainfall. If they do receive recharge, it is at a relatively low rate compared to the rate at which water is withdrawn for use. Nonrenewable aquifers are often located deep below the land surface, in consolidated bedrock deposits, and are generally classified as confined aquifers. A nonrenewable aquifer may be capable of producing water reliably under varying climate conditions (wet and dry years) but may only last a discrete amount of time depending on how much pumping occurs, and therefore would not be considered a reliable, permanent, sustainable water supply. Recharge of nonrenewable bedrock aquifers is slow and withdrawal rates often exceed recharge. As water levels decline in a nonrenewable aquifer, additional, deeper wells are required to maintain a given pumping rate. The southern portion of the High Plains Aquifer in parts of Texas, Oklahoma, New Mexico, and Kansas is an example of a nonrenewable aquifer. In the arid/semi-arid climate of the southwest, most precipitation is lost to evaporation and transpiration and groundwater recharge rates in the aquifer are low. In Missouri, there are no truly nonrenewable aquifers. Still, localized areas exist where, because of slow recharge rates, over-pumping has resulted in large and sustained water-level declines over a long time period, similar to what is occurring in parts of the southern High Plains Aquifer. However, in these areas of Missouri, if pumping were to cease or decline appreciably, the aquifers would be expected to recover over time.

The intent of conjunctive use is to supplement renewable groundwater sources or extend the life of nonrenewable groundwater sources. Conjunctive use also provides supply redundancy because multiple sources are used. Supplementing an existing surface water supply source with a groundwater source to meet peak demands can eliminate or postpone the need for additional surface water sources.

### 7.2.7 System Redundancy

Redundancy refers to the development of secondary, backup, or duplicate critical components of a water supply system with the goal of increasing reliability and resiliency. Redundancy in water systems can be found in many forms and can include backups that can relieve the primary systems in the event of a failure, duplication in intakes and conveyance mains, emergency connections to other water systems, and secondary water supply sources. The primary benefit of redundancy planning and design is the prevention of water supply interruptions. Implementation of system redundancy requires extra costs and resource investments.

### 7.2.8 Regionalization

In Missouri, there are nearly 1,500 public water systems that supply water to the same population year-round (MoDNR 2016). Of these, an estimated 85 percent are considered small and serve 3,300 persons or fewer. Small water systems frequently encounter water supply challenges as a result of limited technical, economic, and/or managerial resources. Many of these systems have declining populations, aging or inadequate infrastructure, loss of water sources, difficulty meeting water quality standards, and/or declining revenues, which hinder, prevent, or challenge the delivery of safe and dependable drinking water. A recent study found that smaller utilities can have water line break rates more than twice as high as larger utilities (Folkman 2018). Aside from small, rural water providers, systems serving fast growing areas where existing infrastructure and supplies are constrained, face unique challenges. Regionalization is a possible solution that has been encouraged by state and federal agencies in Missouri and across the United States (EPA 2016).

Regionalization refers to the merging or alliance of two or more water systems, either through structural or nonstructural measures or a combination of both, to improve planning, operation, and management of the systems (EPA 1983). Regionalization can occur along a broad spectrum of possible approaches that vary in complexity. The most appropriate solution will be unique to the systems that are considering regionalization.

The **CCWWC** was established in 1983 as the first organized water commission in Missouri. The CCWWC purchases raw water from Mark Twain Lake, treats that water, and distributes it to water providers that then serve nearly 73,000 people across 14 counties in northeast Missouri. Governed by a board of directors, 15 cities and 9 rural water districts make up the CCWWC.

Nonstructural regionalization options are generally administrative or managerial arrangements that allow the participating water suppliers to maintain identity and independence. These options emphasize a change in organizational processes and procedures or a joint agreement, either formal or informal, to mutually pursue goals or needs. Nonstructural formal agreements might result in a joint commission, coalition, or council where representatives from each water provider meet and work toward solving regional challenges, or a contract between two water providers that define joint administrative and managerial conditions or conditions for emergency assistance. Informal agreements might result in two water providers meeting regularly to jointly address common concerns or obstacles. More formal agreements might outline job-share responsibilities between staff.

Structural regionalization includes options that result in the creation of a new water supply entity or a shift in control of policy and functions from one or more water providers to another, whether existing or new. This form of regionalization can take on many forms. One example is the creation of an association or nonprofit water supply corporation that develops and controls policies for the association and its members. Once approved by the state to operate, associations can apply for federal financing to expand or improve systems (EPA 1983). Alternatively, new water authorities or special districts can be formed that can enter the bonding market on their own and take ownership of the service area. Structural forms of regionalization also include consolidation, where one entity assumes responsibility and control over the functions of another entity.

The benefits and costs of regionalization will be unique for each circumstance. Through nonstructural arrangements, individual resources of the water providers are pooled to obtain services or facilities that may not have been secured solely. Structural regionalization is generally attractive because it takes advantage of economies of scale. Financially, a larger system operates with more revenue from producing and selling higher volumes of water, while overhead costs for expenditures such as electricity, personnel, testing, chemicals, and maintenance are spread over the larger operation. With higher revenues, the larger system can more sustainably fund needed maintenance. Water quality regulations are more manageable for a larger-scale regional system where staff training is available. Treatment costs can also be spread over the larger customer base. Because solutions are developed locally on a grassroots level, they are generally accepted. As cited in EPA's 2016 Drinking Water Strategy, "a key principle of water system partnership agreements is that the most effective solutions are locally driven" (EPA 2016).

**The Joint Municipal Utility Commission Act** provides authority for water municipalities, public water supply districts, or nonprofit water companies in the State of Missouri to contract together to establish a separate government entity known as a joint utility commission. The newly formed commission can jointly pursue and fund water projects such as reservoirs, pipelines, wells, water treatment plants, and other facilities for the distribution of water within the joint distribution area of the members.

There are obstacles and limitations to regionalization. Perceptions that all regionalization agreements involve the incorporation of a smaller system into a larger system can impede its consideration. Communities may resist any form of consolidation because of their desire to retain local autonomy. Even if communities are interested, there are many factors that may hinder or prevent regionalization from occurring. In structural solutions, interested water providers must consider many complex factors such as the distance to connect, planning or zoning restrictions in the area, share of responsibility, costs for pumping and piping, and engineering challenges (e.g., topography, rivers, highways). Furthermore, regionalization can result in unintended risks and consequences. Widespread consolidation where existing sources are abandoned can lead to dependency on a few water sources.

Regionalization can be a viable pathway to solving water supply issues and challenges through locally driven solutions. While this section focuses on regionalization for water systems, the principles, advantages, and disadvantages presented herein for water providers generally also apply for wastewater systems.

## 7.3 Agricultural Options

This section defines how each of the categories listed below address the water supply needs for agricultural water supply demands.

- Additional storage
- Conveyance
- Conjunctive use of surface water and groundwater
- System efficiency
- Drainage water recycling
- Expanded groundwater use for livestock
- Expanded alluvial groundwater use for additional irrigation
- Surface impoundments for livestock

Several options are listed under each category below and can be evaluated individually or in combination to help meet water supply needs. The likelihood that these options will be successfully implemented and sustained depends, in part, on public and institutional support. That support, to a large extent, depends on how well each option meets water management objectives.

### 7.3.1 Additional Storage

Water harvesting—capturing rain where it falls or as it runs off—and constructing storage ponds is used most commonly for livestock facilities; however, new innovations are allowing the linkage of farm ponds to irrigation systems to recycle water. These systems are especially useful in allowing storage of winter and spring water for use in periods of low precipitation or drought.

### 7.3.2 Conveyance

Open channels, canal systems, and pipelines can be utilized for agricultural conveyance. Benefits and issues with conveyance systems for agriculture are similar to those listed within **Section 7.2.2**. Additionally, agricultural production and efficiency can be increased by transporting water to irrigate crops that otherwise are not irrigable due to supply constraints.

### 7.3.3 Conjunctive Use of Surface Water and Groundwater

Most of the same considerations, advantages, and disadvantages of conjunctive use that apply to the M&I sector also apply to the agricultural sector. Since agricultural demands are much more seasonal in nature compared to M&I demands, aquifer storage of excess surface water in the nongrowing season for use during the growing season could be used to mitigate potential future growing season shortfalls.

### 7.3.4 System Efficiency

In Missouri, agricultural irrigation is the largest water user by volume, accounting for 65 percent of all consumptive withdrawals (see **Section 3**). Water demand for agricultural irrigation is driven by the acreage and type of crop irrigated, irrigation system (i.e., flood, sprinkler, microirrigation), seasonal rainfall, water availability, economic viability, and fuel and commodity prices. Water savings can be achieved through several avenues. The most promising measures for agricultural water-saving in Missouri include the adoption of more efficient irrigation systems or retrofits to existing systems, and better irrigation management through adoption of weather-based controllers or other technology. These techniques have different economic, environmental, and political impacts and have varying likelihoods of implementation across Missouri.

### Improved Efficiency in Irrigation Systems

There are three main types of irrigation systems: sprinkler, gravity, and microirrigation. Sprinkler systems are mechanical-move or hand-move systems that deliver water from above the crop canopy. Gravity systems are those that distribute water over and across land without the use of pumps. Microirrigation systems deliver water directly to the crop root zone at a drip, trickle, or low-flow application rate. Generally, microirrigation has the highest water use efficiency, followed by sprinkler systems. Gravity-fed surface water systems have the lowest water use efficiency. In Missouri, approximately 60 percent of acres irrigated utilize gravity systems as their method of water distribution, with the majority of the remaining acres being irrigated with center-pivot sprinkler systems (USDA 2014). These patterns of use can vary year to year.

Of the gravity-fed systems in Missouri, most (88 percent) utilize temporary poly-pipe tubing technology (USDA 2014). Poly-pipe is a flexible pipe with properly sized and spaced holes that can be easily moved and reduces loss through evaporation and runoff by delivering water closer to the plant root at slower rates. The remaining gravity-fed acreage (approximately 64,000 acres) is irrigated with a system of unlined ditches (USDA 2014). Surface irrigation through unlined canals has the lowest field application efficiency of all methods due to seepage losses in the conveyance system. Typical efficiency measures to reduce these losses include canal lining, compaction, or the conversion of irrigation practices and technology from flood irrigation to gated pipe (plastic pipes with gated openings and controls to allow water to flow down rows).

There are numerous types of sprinkler systems on the market with varying levels of efficiency. A low-pressure center-pivot system with drop-down nozzles increases efficiency over standard sprinkler systems by reducing evaporation losses. Examples of these systems include the low energy precision application (LEPA) and low elevation sprinkler application (LESA) systems. LEPA is a highly efficient sprinkler system and is reported to have irrigation efficiencies ranging from 85 percent to 95 percent (Lynne and Morris 2006, Aillery et al. 2009). LEPA systems can be used on low-pressure linear-move and center-pivot sprinkler irrigation systems and apply water on the soil surface or at crop height. LESA systems position the sprinkler heads 3 feet or less above the soil surface. Both technologies reduce evaporation from the sprinkler, reduce moisture loss from wet leaves, and require less pressure to operate, thus reducing the amount of water withdrawn, energy consumption and pumping costs. In Missouri, 61 percent of center-pivot irrigation systems are low-pressure (USDA 2014). Conversion of the remaining medium- and high-pressure center-pivot systems in the state to a LEPA or LESA system could result in a 5 to 15 percent water savings statewide (Bonneville Power Administration 2019).

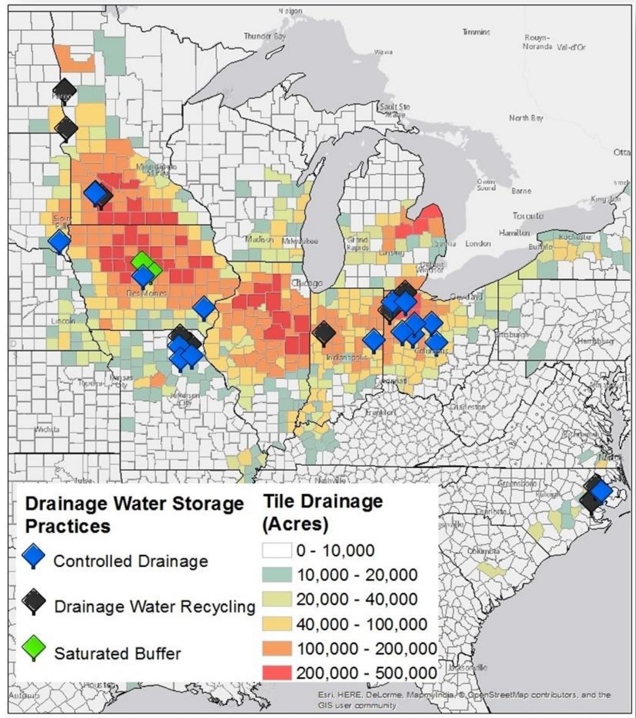
### Irrigation Management

Center-pivot irrigation systems can be improved by reducing overwatering and/or ineffective watering. Several advances have been made over the past decade. Software applications have been developed that improve irrigation efficiency by assisting farmers with scheduling irrigation at the field level. Improvements in water monitoring and management technology save producers time, water, and pumping costs. These applications use soil type, crop type, planting date, and local weather information to provide data that producers use to decide when and how much to water. The University of Missouri Agriculture Extension Center offers a Crop Water Use online program and mobile application for irrigators that assists them with irrigation timing based on the estimated soil-water balance, which considers soil type and weather conditions.

Where overwatering and/or inefficient irrigation occurs, these types of applications can help reduce water waste and pumping costs.

### 7.3.5 Drainage Water Recycling in Northern Missouri

Drainage water recycling is the practice of capturing excess water drained from fields; storing the drained water in a pond, reservoir, or drainage ditch; and using the stored water to irrigate crops when there is a water deficit due to insufficient precipitation. Relative to conventional drainage, drainage water recycling has three major benefits: (1) increased crop yield by removing excess water and applying it when needed, (2) reduced water withdrawals, and (3) improved downstream water quality.




Tile drainage sources: 2012 USDA NASS Census of Agriculture; World Resources Institute. 2008. Assessing Farm Drainage; USGS Northern Prairie Wildlife Research Center. 2014. Assessment of agricultural subsoil pattern tile drainage on wetland hydrology and ecosystem services in the Prairie Pothole Region

**Figure 7-1. Sites Researching Drainage Water Storage Practices and Spatial Distribution of Tile Drainage in Cropping Systems**

Although precipitation in the Midwest is generally plentiful, the timing and amount received does not always coincide with crop water needs. Drainage occurs mostly in the spring due to excess precipitation, while crop water uses in mid- to late-summer may result in periods when available water is insufficient. Stored drainage water can meet crop water needs when the need exceeds available soil water. Reusing the drainage water can also provide irrigation water when the source water supply is inadequate or of low water quality. This practice may be appropriate for northern Missouri because of the extensive row crop operations and limited groundwater supplies for irrigation. Research teams in Missouri, Minnesota, and Ohio continue to evaluate management of these systems. Fifty-four site-years of data show 15 to 30 percent benefits to corn and soybean yield (Frankenberger et al. 2017). These results not only derive from irrigation potential but excess water drainage during the early growing season. If nitrate leaches from fields, a drainage water recycling system helps capture nitrate and return it when pumped back during moisture deficit periods. Some denitrification occurs in the holding pools, such that about 25 percent of the leached nitrate can be removed. These processes improve water quality downstream of the watershed where sites are implemented, as shown in **Figure 7-1** (Frankenberger et al. 2017). The capital investment for these systems is large and though the adoption rate to date is low, field days and extension programming around this technology have received considerable attention.

### 7.3.6 Expanded Groundwater Use for Livestock

Soil and water conservation districts invest money in different segments of agriculture to fortify production chains, minimize risk in production, and improve environmental outcomes (MoDNR 2019a). Through the NRCS' Environmental Quality Incentives Program (EQIP), producers can access financial resources to improve practices. Analysis of EQIP funding (**Table 7-4**) shows that statewide, less than $5 million was spent on grazing management while over $30 million targeted erosion in cropping systems. The grazing management category includes water wells and piping of water to support animal agriculture. This is often correlated with land resource areas. Land resources areas are delineated by NRCS and characterized by a particular pattern that combines soils, water, climate, vegetation, land use, and type of farming. Additionally, 80 percent of the grazing management funds supported the Land Resource Area 116, which covers most of the southern Missouri Ozarks. In other parts of the state, investments in 2018 focused on cropping systems and mitigating erosion losses. Part of this disparity centers around the agriculture enterprises in northern versus southern Missouri. While northern Missouri is generally thought of as the row crop region, the region does contain considerable numbers of livestock that would benefit from greater investment in water infrastructure under the EQIP grazing management program (MoDNR 2019b). Based on this information, there appears to be potential for additional investment in groundwater supplies for grazing management in areas outside the Ozarks to mitigate the impacts of drought.

**Table 7-4. EQIP Funding by Category**

| Region of Missouri | | EQIP Cost-Share Category | |
|---|---|---|---|
| Geographic | Land Resource Area | Grazing Management | Erosion Prevention |
| | | State $ Invested, Millions | |
| Northwest alluvial | 107 | - | 5.75 |
| North central | 109 | <0.1 | 10.35 |
| West central | 112 | 0.1 | 2.19 |
| East central | 113 | <0.1 | 3.74 |
| East alluvial | 115 | 0.27 | 3.96 |
| Ozarks | 116 | 3.8 | 2.92 |
| Bootheel | 131 | <0.1 | 1.29 |
| | **Totals** | **4.3** | **30.2** |


## 7.3.7 Expanded Alluvial Groundwater Use for Additional Irrigation

Water in the alluvium of major rivers like the Missouri and Mississippi and in Missouri's Bootheel is cost effective to pump because the water table is shallow and recharges quickly. In the Bootheel farmers irrigate about 85 percent of the arable land, while farmers outside of the Bootheel but along the alluvial plains of the Missouri and Mississippi rivers irrigate only about 20 percent of the arable land. However, economic and other factors could influence farmers in these areas to increase the irrigation rate to levels seen in the Bootheel. Infrastructure built to tap into this somewhat underutilized alluvial supply would open up new opportunities for irrigation in prime farmland in the state. Potential drawbacks of expansion to farmers include the cost of irrigation systems, liability and natural disaster insurance, as well as possible theft of high-value components. Absentee landowners that are uninterested in investing in irrigation infrastructure may also slow the adoption of expanded agriculture along the alluvium.

**Small impoundments** placed in strategic areas provide water for livestock and reduce runoff and soil erosion. Typically, cost-share programs require the impoundments be fenced to exclude continuous access by livestock. Vegetation control through intermittent grazing is allowed within the confines.

### 7.3.8 Surface Impoundments for Livestock

Frequently, short-term and moderate droughts affect producers' ability to provide water to livestock. In severe cases, public water districts may limit water available for livestock to lessen the stress on human use (Scherer 2018). Severe shortages in available water often lead to producers selling livestock (Dailey 2018). Because many producers are forced into early livestock sales at the same time, the local market is flooded and livestock values are low. Stakeholders can mitigate the effects of drought through public and private investment in surface impoundments for livestock water. These structures retain excess surface water and can be used for livestock, fishing, or aesthetic purposes (USDA 1997).

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# Section 8 Planning Methods

## 8.1 Introduction

Water supply planning and water resources management take place at multiple levels (e.g., local, regional, statewide) and can be accomplished using several different methods. This section summarizes the most commonly used methods for planning, discusses the roles of various entities in water supply planning in Missouri, and presents the planning methods that were selected for the Missouri WRP 2020 Update.

### Overview of Section 8 Planning Methods

This section of the Missouri WRP summarizes the various planning methods that can be used for water supply planning and water resources management at the local, regional, and state levels. Subsections are organized as follows:

- Section 8.2 Scenario Planning – presents an overview of scenario planning and how it can be applied to water supply planning.
- Section 8.3 Adaptive Management – discusses how the concept of adaptive management can be used in conjunction with scenario planning for water supply planning.
- Section 8.4 Other Planning Methods – summarizes other planning methods that can be used for water resources management.
- Section 8.5 Selection of Planning Methods for the Missouri WRP 2020 Update – presents the planning methods that were selected for this plan.
- Section 8.6 Roles in Water Planning in Missouri – discusses the various roles of municipal, regional, and state government in water supply planning for the state.

## 8.2 Scenario Planning

It is important that water managers develop plans to provide reliable, high-quality, and affordable water services well into the future. The traditional method for water supply planning is to forecast water demands based on past trends in population growth and assess water supply availability based on past hydrological conditions. This approach was adequate in the past as demographic growth and water demands were well correlated, climate was less extreme, and the cost of developing new water supplies was lower. However, in the last several decades, changes in water use patterns, more extreme climate, changes in regulations, and increased competition for fresh water supplies have been observed and are likely to cause greater uncertainties in the future. In addition, aging water infrastructure will increase the risk of system failures. These greater uncertainties and risks can lead to disruptions that fall outside of planned future conditions, as shown in **Figure 8-1**.

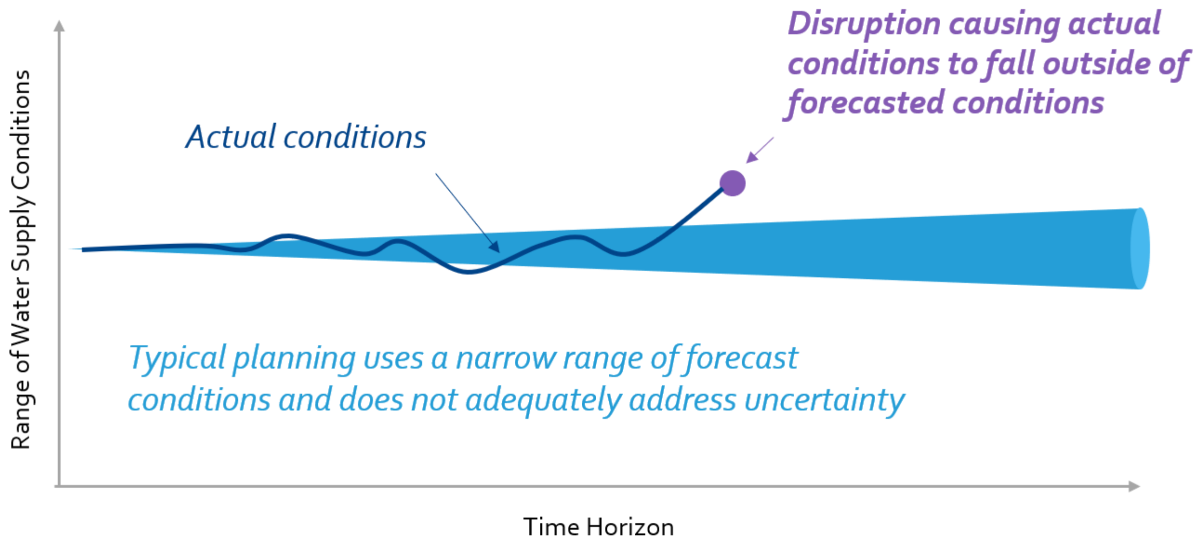


**Figure 8-1. Traditional Water Supply Planning with a Narrow Range of Forecast Conditions**

As an alternative to traditional water planning, *scenario planning* is a technique that captures a wider range of uncertainties and risks. Scenario planning is a structured process by which future uncertainties are bundled together using scenario narratives that represent plausible future conditions. Impacts for each scenario, such as water supply shortages, are then estimated. Through scenario planning, major disruptions in the future can be addressed more adequately, as shown in **Figure 8-2**.

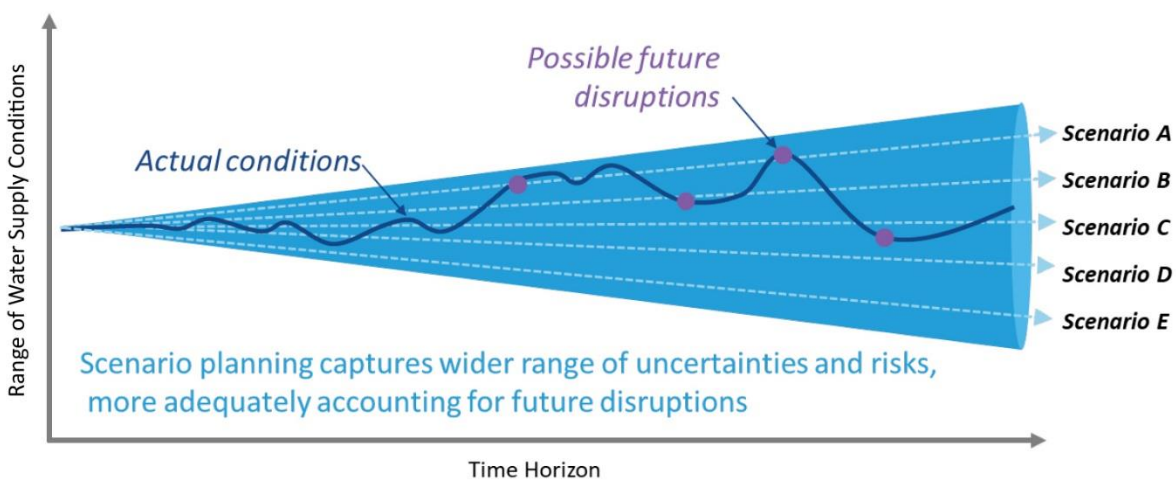


**Figure 8-2. Scenario Planning with a Greater Range of Uncertainty in Forecast Conditions**

Scenario planning usually has four main steps, which are listed below and subsequently discussed in further detail:

1) Identify major uncertainties that can impact the future.
2) Select the most important uncertainties to be used in the scenarios.
3) Develop scenario narratives from combinations of the most important uncertainties.
4) Assess the impacts of scenarios and identify strategies to address those impacts.

### Step 1. Identify major uncertainties that can impact the future.

Uncertainties can be both long-term trends that fall outside of historical norms such as changing climate or shifts in economic conditions, or disruptions such as unplanned system outages. It is important to identify the major uncertainties that can impact water supply reliability and future infrastructure needs; examples of these are shown in **Figure 8-3**.


**Figure 8-3. Examples of Major Uncertainties Effecting Water Supply Reliability and Infrastructure Needs**

### Step 2. Select the most important uncertainties to be used in the scenarios.

Scenario planning is most effective when the scenarios are robust, meaning they span a plausible range of outcomes or impacts while being relatively few in number (generally three to five scenarios). Thus, it is critical to be disciplined in incorporating the most important uncertainties in the scenario narratives. One method to select the most important uncertainties for the scenario narratives is to assess both the variability and impact of each uncertainty. **Figure 8-4** shows an example of the selection process. Those uncertainties that have high impacts and low variability should be reflected in most or all of the scenarios, while those uncertainties that have high impacts and high variability should be reflected in different scenarios to understand the range of possible impacts. Uncertainties that have low impacts, regardless of their variability, are usually not included in scenario narratives.

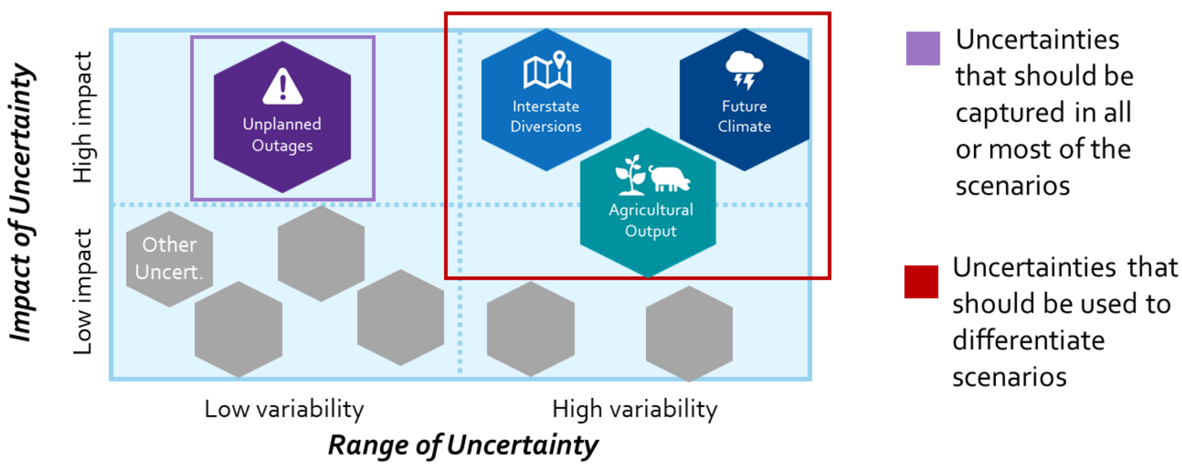


**Figure 8-4. Example for Selecting the Most Important Uncertainties for Future Scenarios**

### Step 3. Develop scenario narratives from combinations of the most important uncertainties.

Scenario narratives represent different combinations of those uncertainties that are most important when assessing possible outcomes and impacts. When developing the scenario narratives, the following should be considered:

- Scenarios should represent plausible future conditions that are realistic and not constrained by past observations or trends.
- Scenarios should be robust (i.e., use the fewest number of scenarios showing the full potential range of impacts).
- Scenarios should have internal consistency, so that if a scenario has significant impacts, some relief by way of potential mitigation can also be assumed.

Illustrative examples of scenario narratives are shown in **Table 8-1**.

**Table 8-1. Illustrative Examples of Scenario Narratives**

| | Major Uncertainties | | | |
|---|---|---|---|---|
| **Scenario Name** | **Growth/ Economy** | **Water Supply Constraints** | **Future Climate** | **Water Treatment** |
| **Business-as-Usual** | Baseline Projection | Medium | Historical variability | Current Levels |
| **Weak Economy** | Lower Projection | Low | Warmer/ Wetter | Current Levels |
| **Hot Growth** | Higher Projection | High | Hotter/ Drier | Additional Levels Needed |
| **Adaptive Innovation** | Smart Growth | High but with New Reallocations | Hotter/ Drier | Adaptive Treatment |

### Step 4. Assess the impacts of scenarios and identify strategies to address those impacts.

Each scenario can be assessed in terms of its impacts. In state water planning, the most likely impact measured is water shortage. Potential water shortage can be calculated by comparing projected water demands and existing water supplies by region using the drought of record for each scenario.

While most water supply and infrastructure investment decisions to mitigate potential water shortages will be made at the local, municipal, or regional levels, scenario planning can be useful for state water planning to identify future water supply needs, broad strategies, and policies that can guide local decision-makers. Strategies may include an investment in critical and aging water infrastructure, increased redundancy in water supplies, regionalization of small water systems, potential grant funding for new water supply development, and policies to encourage the increased sustainability of groundwater.

### Scenario Planning in Practice

Scenario planning is being used for statewide water supply planning by Colorado and California. In addition, several municipal and regional water agencies in North America are currently using it for long-term planning. Such agencies include the City of San Diego Public Utilities Department (California), the Municipal Water District of Orange County (California), St. Johns County Utility Department (Florida), Tarrant Regional Water District (Texas), and Metro Vancouver (British Columbia, Canada).

## 8.3 Adaptive Management

Scenario planning can be a useful planning approach to capture uncertainties and estimate a plausible range of future water needs, but does not provide a strategy for the timing and sizing of new projects and policies. Adaptive management is useful as a stand-alone planning method or in combination with scenario planning to develop implementation strategies for major uncertainties in a structured decision-making fashion. First developed for the ecological sciences, traditional adaptive management follows a cyclical process where objectives are developed for enhancing natural systems (Plan), alternatives are then implemented to meet objectives (Do), and those actions are monitored for effectiveness (Learn); the process repeats and adapts over time for more optimal performance (**Figure 8-5**).

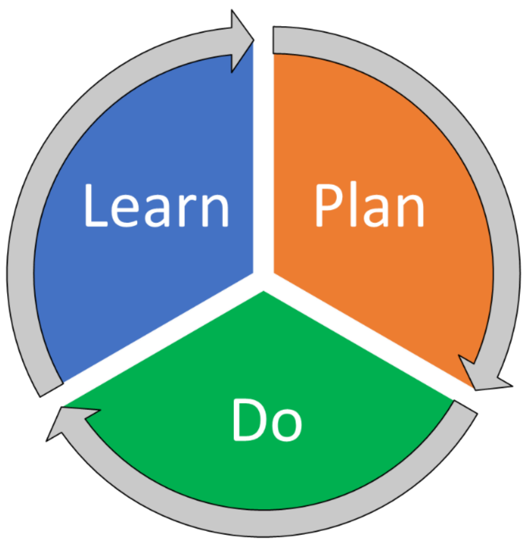


**Figure 8-5. Adaptive Management as Applied to Environmental Systems**

As applied for water supply planning, adaptive management often looks more like a decision tree rather than circular approach. In this context, adaptive management has four main elements:

1) Identify ***no-regret actions***, which are recommendations that are expected to provide benefits no matter what future scenario unfolds.
2) Define major ***risk triggers***, which represent major uncertainties that can occur through time.
3) Assess plausible ***outcomes*** for each trigger.
4) Recommend ***actions*** for each outcome.

Adaptive management addresses the challenge of balancing underperformance (i.e., if actions are not taken quickly enough should a more stressful future scenario occur) with overinvestment (i.e., if too many actions are implemented, and a less stressful future occurs). The triggers and outcomes are regularly monitored and assessed, along with any actions that have already taken place, in order to incrementally implement strategies as the future unfolds. An example of adaptive management, as applied to water supply planning, is shown in **Figure 8-6**.

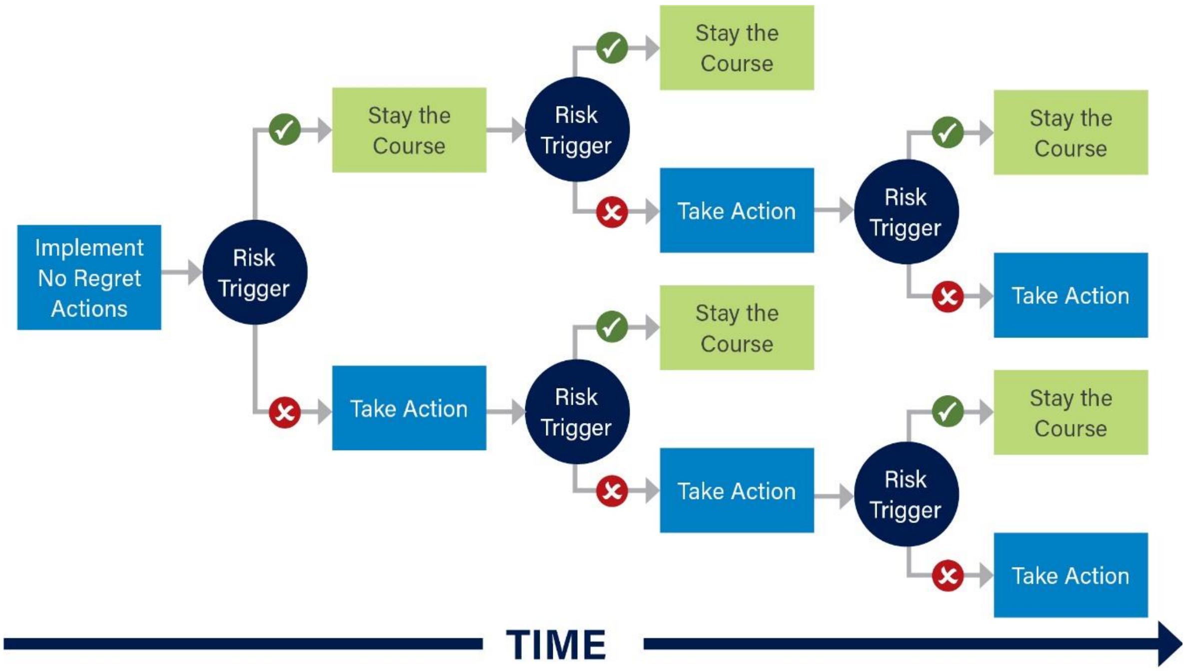


**Figure 8-6. Example of Adaptive Management using a Decision Tree Approach**

As applied to water supply planning, a potential risk trigger could be future climate, resulting in three possible outcomes: historical average temperature and precipitation, warmer temperatures and higher precipitation, and hotter temperatures with lower precipitation. Depending on which outcome occurs, different actions should be identified, such as stay the course, construct a new regional water supply project, or implement water reuse.

### Adaptive Management in Practice

Adaptive management for water supply planning is currently being implemented in North America by the City of San Diego Public Utilities Department (California), the Metropolitan Water District of Southern California, Denver Water (Colorado), Austin Water (Texas), and Metro Vancouver (British Columbia, Canada).

## 8.4 Other Planning Methods

The following describes other planning methods that are commonly used for water resources management; some of these other methods are more appropriate for municipal or regional water planning levels.

### 8.4.1 Integrated Water Resources Management or One Water

Integrated Water Resources Management (IWRM), sometimes referred to as *one water*, is a planning method by which water, wastewater, and stormwater are viewed in a more interconnected and holistic manner. By viewing all water resources as one water that undergoes several natural and man-made transformations, multipurpose/multibenefit projects can be more easily seen and implemented. For example, a project that captures stormwater for water supply augmentation provides both water supply and receiving water quality benefits. **Figure 8-6** presents how water resources can be managed under an Integrated Water Resource Plan framework. IWRM often leads to greater water resources sustainability and resiliency against climatic extremes and unplanned system outages.

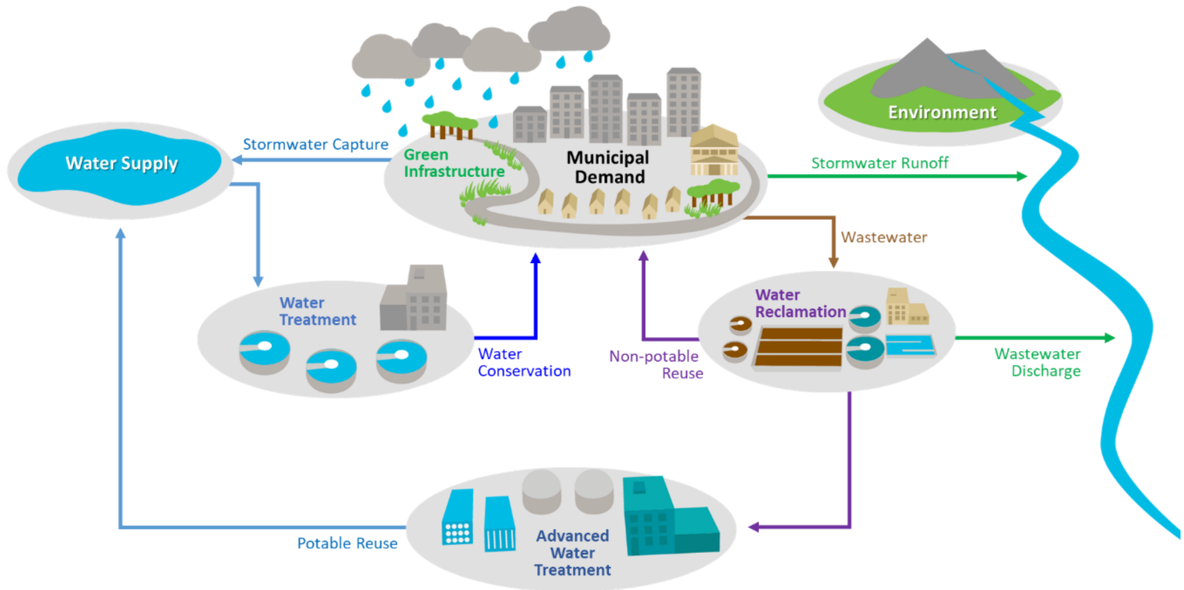


**Figure 8-7. Example of Integrated Water Resources Management**

IWRM is often implemented at the municipal or regional level, where integrated water resources challenges and responsible agencies are well aligned. Sometimes IWRM will have a stronger focus on water supply goals, while other times it will focus more on watershed health or green infrastructure goals. Examples of comprehensive IWRM programs include: Integrated Water Resources Plan (Columbia, Missouri), Integrated Plan for the Environment (Springfield, Missouri), One Water LA (Los Angeles, California), One Watershed/One Plan (St. Paul, Minnesota), Green City/Clean Water Program (Philadelphia, Pennsylvania), and Water Forward: Integrated Water Resources Plan (Austin, Texas).

Several leading organizations are strong advocates for IWRM/One Water and have led research efforts to advance the process. Such organizations include:

- The American Planning Association (www.planning.org/knowledgebase/watermanagement)
- The U.S. Water Alliance (www.uswateralliance.org/one-water)
- The Water Research Foundation (www.waterrf.org/research/projects/blueprint-one-water)

In addition, the Water Education Foundation and the AWWA often have IWRM/One Water featured at their annual conferences.

Over the past 45 years, municipalities, states, and EPA have made significant progress protecting public health and the environment through implementation of the

CWA. However, population growth, aging infrastructure, limited resources, extreme climate, and increasingly complex water quality issues are making the implementation of the CWA more challenging. Currently, municipalities often focus on each CWA requirement individually. This may not be the best way to address these stressors and may have the unintended consequence of constraining a municipality from addressing its most serious water quality issues first. Recognizing the limits of this approach, EPA developed an integrated planning approach for stormwater and wastewater that offers a voluntary opportunity for a municipality to propose to meet multiple CWA requirements by identifying efficiencies from separate stormwater and wastewater programs and sequencing investments so that the highest priority projects come first. This approach can also lead to more sustainable and comprehensive solutions, such as green infrastructure, that improve water quality and provide multiple benefits that enhance community vitality.

### 8.4.2 Shared Vision Planning

Shared vision planning was developed by the USACE during the National Drought Study (1989 to 1993). At the end of the drought study, shared vision planning had three basic elements: (1) an updated version of the systems approach to water resources management developed during the Harvard Water Program; (2) an approach to public involvement called *circles of influence*; and (3) collaboratively built computer models of the system to be managed. A key tenant of shared vision planning involves methods for dispute resolution and collaborative decision-making called *informed consent*, which is used to arrive at decisions that are internally consistent, more defensible, and transparent.

Shared vision planning is now overseen by the USACE Institute for Water Resources. There are numerous case studies where shared vision planning has been used to help settle interstate and intrastate water challenges and address long-term water resources sustainability, which include the International Joint Commission in the Lake Ontario-St. Lawrence River study (2000 to 2006), the Upper Great Lakes study (2007 to 2012), and the Rainy Lake study (2014). The method has also been applied in Peru in support of some World Bank and Interamerican Development Bank water projects.

### 8.4.3 Effective Utility Management

The AWWA has partnered with EPA and nine other entities representing the water and wastewater sector to develop an approach for water utility management. This approach is based on The Ten Attributes of Effectively Managed Water Sector Utilities and Five Keys to Management Success, collectively known as Effective Utility Management (EUM).

*Effective Utility Management: A Primer for Water and Wastewater Utilities* (EPA 2017) is the foundation of EUM. Originally released in 2008, the primer was updated in 2017. The primer states that “It is designed to help water and wastewater utility managers make informed decisions and practical, systematic changes to achieve excellence in utility performance in the face of everyday challenges and long-term needs for the utility and the community it serves.”

One of the primary components of the EUM approach is the 10 attributes of effectively managed water sector utilities. These attributes provide reference points that utilities can use to maintain a balanced perspective of key operational areas rather than reacting to the “problem of the day.” These 10 attributes are:

- Product Quality
- Customer Satisfaction
- Employee and Leadership Development
- Operational Optimization
- Financial Viability
- Infrastructure Strategy and Performance
- Enterprise Resiliency
- Community Sustainability
- Water Resources Sustainability
- Stakeholder Understanding and Support

Another primary component of the EUM approach is the five keys to management success. These keys are based upon frequently used management approaches. They provide context for water and wastewater utilities and define management success associated with the 10 attributes. These keys to management success are: leadership, strategic business planning, knowledge management, measurement, and continual improvement management.

## 8.5 Selection of Planning Methods for the Missouri WRP 2020 Update

For the Missouri WRP 2020 Update, MoDNR decided that both scenario planning and adaptive management would be used to identify a range of possible water supply needs by hydrologic region. MoDNR and USACE have developed an adaptive management strategy for illustration that can be used by municipal and regional water agencies. The application of scenario planning and adaptive management for Missouri is presented in **Section 9**.

## 8.6 Roles in Water Planning in Missouri

For adaptive management to be successful, all stakeholders need to understand and perform their respective roles in the planning and implementation process. The number of groups invested in Missouri's water as a resource can make this seem difficult but the benefits of all parties working together cannot be overstated.

Each party has its own important duties though they all coordinate efforts, provide stakeholder outreach, and fund projects. For many projects, securing funding may seem like an insurmountable obstacle, but, as seen in **Section 6**, assistance can be provided by a variety of sources and programs. Depending on the specific project, water providers may partially fund their projects and be supplemented by grants or loans from an organization with programs that encourage the specific type of project (water supply planning, development of rural infrastructure, enhancing water treatment, etc.).

If policy setting, monitoring, planning, and implementation are coordinated among all participating agencies, there is a higher chance of successfully overcoming water supply challenges caused by prolonged droughts; unanticipated supply disruptions; high municipal, industrial, and agricultural growth; or other risk triggers. By adopting an adaptive management framework that focuses on partnerships, along with utilizing the many tools and resources provided locally, by the state, and federally, water planners can make high-level, well-informed decisions. There are many agencies and organizations that are important to water planning in Missouri. The following descriptions of water planning entities is intended to provide an introduction to some of the water planning agencies and organizations that affect Missouri.

### 8.6.1 Local Entities

Municipalities, local districts, agricultural users, volunteer organizations, and private entities play a role in identifying water supply projects and leading the charge to implement those projects. Local entities are often the most familiar with the challenges and opportunities. When the projects reach a certain size relative to the local entity there may be a need to partner with a larger water agency, state or federal government for technical and possibly financial support. This group of water users collects and maintains information that may not be meaningful when considered in isolation, but when considered holistically, the information can help identify trigger points that suggest action is warranted.

Local water providers know what their respective water systems need to be maintained and expanded to meet the water demands of their customers or users. It is imperative the providers communicate with their customers so they understand their customers' needs and can provide them with clean and reliable water supplies. Local providers need to implement programs to replace aging infrastructure, update water and wastewater treatment systems to meet water quality standards, and provide a long-term water supply to existing and future customers.

### 8.6.2 State Entities

#### Missouri General Assembly

In Missouri the General Assembly, composed of the House of Representatives and the Senate, is responsible for creating laws. Echoing the voices of the citizens, the General Assembly sets polices and laws in place to optimize Missouri's use of resources. It is under the guidance of these policies that state agencies operate.

### Missouri Department of Natural Resources

Among other responsibilities, MoDNR implements state-level policies related to water. The following subsections describe the functions of some groups within MoDNR that contribute to this task. This is not meant to be an exhaustive list but more an introduction on how programs and sections support one another.

#### Water Resources Center

The Water Resources Center is tasked with overseeing science, planning, and policy on how Missouri utilizes water as a resource to meet its water supply needs. There are two sections carrying out this function, Groundwater and Surface Water.

The Groundwater Section focuses on refining knowledge of groundwater use in Missouri, primarily by managing the Major Water Users Database and maintaining and expanding Missouri's groundwater observation well network. The Groundwater Section also contributes to the protection of public drinking water wells. Using well logs and GIS layers developed by the section, they are able to recommend casing depths for new wells that will help protect the drinking water from contamination. The tools that the Groundwater Section develops also aid the functions of other programs.

The Surface Water Section works to expand knowledge and understanding of Missouri's surface waters, monitors interstate waters issues, and oversees statewide water planning efforts such as this Plan. The Surface Water Section partners with USGS to fund may stream gages in Missouri, acts as a liaison between MoDNR and regional water supply projects, conducts hydraulic and hydrologic studies, and provides technical expertise during floods and droughts. Additionally, the Surface Water Section has been tasked with the administration of the Multipurpose Water Resources Fund which provides financial assistance to projects to ensure adequate, long-term, reliable public water supply, treatment, and transmission facilities.

#### Water Protection Financial Assistance Center

MoDNR's Financial Assistance Center (FAC) provides funding to communities for water, wastewater and stormwater infrastructure. Most of the funding available is provided through the two State Revolving Funds - Drinking Water and Clean Water, though there are additional state grants and loans that FAC administers for a variety of other projects. Through outreach and workshops, FAC works to provide information and guidance on the funding opportunities available to communities.

#### Water Pollution Control Branch

The Water Pollution Control Branch has the responsibility of overseeing water quality, not related to drinking water, in Missouri. To complete this task there are several sections that serve different functions. When constructing a facility that will have wastewater discharge, a construction permit must be obtained. The Engineering section is responsible for evaluating construction permits and design specifications of the proposed infrastructure. For established facilities, the Operating Permit section is responsible for administering permits for the operation of a system, given the system is in compliance with standards. The Compliance & Enforcement section is responsible for managing water systems' compliance with regulations. Should a system fall out of compliance, this section assists in finding solutions to system issues. If the issues remain unresolved, this section is responsible for establishing a case and enforcing any laws or regulations related to unmet standards. Monitoring and assessment of water quality is the responsibility of the Watershed Protection section. This section also reviews water quality standards.

#### Public Drinking Water Branch

The Public Drinking Water Branch addresses water quality in Missouri specific to drinking water. They have the same functions as the Water Pollution Control Branch with a modified structure. The sections that make up Public Drinking Water Branch are Monitoring, Permits & Engineering, and Compliance & Enforcement. Monitoring looks at the results of required sampling submitted by systems. Permits & Engineering reviews technical plans and issues permits. Compliance & Enforcement looks at systems to confirm compliance with current regulations. If a system is unable to meet standards a case is created to document the issue and enforce any laws or regulations related to unmet standards

### Soil and Water Conservation Program

The Soil and Water Conservation Program supports best management practices designed to reduce soil loss, improve water quality, and promote sustainable agricultural in the state. Mirroring the 114 counties in Missouri, there are 114 soil and water conservation districts that the Soil and Water Conservation Program supports. Through a cost share approach, the Soil and Water Conservation Program provides partial reimbursements using funds generated by the Parks, Soils and Water sales tax to the districts for the implementation of voluntary best management practices. Over 50 practices are eligible for the cost share program. Eligible practices assist with the following resource concerns: sheet and sill/gully erosion, grazing management, irrigation management, animal waste management, nutrient and pest management, sensitive areas, and woodland erosion.

Soil and water conservation districts are composed of local landowners in their respective counties who determine which practices their district would like to implement. While the districts determine the needs of the area, the Soil and Water Conservation Program serves as a technical, financial, and educational resource. The Soil and Water Conservation Program is also responsible for the Section 319 Nonpoint Source Management Program, a program meant to increase public awareness of nonpoint source pollution and how to mitigate it. Grants related to nonpoint source pollution projects are available through the Soil and Water Conservation Program.

### Regional Offices

MoDNR operates five regional offices across Missouri: the Kansas City Regional Office, the Northeast Regional Office (Macon), the Southeast Regional Office (Poplar Bluff), the Southwest Regional Office (Springfield), and the St. Louis Regional Office. The offices provide field inspections, complaint investigation, front-line troubleshooting, problem solving, and technical assistance on environmental issues and emergencies. Each office strives to make connections and work closely with the communities in their respective regions. The central office in Jefferson City relies on the regional offices for current information from all the regions.

### Missouri Department of Conservation

MDC is charged with the control, management, restoration, conservation, and regulation of the bird, fish, game, forestry, and wildlife resources of the state. MDC is guided by a four-member commission appointed by the governor, with the advice and consent of the senate.

Within MDC, the Division of Fisheries is one of the more important for water planning. Fisheries manages public fishing on lakes, reservoirs and streams and conducts water pollution impact investigations. MDC currently has an ongoing research program to measure fish populations and trends to determine limiting factors and develop better management techniques (MDC 2019).

## 8.6.3 Federal Entities

### U.S. Army Corps of Engineers

USACE's role in water supply has developed over many years through the Rivers and Harbor and Flood Control acts and later water resources development acts. USACE's current role includes the construction, maintenance, and operation of federal navigation, flood control, irrigation, or multipurpose projects. USACE provides a wide range of services related to water supply and water resources planning. In Missouri, USACE is most recognized for their operations on the Mississippi and Missouri rivers and several reservoirs. As part of reservoir operations, USACE manages reservoir regulation and reallocation processes. The allocation and reallocation of water storage in existing USACE facilities has and will continue to play a key role in managing water resources in Missouri. In addition to overseeing these operations, when asked by local or state partners, USACE initiates and performs water studies. This update of the Missouri WRP is being partially funded utilizing the USACE's PAS authority (Section 22 WRDA 1974 P.L. 93-251). This provides USACE authority to assist state and local governments in preparing comprehensive plans for the development, utilization, and conservation of water- and land-related resources. As part of the PAS program, USACE can also provide technical assistance and project coordination for water resources planning activities.

### United States Geological Survey

According to the USGS website, the agency's mission is to "provide science about the natural hazards that threaten lives and livelihoods; the water, energy, minerals, and other natural resources we rely on; the health of our ecosystems and environment; and the impacts of climate and land-use change. Our scientists develop new methods and tools to supply timely, relevant, and useful information about the Earth and its processes." (USGS 2019).

USGS is a vital source of high quality data about Missouri's water resources. By partnering with others including DNR, USGS implements monitoring systems across Missouri. With these systems, they can measure, assess, and conduct targeted research on the water resources in a wide area. This information is then made available for public use and includes information on streamflow, groundwater, water quality, supply, and water use.

### U.S. Environmental Protection Agency

EPA is an independent agency of the United States federal government for environmental protection. EPA's mission is to protect and conserve the natural environment and improve the health of humans by researching the effects of and mandating limits on the use of pollutants. PA regulates the manufacturing, processing, distribution, and use of chemicals and other pollutants. In addition, EPA is charged with determining safe tolerance levels for chemicals and other pollutants in food, animal feed, and water. The CWA and SDWA are key environmental laws related to water resources that are overseen by EPA.

The SDWA is the federal law that protects public drinking water supplies throughout the Unites States. Under the SDWA, EPA sets standards for drinking water quality and, with its partners, implements various technical and financial programs to ensure drinking water safety. The CWA establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. Discharges are permitted by EPA's National Pollutant Discharge Elimination System.

In addition, the EPA oversees the CWSRF program. The CWSRF is a federal-state partnership that provides communities a permanent, independent source of low-cost financing for a wide range of water quality infrastructure projects. CWSRF programs provide loans to construct municipal wastewater facilities, control nonpoint sources of pollution, build decentralized wastewater treatment systems, create green infrastructure projects, protect estuaries, and fund other water quality projects (EPA 2019).

### United States Department of Agriculture

USDA is responsible for developing and executing federal laws related to farming, forestry, rural economic development, and food. USDA promotes agriculture production to feed people in the United States and throughout the world. This is done while preserving the nation's natural resources through conservation, restored forests, improved watersheds, and healthy private working lands. USDA accomplishes this through 19 agencies within its department, ranging from the Agricultural Research Service to the NRCS (USDA 2019).

### Natural Resources Conservation Service

NRCS is a part of USDA and is known for assisting in the restoration of watersheds on private land. NRCS provides technical and financial assistance to landowners who practice conservation and implement management strategies on their land, with an emphasis on improving water management and quality.
The science behind these conservation and management strategies is developed by NRCS directly. Some of the tools they have developed include improved models to track nutrients, methods for increasing irrigation efficiency, methods for increasing water storage, and strategies for minimizing loss of sediment and nutrients from water sources. NRCS is also a key sponsor of the construction of reservoirs for a variety of purposes connected to their mission (NRCS 2019).

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# Section 9 Future Scenarios Assessed

## 9.1 Introduction

In the previous sections of the Missouri WRP, population and water demands are projected out to 2060, water supplies are assessed, options to meet future water needs are identified, and planning methods are evaluated. Although we can attempt to predict the availability of and demand for water into the future, effective water planning needs to consider a wide range of uncertainty. To account for uncertainty, several future scenarios were developed and evaluated to more thoroughly consider the range of options, actions and strategies that may be needed.

### Overview of Section 9 Future Scenarios Assessed

This section of the Missouri WRP builds upon the options to meet future water needs discussed in **Section 7**, and identifies scenario planning and an adaptive management framework to address future water needs as they arise. This section is organized as follows:

- Section 9.2 Future Scenarios Assessed in Missouri – provides an overview of the future scenarios.
- Section 9.3 Considerations and Limitations of the Analyses – explains how to interpret the scenario planning results and identifies important limitations.
- Section 9.4 Uncertainty Drivers – describes the uncertainty drivers.
- Section 9.5 Impacts of Scenarios – describes the impact of each scenario on supply.
- Section 9.6 Using Adaptive Management with Scenario Planning – describes how the adaptive management process is used to enhance water planning and the water supply options to consider for each planning scenario.
- Section 9.7 Summary – provides a summary of the scenarios results.

## 9.2 Future Scenarios Assessed in Missouri

Utilizing the scenario planning process described in **Section 8**, and with input from the technical workgroups, the following four planning scenarios were formulated for analysis:

1) Business-as-Usual (also known as the baseline scenario).
2) Strong Economy/High Water Stress.
3) Substantial Agricultural Expansion.
4) Weak Economy/Low Water Stress.

The four planning scenarios are summarized in **Table 9-1** and described further in this section. The planning scenarios are characterized by a range of future assumptions based on six major categories of uncertainties: M&I and rural water demands, agriculture demands, climate, water treatment levels, supply constraints, and reservoir regulation. **Appendix G** discusses the calculations for climate, water supply, and demands uncertainties. Each scenario was evaluated through the 2060 planning period for an average hydrologic year. Scenarios were also evaluated to identify potential stress and gaps to surface water for a drought year, where a drought year represents conditions during the drought of record in the 1950s.

**Table 9-1. Planning Scenarios**

| Scenario Number and Name | Uncertainty Drivers | | | | | |
|---|---|---|---|---|---|---|
| | M&I and Rural Water Demands | Agriculture Demands | Climate | Water Treatment Levels | Supply Constraints | Reservoir Regulation |
| 1. Business-as-usual | ▪ Baseline M&I Demands<br>▪ Baseline Rural Demands | ▪ Medium Irrigation Demands<br>▪ Medium Processing Demands | ▪ Historical Temperature and Precipitation | ▪ Existing Water Treatment Levels | ▪ Bed Degradation | ▪ No Reallocation of USACE Reservoirs for Supply in Missouri<br>▪ Existing Permitting Process for New Reservoirs |
| 2. Strong economy/high water stress | ▪ High M&I Demands<br>▪ Higher Rural Demands | ▪ High Irrigation Demands<br>▪ Medium-High Processing Demands | ▪ Hotter Temperature and Lower Precipitation | ▪ High Increase in Water Treatment Levels | ▪ Upstream Diversions out of Missouri River<br>▪ Limitations on Groundwater (Select Areas)<br>▪ Prolonged Supply Disruption on River Intakes<br>▪ Bed Degradation | ▪ Limited Reallocation of USACE Reservoirs for Supply in Missouri<br>▪ Streamlined Permitting Process for New Reservoirs |
| 3. Substantial agricultural expansion | ▪ Baseline M&I Demands<br>▪ Baseline Rural Demands | ▪ Medium Irrigation Demands<br>▪ High Processing Demands | ▪ Warmer Temperature and Greater Precipitation | ▪ Moderate Increase in Water Treatment Levels | ▪ Upstream Diversions out of Missouri River<br>▪ Limitations on Groundwater (Select Areas)<br>▪ Bed Degradation | ▪ Limited Reallocation of USACE Reservoirs for Supply in Missouri<br>▪ Existing Permitting Process for New Reservoirs |
| 4. Weak economy/low water stress | ▪ Low M&I Demands<br>▪ Baseline Rural Demands | ▪ Medium Irrigation Demands<br>▪ Medium Processing Demands | ▪ Warmer Temperature and Greater Precipitation | ▪ Existing Water Treatment Levels | ▪ Bed Degradation | ▪ No Reallocation of USACE Reservoirs for Supply in Missouri<br>▪ Existing Permitting Process for New Reservoirs |

### 9.2.1 Business-as-Usual (Scenario 1)

This baseline scenario uses the current projections for population growth and M&I demands, and historical long-term averages for temperature and precipitation. Medium levels of water demand for irrigation and agricultural processing were assumed. Water treatment levels were left unchanged from existing levels. No new water supply constraints other than ongoing localized Missouri River bed degradation, which may impact select water supply intakes on the river, were assumed. No reallocation of USACE reservoirs located in Missouri was assumed. The permitting process for building new reservoirs was assumed to remain unchanged. The permitting process is important because of the time and expense necessary to develop new water supply reservoirs.

### 9.2.2 Strong Economy/High Water Stress (Scenario 2)

This scenario assumes that population growth through 2060 is approximately 22 percent higher than the baseline projected population growth. Consistent with a strong economy, high M&I and agriculture demands were assumed relative to the other scenarios. Demands for agricultural processing were set at a medium-high level relative to the other scenarios. Climate projections categorized by hot, dry temperatures and lower precipitation were used. An increase in water treatment levels was assumed. Various supply constraints focusing on groundwater and surface water were applied. Limited storage reallocation of existing USACE reservoirs in Missouri and a streamlined permitting process for the development of new reservoirs were assumed.

### 9.2.3 Substantial Agricultural Expansion (Scenario 3)

This scenario primarily evaluates the implications of strong growth in the agricultural processing sector. Like the baseline, this scenario uses current projections for population growth and M&I demands. Relative to the other scenarios, a medium level of water demand for irrigation was assumed; however, high demands for agricultural processing were included. Climate projections categorized by warmer temperatures and greater precipitation were used. Various supply constraints focusing on groundwater and surface water were applied. Limited reallocation of existing USACE reservoirs was assumed. The permitting process for building new reservoirs was assumed to remain unchanged.

### 9.2.4 Weak Economy/Low Water Stress (Scenario 4)

This scenario assumes slightly lower population growth, resulting in an 8 percent lower 2060 population compared to the baseline scenario 2060 population. This corresponds to a 10 percent lower urban population growth and a baseline (no change) in rural population. Consistent with the slower population growth and a weak economy, lower M&I demands were assumed relative to the other scenarios. A medium level of water demand for irrigation and agricultural processing was assumed. Climate projections categorized by warmer temperatures and greater precipitation were used. Water treatment levels were left unchanged from existing levels. No new water supply constraints other than ongoing Missouri River bed degradation, which may impact select water supply intakes in the Lower Missouri subregion including those for Kansas City, were assumed. USACE reservoirs in Missouri were assumed to remain as currently allocated. The permitting process for building new reservoirs was assumed to remain unchanged.

## 9.3 Considerations and Limitations of the Analyses

The analyses to support scenario planning were developed and implemented to evaluate a range of plausible impacts at the subregion level and evaluate several select subbasins. The results detailed in this section, such as a characterization of *No Stress* in a subregion, do not imply that localized stress or supply shortages might not still occur under one or more scenarios. Numerous factors, many of which were not considered as part of the scenario planning exercise, can influence water availability and demands within a subregion differently, resulting in water supply stress in one area but not in another. For example, the presence of reservoirs to store water and buffer against the impacts of drought was not explicitly considered when evaluating potential surface water stress. Also, alluvial demands were treated as groundwater demands, but may impose stresses on surface water. No attempt was made to evaluate the impacts to surface water availability from increased alluvial demands.

The analyses focus on total water supply in a subregion or subbasin, but do not explicitly evaluate whether the infrastructure exists to deliver the water where needed. Additional evaluation is necessary to better identify potential infrastructure gaps that might exist within a subregion or subbasin.

It is recognized that in some subregions, such as the Chariton-Grand and Missouri-Nishnabotna, planning for regional projects is already underway to supplement water supply and provide the necessary infrastructure to meet future water supply needs. These regional projects, which are still being planned, were not explicitly included in the scenarios.

## 9.4 Uncertainty Drivers

In the scenario planning process, a range of plausible, major uncertainties are identified, characterized, and grouped together to evaluate their combined impact. The major assumptions that define the range of uncertainty drivers used in the four planning scenarios are summarized in this section. Further details regarding development of climate, water supply, and demands uncertainties are provided in **Appendix G**.

### 9.4.1 M&I and Rural Water Demands

A range of M&I and rural water demands reflecting a weak, average, and strong economy were developed for evaluation within select scenarios. The evaluation of economic impacts relied upon a designation of *urban* or *rural* for each county because urban and rural counties are assumed to grow at different rates as presented in **Appendix G**. The range of demands are represented as follows:

- **Baseline M&I and Rural Demands** are represented by the baseline demand projections to 2060, as described in **Section 3**. M&I and rural water demands map to the Major Water Users sector and Self-Supplied Domestic and Minor Systems sector described in **Section 3**.
- **High M&I Demands** are associated with the Strong Economy/High Water Stress scenario. Population growth in 2060 for urban counties is assumed to be 25 percent higher than the Woods & Poole series used in the baseline projections.
- **Low M&I Demands** are associated with the Weak Economy/Low Water Stress scenario. Population growth in 2060 for urban counties is assumed to be 10 percent less than the Woods & Poole series used in the baseline projections.
- **Higher Rural Demands** are associated with the Strong Economy/High Water Stress scenario. Population growth in 2060 for rural counties is assumed to be 10 percent higher than the Woods & Poole series used in the baseline projections.

Additionally, each scenario required an assessment of M&I and rural water demands under specific weather conditions, as water use and weather are highly correlated in summer months. The baseline demands represent average weather conditions. To model the impacts of average weather deviations, an analysis was conducted (see **Appendix G** for details) to evaluate the sensitivity of public water supply to variations in weather conditions. Ultimately, the analysis resulted in weather adjustment factors for water demand by subregion (HUC 4) for the summer months.

### 9.4.2 Agriculture Demands

Demands for irrigation and agricultural processing were developed separately to represent medium to high growth beyond the baseline demand projections for these sectors. These scenarios explore the what-if water use impacts associated with expanded industries that manufacture agriculture inputs (fertilizers, chemicals, machinery, etc.) and create consumable products from the outputs (meat processing plants, ethanol plants, etc.). The irrigation and agricultural processing demands map to the Agriculture Irrigation sector and Self-Supplied Nonresidential sector described in **Section 3**. The range of demands is represented as follows:

- **Medium Irrigation and Agricultural Processing Demands** are represented by the baseline demand projections to 2060, as described in **Section 3** for the Agriculture Irrigation sector and Self-Supplied Nonresidential sector.
- **Medium-High Processing Demands** represent an overall increase in the baseline agriculture processing demands of 5 percent. Ethanol plant growth increases over baseline are estimated separately and assume three additional plants. Anticipated growth in agricultural processing will most likely occur in the existing areas in which the respective processing is already occurring, but on a larger scale.
- **High Irrigation Demands** were developed assuming that potentially irrigable land is irrigated, and that amount was added to the irrigation demand projection. The percentage of irrigated lands in the Bootheel is assumed to increase from 75 to 85 percent of total acres. Along the Missouri River and its tributaries, the percent of irrigation acres is assumed to increase from 20 to 85 percent of total acres.
- **High Processing Demands** represent an overall increase in the baseline agricultural processing demands by 10 percent. Ethanol plant growth increases over baseline are estimated separately and assume six

additional plants. Anticipated growth in agricultural processing will most likely occur in the existing areas in which the respective processing is already occurring, but on a larger scale.

Irrigation demands were also adjusted depending on whether the average hydrologic year or dry year conditions were applied. For the drought year condition, irrigation demands were increased to make up for the crop demand deficit due to less precipitation. Processing demands were assumed to not vary between the average year and dry year hydrologic conditions.

### 9.4.3 Climate

Changing climatic conditions can significantly influence both water availability and demand. To incorporate uncertainty associated with potentially changing climatic conditions in Missouri, future climate scenarios were developed by combining projections from over 100 state-of-the-art climate models and historically available climate observations using the hybrid delta ensemble (HDe) method. The HDe method, developed by the Bureau of Reclamation, is a numerical approach used to incorporate downscaled global circulation model projections into a water resources planning study (Bureau of Reclamation 2010). The *ensemble* term in the HDe name refers to the fact that a group of projections is combined and used jointly, rather than applied discretely. The method is well suited for water supply planning studies and was used to generate inputs to the hydrologic analyses conducted for each scenario.

Several plausible climatic conditions were selected to represent uncertainty drivers for the scenarios. The climatic conditions selected fall within the model projected range of temperature and precipitation. Average annual temperature increases by year 2060 generally range from less than 1 degree Celsius (°C) to around 5°C. For precipitation, model projections vary from between 25 percent drier to nearly 30 percent wetter. No attempt was made to assess the likelihood that these potential climate futures will occur, but rather they are presented as a range of projected conditions based on the best available science and engineering. The range of climate conditions developed and represented is:

- **Historical Temperature and Precipitation.** This category assumes no change to long-term average temperature and precipitation. As such, no climate-related adjustments to demands were made. Reservoir evaporation was assumed not to increase over long-term averages. Supply availability was based on streamflow resulting from historical, long-term average precipitation.
- **Hotter Temperature and Lower Precipitation.** Hotter temperatures represent the ensemble of climate models that fall within the $50^{th}$ to $100^{th}$ percentile for temperature when compared to all climate model predictions. Lower precipitation represents the ensemble of climate models that fall within the 0 to $50^{th}$ percentile for precipitation. As previously noted, weather adjustment factors were developed and applied to reflect appropriate climate-related changes in water demand by subregion (HUC 4).
- **Warmer Temperature and Greater Precipitation.** Warmer temperatures represent the ensemble of climate models that fall within the 0 to $50^{th}$ percentile for temperature when compared to all climate model predictions. Greater precipitation (and the resulting greater runoff) represents the ensemble of climate models that fall within the $50^{th}$ to $100^{th}$ percentile for precipitation. As previously noted, weather adjustment factors were developed and applied to reflect appropriate climate-related changes in water demand by subregion (HUC 4).

It is important to recognize that the qualifiers *hotter*, *warmer*, *lower*, and *greater* are relative to future climate projections and not necessarily to current conditions. For more information on the construction of the climate data ensembles, see **Appendix G**.

The process described above to investigate a range of future climate conditions focused exclusively on Missouri. Separate recent studies have focused on the entire Missouri River Basin. For example, snowpack and streamflow in the Missouri River Basin are projected to decrease based on continuing warmer temperatures, as discussed in the journal article "Hydroclimatology of the Missouri River Basin" (Wise et al. 2018). In the basin, plains snowpack, mountain snowpack, and rainfall combine to contribute runoff to the Missouri River. Declining snowpack will mean reduced Missouri River flows. Decreased Missouri River flows into the state may negatively affect water quality, navigation structures, water supply intakes, recreation, and fish and wildlife. Future changes to the climate in the Missouri River Basin upstream of Missouri were not explicitly considered as part of the scenario planning process; however, potential impacts from changing Missouri River flows entering the state were identified.

### 9.4.4 Water Treatment Levels

Water treatment levels can range from relatively simple to complex depending on the water source and potential pollution sources. Certain water quality parameters are of greater concern when considering public health and safety and the aesthetic quality of drinking water. With newer technologies and advancements in research, the wide range of water quality concerns is becoming more refined and updated. The following is a list of current water quality categories that are of primary concern for drinking water, as defined by EPA. The presence and concentration of contaminants in these categories in source waters drives the level of treatment needed.

- Microorganisms
- Disinfectants
- Disinfection by-products
- Inorganic chemicals
- Organic chemicals
- Radionuclides

Water that is free of pathogens and contaminants may require only minimal treatment. However, varying concentrations of man-made contaminants or naturally occurring organic and inorganic constituents can cause problems in drinking water supplies that range from minor aesthetic issues to chronic or acute health risks. Individually, these contaminants often require additional treatment. Combinations of contaminants can result in complex treatment facilities with multiple processes, and multiple liquid and/or solid residuals that require proper disposal.

#### Existing Water Treatment Levels

The MoDNR 2018 Safe Drinking Water Information System (SDWIS) database characterizes existing treatment levels of water systems across the state. The dataset covers a range of treatment levels, which are summarized in **Table 7-2** of **Section 7**. Most of the surface water systems use conventional treatment, but often incorporate additional technologies such as enhanced coagulation or lime softening to address specific issues associated with their source water quality. Most of the groundwater systems use disinfection, and some incorporate additional processes and technologies such as sequestration to remove iron and manganese. Existing treatment levels are associated with the Business-as-Usual and Weak Economy/Low Water Stress scenarios.

#### Moderate Increase in Water Treatment Levels

For scenario planning purposes, a moderate increase in the level of treatment from existing levels assumes that water systems across the state, which only employ conventional treatment for surface water and disinfection for groundwater, must add additional technologies to treat source water that has degraded in quality or to comply with changing regulations. For example, systems that currently provide only conventional treatment might have to incorporate additional processes such as enhanced filtration. Moderate increases in treatment levels are associated with the Substantial Agricultural Expansion scenario.

### High Increase in Water Treatment Levels

A high increase in water treatment levels assumes that water systems across the state must employ the most rigorous and expensive treatment technologies as a result of significantly degraded water quality or more stringent regulations. For example, systems might have to incorporate more chemical additions or utilize technologies, such as enhanced filtration or UV systems, to remove difficult to treat and/or emerging contaminants. The high increase in treatment levels is associated with the Strong Economy/High Water Stress scenario.

## 9.4.5 Supply Constraints

Water supplies can be constrained by a range of factors, from reduced major river flows coming into Missouri to new limitations placed on groundwater withdrawals to prevent aquifer depletion. Supply constraints can be temporary, such as a short-term disruption in supply due to failing infrastructure or a chemical spill, or long term, as would be expected with the fulfillment of claims and water rights on water that might normally flow into Missouri from upstream states. In this scenario planning exercise, several plausible uncertainty drivers that could reduce or limit water supplies were identified and assigned to the scenarios, as described below.

### Missouri River Bed Degradation

Bed degradation considers the effects of downcutting and erosion along the Missouri River. Significant impacts can occur from bed degradation on infrastructure such as water supply intakes, levees, and bridges. According to the *Missouri River Bed Degradation Feasibility Study* (USACE 2017), significant bed degradation has occurred and is expected to continue within certain portions of the Missouri River between St. Joseph and Waverly. The impacts to water supply infrastructure need to be considered, should these structures become unusable. Since bed degradation is already occurring and is expected to continue to occur, it is included in the baseline and all other scenarios.

### Upstream Diversions out of the Missouri River and Reduced System Storage

Development in the Missouri River Basin upstream of Missouri is anticipated to continue through and beyond 2060. Both public supply and industrial demands are forecasted to increase, and an increase in irrigated crop acreage is likely. Furthermore, development fueled by existing state and tribal water rights may result in additional withdrawals in the basin and/or directly from the Missouri River. For this planning exercise, it was estimated that the combination of these potential upstream diversions would reduce Missouri River flows (at the point the river flows into Missouri) by 14 percent by 2060. This value is based on estimates made by USACE that account for reasonably foreseeable water supply projects through 2060 (USACE 2013). The ongoing sedimentation of Missouri River System reservoirs may also reduce flow into Missouri during droughts. For this planning exercise, it was assumed that during a drought, there would be a 9 percent reduction in 2060 Missouri River flows because of the expected reduction in upstream reservoir storage. This estimated reduction is based on historical reservoir sedimentation rates and calculations made by USACE (2013) and MoDNR (2018).

### Prolonged Supply Disruption on Missouri River Intakes

Prolonged supply disruptions might occur as a result of a chemical spill or infrastructure failure (e.g., major mechanical failure, earthquake, ice dams). For scenario planning purposes, a supply disruption on the Missouri River that results in a loss of supply for approximately 1 month was included in the Strong Economy/High Water Stress scenario. A supply disruption would require water users with intakes on the Missouri River to temporarily rely on an alternative source of water. It is assumed that not all users will lose supply at the same time (i.e., some intakes may be used while others are not operable, as could be the case with a chemical spill). This uncertainty driver evaluates the resiliency of water users and helps identify potential vulnerabilities due to a lack of interconnections, lack of an alternative water source, or inability to quickly identify and connect to an alternative water source.

### Limitations on Groundwater Withdrawals

Whether it be in Missouri or elsewhere, the availability of groundwater resources may become limited due to numerous factors. Pumping more water out of an aquifer than is recharged naturally can result in aquifer depletion, causing reduced yields or dry wells. Groundwater declines may limit or restrict groundwater availability. Additionally, groundwater users may voluntarily limit their groundwater use to maintain the viability of the resource.

In southwest Missouri, Ozark Aquifer groundwater levels have declined from predevelopment conditions by over 300 feet in localized areas near heavy pumping centers. In Jasper, McDonald, and Newton counties, the largest groundwater declines generally range from over 100 feet to 300 feet. For scenario planning purposes, it was assumed that the localized declines in groundwater levels indicated by the Ozark Plateaus Aquifer System Groundwater Flow Model analysis (**Section 4.8**) would be realized and result in a 30 percent reduction in projected 2060 groundwater withdrawal rates in southwest Missouri. To implement this uncertainty driver, the community water systems in the Neosho-Verdigris subregion using groundwater were assigned a 30 percent reduction in projected 2060 groundwater withdrawals. There are approximately 101 active community water system wells in this subregion (**Figure 9-1**), most of which withdraw groundwater from the Lower Ozark Aquifer. A corresponding increase in surface water withdrawals was assumed to be necessary to meet the community water system demands.

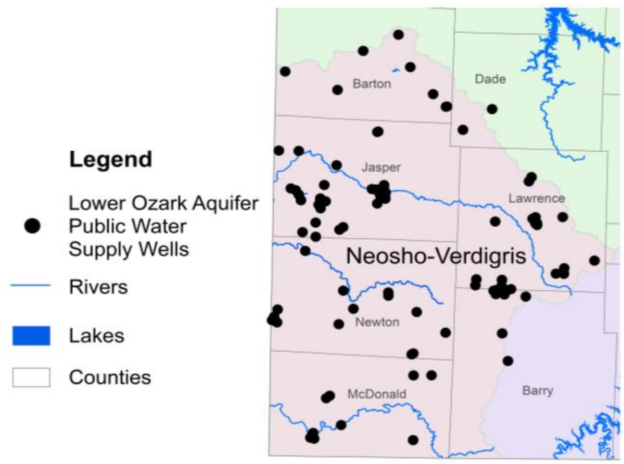


**Figure 9-1. Lower Ozark Aquifer Public Water Supply Wells in the Neosho-Verdigris Subregion**

## 9.4.6 Reservoir Regulations

Reservoirs are an important source of water supply for many communities, especially in northern Missouri where poor groundwater quality limits its use. Two factors that influence the ability of water suppliers to use existing reservoirs and develop new reservoirs were included as uncertainty drivers for scenario planning: (1) the reallocation of USACE reservoirs located in Missouri, and (2) the permitting process for the development of new reservoirs.

### Reallocation of USACE Reservoirs in Missouri for Water Supply

The potential reallocation of Stockton Lake, Pomme de Terre Lake, and/or Table Rock Lake to increase the amount of stored water available to meet water supply needs is already being explored by the Southwest Missouri Regional Water Commission, whose members include communities and water suppliers in southwest Missouri. The commission continues to work with USACE, state and federal agencies, and others to navigate the complex series of steps required to potentially obtain storage from these existing reservoirs. To incorporate this driver into scenario planning, two possible outcomes were included. These represent only two of several potential outcomes, and no claim is made as to their likelihood of occurring. The outcomes include:

- **Limited Reallocation**, which assumes that by 2060, 39 MGD (44,000 AFY) of water supply storage is granted for Stockton Lake and Pomme de Terre Lake (combined) for use by members of the Southwest Missouri Regional Water Commission and/or their wholesale customers. Limited Reallocation is associated with the Strong Economy/High Water Stress and Substantial Agricultural Expansion scenarios.
- **No Reallocation**, which assumes that by 2060, there is no change to existing USACE reservoir allocations. No Reallocation is associated with the Business-as-Usual and Weak Economy/Low Water Stress scenarios.

All scenarios assume that the 67.5 MGD (75,700 AFY) of allocated water supply storage from Smithville Lake is available for use by customers in the Kansas City area, once infrastructure is in place.

#### Development of New Storage Reservoirs

The current process to build support for, study, design, obtain permits for, fund, acquire lands, and construct a new reservoir can take 20 years or more. This relatively long period to develop a reservoir-based source of water supply has important implications to water supply planning. To evaluate the implications to water supply planning, two versions of this driver were included:

- For most scenarios, the **Existing Process for New Storage Reservoirs** was assumed to remain in place. For this version of the driver, only reservoirs that are currently in the planning and/or permitting stages are assumed to be available for use by 2060.
- A **Streamlined Permitting and Development Process for New Storage Reservoirs** was assigned to the Strong Economy/High Water Stress scenario. This assumes that a streamlined, expedited process for developing and permitting new reservoirs would be implemented, effectively lowering the time to construct a new reservoir. Therefore, more new reservoirs would be established by 2060 under this scenario.

## 9.5 Impacts of Scenarios

The four planning scenarios (Business-as-Usual or baseline scenario, Strong Economy/High Water Stress, Substantial Agricultural Expansion, and Weak Economy/Low Water Stress) were evaluated to identify potential future impacts to Missouri's ability to meet water resource needs. When possible, quantitative analyses were performed by adjusting the water budgets described in **Section 4**, based on the combination of uncertainty drivers in each scenario. The water budgets were revised to reflect changes to demands (as influenced by economic and climate factors) and supply (as influenced by climate factors). In all subregions and in select subbasins, the revised 2060 monthly demands were compared to the revised supply totals to identify potential water stress or gaps arising under each scenario. For some of the uncertainty drivers, quantitative analysis was not possible. Semiquantitative and qualitative evaluations were used to identify and evaluate potential impacts of Missouri River supply constraints, reservoir reallocation, reservoir development and permitting, groundwater limitations, and water treatment levels.

### 9.5.1 Average Condition Surface Water Impacts

In all subregions and select subbasins, projected 2060 surface water demands were compared to surface water supplies under an average hydrologic condition. The average hydrologic condition (before adjustment by the specific scenario drivers) reflects historical average streamflow measured between 1986 and 2016. Flow in the Missouri River and demands on it were evaluated separately when identifying water supply stress and gaps within the subregions bordering the river.

The method used to characterize, categorize, and graphically depict the level of potential surface water supply stress under each scenario is shown in **Table 9-2**. When projected 2060 demands in a subregion or subbasin were less than 50 percent of available supply for every month of the year, *No Stress* was assigned. Two categories of increasing levels of potential water supply stress were defined, *Low Potential Stress* or *Higher Potential Stress*. If demand was greater than 50 percent but less than 100 percent of the supply for 1 month or more, *Low Potential Stress* was assigned. If demand was greater than supply for 1 month or more, *Higher Potential Stress* was assigned. The categorization of relative potential surface water supply stress helps to compare the impacts between different scenarios and identify options and strategies to mitigate or eliminate impacts. For this portion of the analysis, major river demands and supply were not included in the evaluation of determining potential surface water supply stress.

**Table 9-2. Identifying Potential Surface Water Supply Stress for Surface Water**

| Condition | Analysis | Result | Potential Water Supply Stress | Key for Figures |
|---|---|---|---|---|
| Average and Drought of Record | Monthly | Demand < 50% of supply for entire year | No Stress | Green semicircle |
| | | Demand > 50% and <100% of supply for 1 month or more | Low Potential Stress | Yellow semicircle |
| | | Demand > supply for 1 month or more | Higher Potential Stress | Red semicircle |

## Scenario Results for Subregion Average Conditions

A summary of the subregion surface water supply stress for each scenario in an average condition is shown in **Table 9-3**. The Strong Economy/High Water Stress scenario shows the greatest potential water supply stress, with five subregions' demand exceeding supply for 1 or more months and two subregions with demand greater than 50 percent but less than 100 percent of supply for 1 or more months. The Substantial Agricultural Expansion scenario has a greater potential water supply stress than the Business-as-Usual and Weak Economy/Low Water Stress scenario, with three subregions' demand exceeding supply for 1 month or more. The Business-as-Usual and Weak Economy/Low Water Stress scenarios have the same number of subregions showing similar potential water stress.

**Table 9-3. Subregion Surface Water Supply Stress Summary (Average Conditions)**

| Potential Water Supply Stress Category | Number of Subregions in Each Category | | | |
|---|---|---|---|---|
| | Scenario 1 – Business-as-Usual | Scenario 2 – Strong Economy/ High Water Stress | Scenario 3 – Substantial Agricultural Expansion | Scenario 4 – Weak Economy/ Low Water Stress |
| Demand <50% of supply for entire year | 3 | 2 | 3 | 3 |
| Demand >50% and <100% of supply for 1 month or more | 5 | 2 | 3 | 5 |
| Demand > supply for 1 month or more | 1 | 5 | 3 | 1 |

**Figures 9-2** through **9-5** show the potential 2060 water supply stress for each subregion under average conditions, as depicted using the notation in **Table 9-4**. The number of months exceeding the potential stress level for each subregion is listed in the yellow and red semicircles.

The Business-as-Usual scenario results for average conditions are shown in **Figure 9-2**. *No Stress* was identified in three of the nine subregions (Chariton-Grand, Gasconade-Osage, and Upper White). In five of the subregions, demand is greater than 50 percent and less than 100 percent of the supply for 1 or more months, indicating *Low Potential Stress*. In the Lower Mississippi-St. Francis, demand is greater than supply for 1 month, indicating the potential for a slightly higher level of stress relative to the other subregions. The Strong Economy/High Water Stress scenario results are shown in **Figure 9-3**. To easily compare results between scenarios, the results for the Business-as-Usual scenario are represented as the top half of the circle and the Strong Economy/High Water Stress results are represented as the bottom half of the circle.

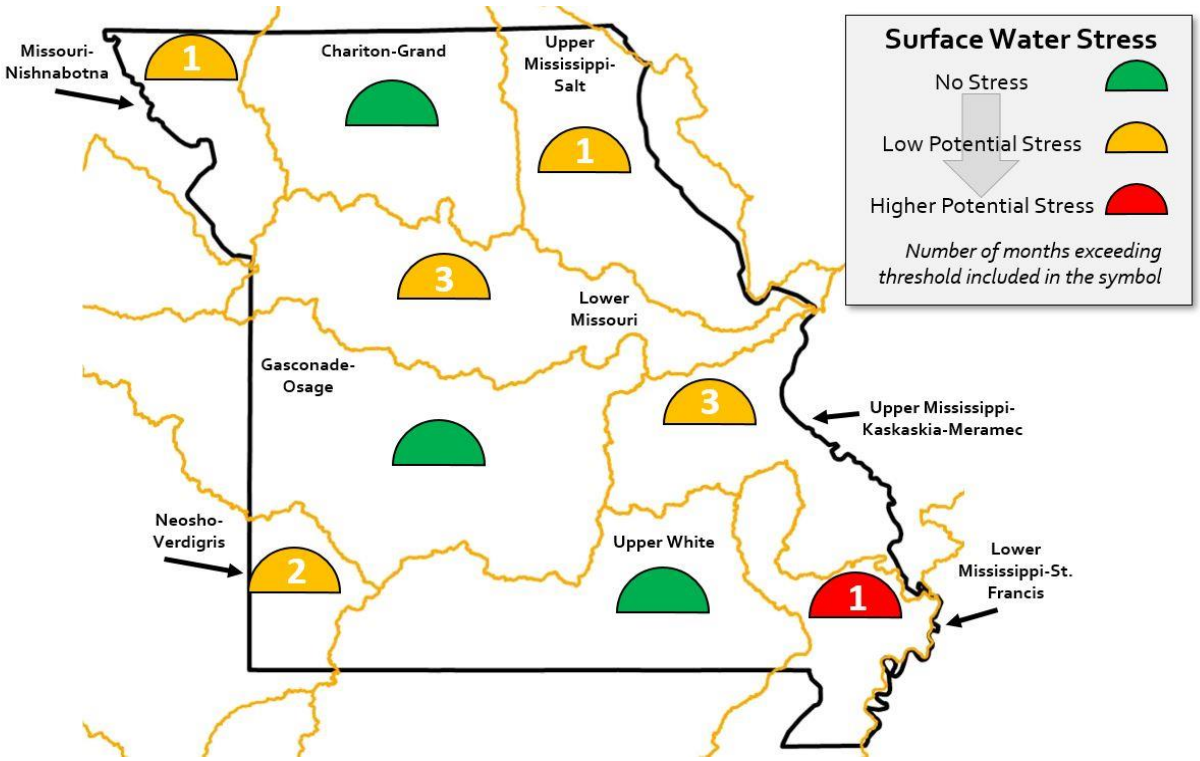


**Figure 9-2. Scenario 1 Business-as-Usual Results for Average Hydrologic Conditions (Surface Water)**

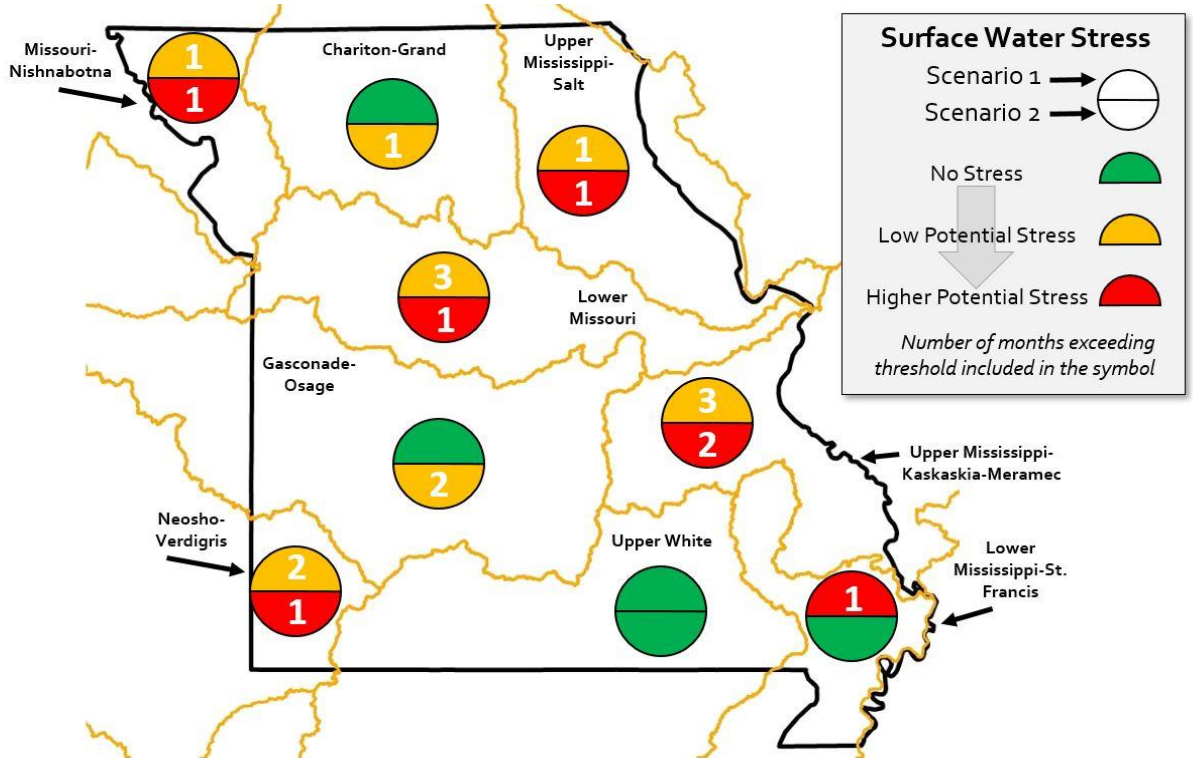


**Figure 9-3. Scenario 2 Strong Economy/High Water Stress Results for Average Hydrologic Conditions (Surface Water)**

As would be expected, the combination of higher demands, hotter temperatures, and lower precipitation result in the potential for increased surface water stress in most of the subregions. The reduction in potential stress in the Lower Mississippi-St. Francis compared to the Business-as-Usual scenario is due to the assumptions made for the source of water. It was assumed that groundwater will play an even larger role in meeting agricultural demands compared to surface water in this part of the state under the Strong Economy/High Water Stress scenario.

**Figures 9-4** and **9-5** show the results for the Substantial Agricultural Expansion and Weak Economy/Low Water Stress scenarios, respectively. Again, the scenario results are shown in the bottom half of the circles for easy comparison to the Business-as-Usual results. The uncertainty drivers of the Substantial Agricultural Expansion scenario are similar to those of the Business-as-Usual scenario, except for an increase in water demand for agricultural processing, warmer temperatures, and greater rainfall. This combination of drivers results in potential stresses that are very similar to the Business-as-Usual scenario in most subregions. Likewise, the Weak Economy/Low Water Stress scenario results are nearly identical to the Business-as-Usual scenario results.

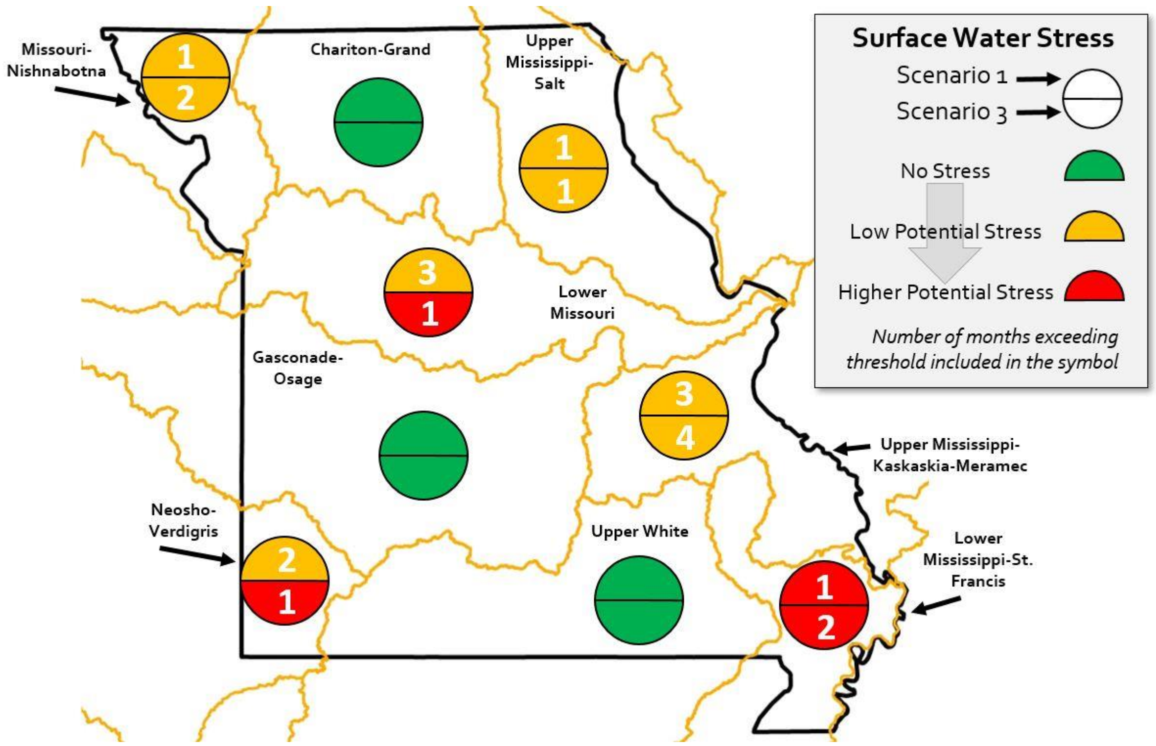


**Figure 9-4. Scenario 3 Substantial Agricultural Expansion Results for Average Hydrologic Conditions (Surface Water)**

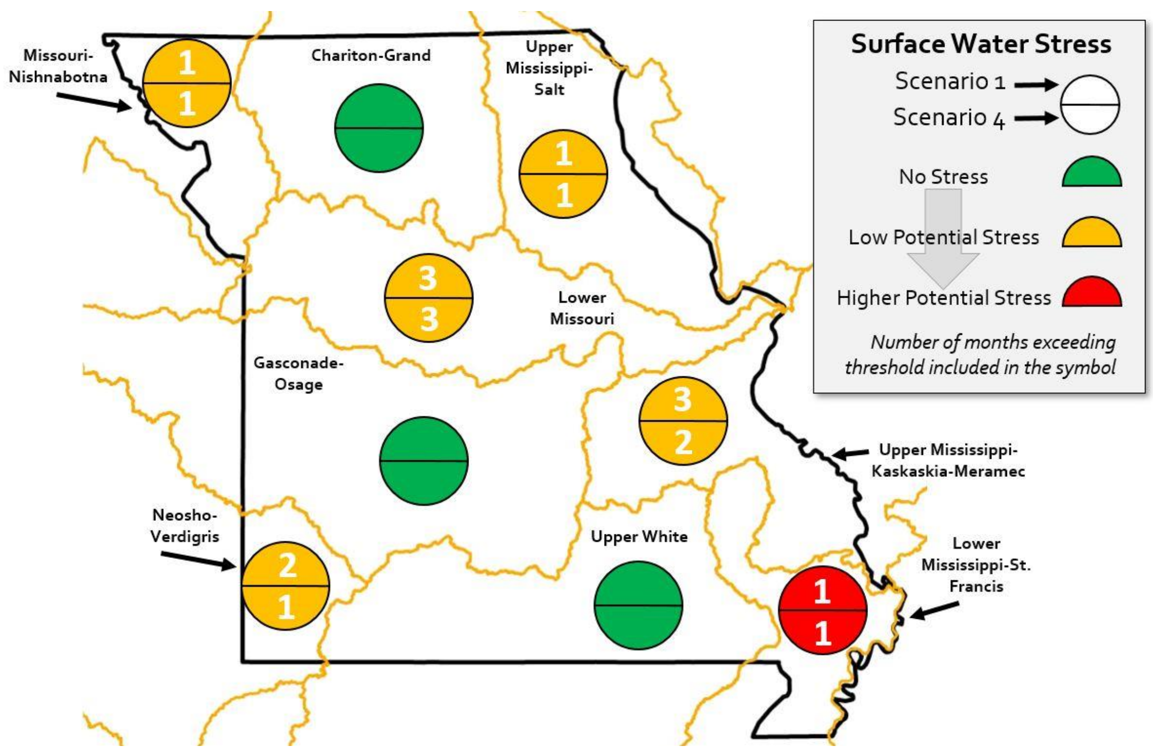


**Figure 9-5. Scenario 4 Weak Economy/Low Water Stress Results for Average Hydrologic Conditions (Surface Water)**

### Scenario Results for Subbasin Average Conditions

Select subbasins were chosen by MoDNR and stakeholders participating in the technical workgroups for more detailed analysis. The subbasins included all those within the Chariton-Grand subregion and the Little Osage subbasin within the Gasconade-Osage subregion. These subbasins were selected because of their known history of water supply stress during droughts.

A summary of the surface water supply stress for each scenario under average conditions is shown in **Table 9-4**. The Strong Economy/High Water Stress scenario shows the highest potential water supply stress, with three subbasins with demands exceeding supply for 1 or more months, and four subbasins with demands greater than 50 percent and less than 100 percent of the supply for 1 or more months.

**Figures 9-6** through **9-9** show the potential 2060 water supply stress for each subbasin under average conditions, as depicted using the notation in **Table 9-4**. The number of months exceeding the potential stress level for each subregion is listed in the yellow and red semi-circles.

The Business-as-Usual scenario results for average conditions are shown in **Figure 9-6**. *No Stress* was identified in six of the seven subbasins. None of the subbasins in the Chariton-Grand subregion showed water stress, but results for the Little Osage subbasin in the Gasconade-Osage subregions indicated that demand is greater than 50 percent and less than 100 percent of the supply for 1 or more months, indicating *Low Potential Stress*.

**Table 9-4. Subbasin Surface Water Supply Stress Summary (Average Conditions)**

| Potential Water Supply Stress Category | Number of Subbasins in Each Category | | | |
|---|---|---|---|---|
| | Scenario 1 – Business-as-Usual | Scenario 2 – Strong Economy/ High Water Stress | Scenario 3 – Substantial Agricultural Expansion | Scenario 4 – Weak Economy/ Low Water Stress |
| Demand <50% of supply for entire year | 6 | 0 | 6 | 5 |
| Demand > 50% and < 100% of supply for 1 month or more | 1 | 4 | 0 | 2 |
| Demand > supply for 1 month or more | 0 | 3 | 1 | 0 |

The Strong Economy/High Water Stress scenario results are shown in **Figure 9-7**. As would be expected, the combination of higher demands, hotter temperatures, and lower precipitation result in the potential for increased surface water stress in all the subbasins compared to the Business-as-Usual scenario.

**Figures 9-8** and **9-9** present the results for the Substantial Agricultural Expansion and Weak Economy/Low Water Stress scenarios, respectively. The uncertainty drivers of the Substantial Agricultural Expansion scenario are similar to those of the Business-as-Usual scenario, except for an increase in water demand for agricultural processing, warmer temperatures, and greater rainfall. This combination of drivers results in potential stresses that are very similar to the Business-as-Usual scenario in most subbasins, except for the Little Osage, which shows *Higher Potential Stress*. Likewise, the Weak Economy/Low Water Stress scenario results are nearly identical to the Business-as-Usual scenario results, with *Low Potential Stress* in both the Upper Chariton and Little Osage.

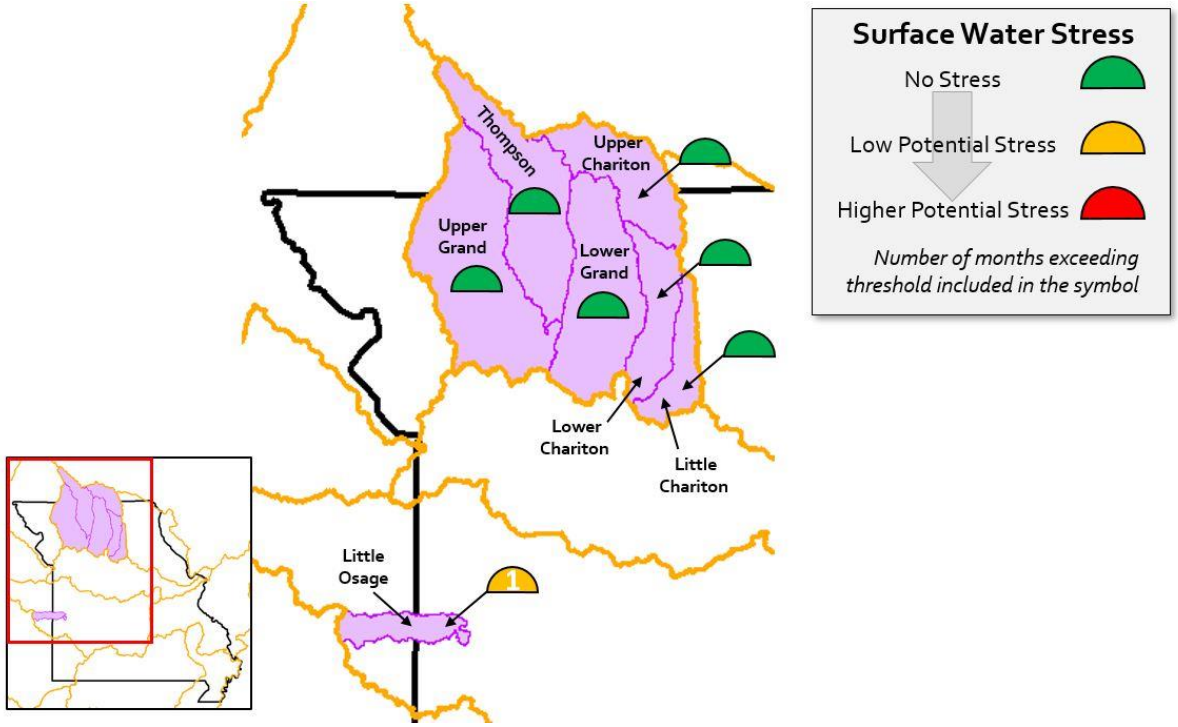


Figure 9-6. Scenario 1 Business-as-Usual Results for Average Hydrologic Conditions (Surface Water)

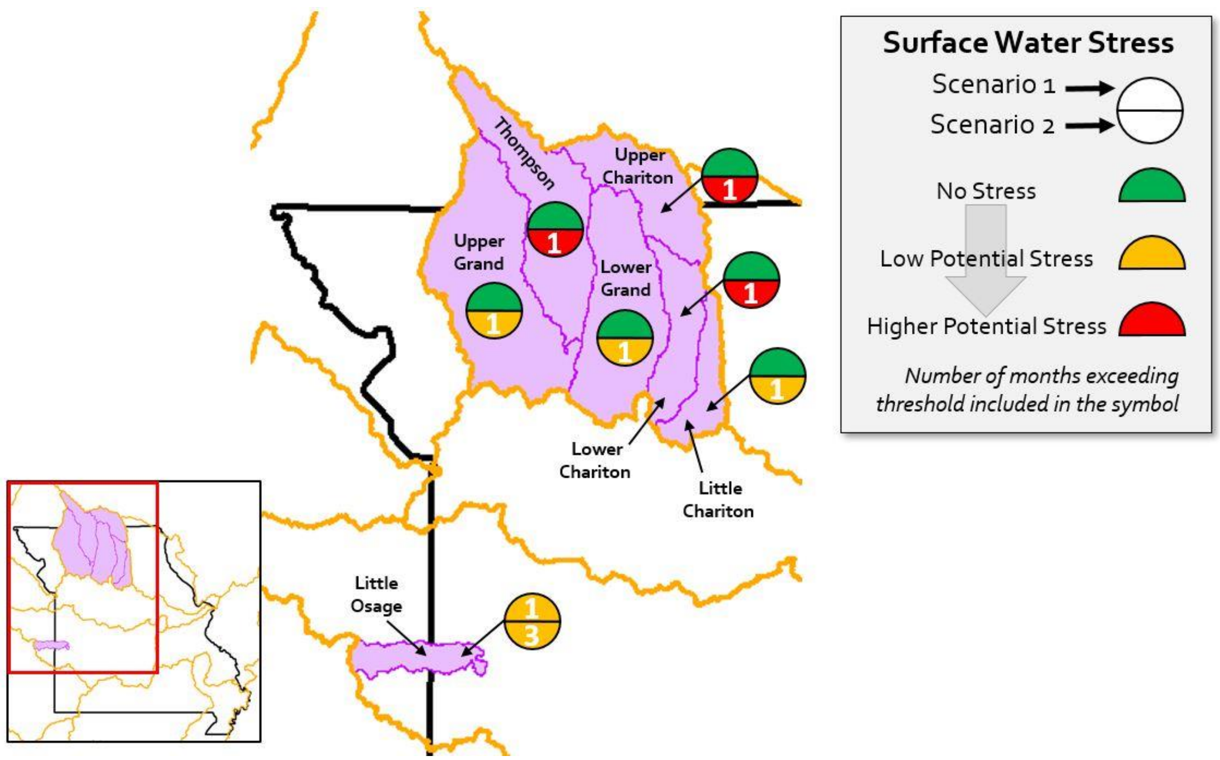


Figure 9-7. Scenario 2 Strong Economy/High Water Stress Results for Average Hydrologic Conditions (Surface Water)

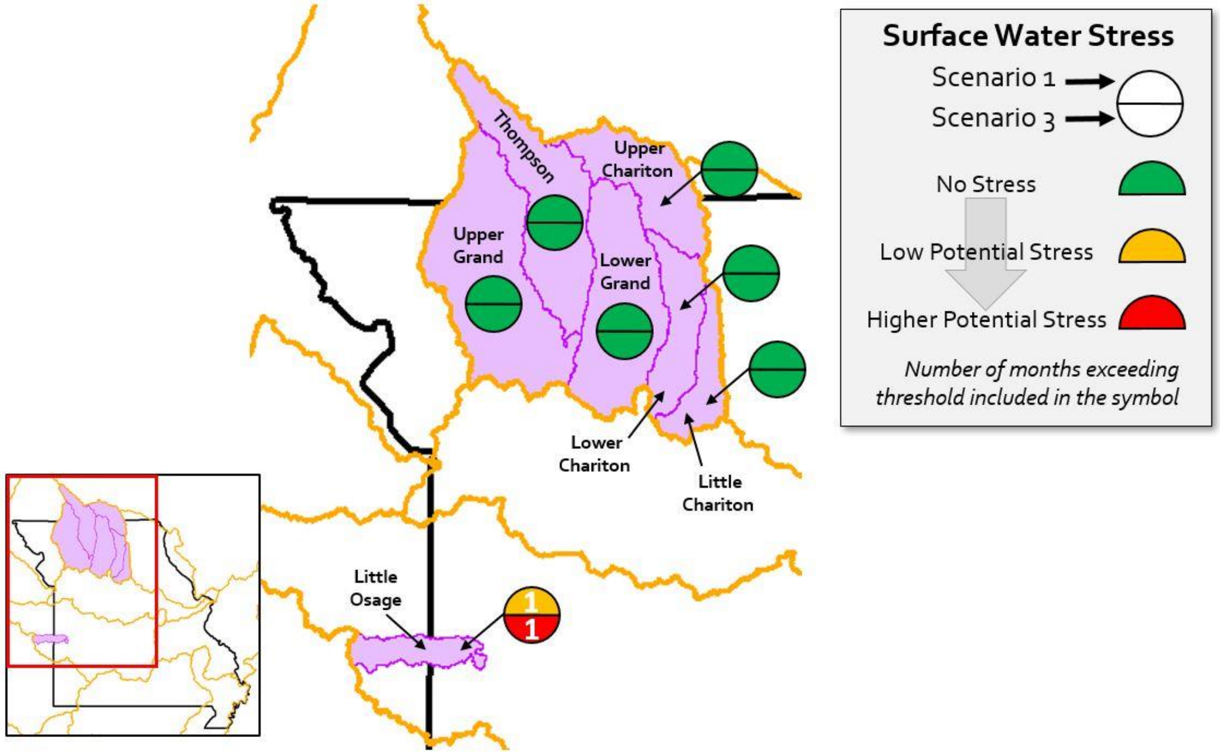


Figure 9-8. Scenario 3 Substantial Agricultural Expansion Results for Average Hydrologic Conditions (Surface Water)

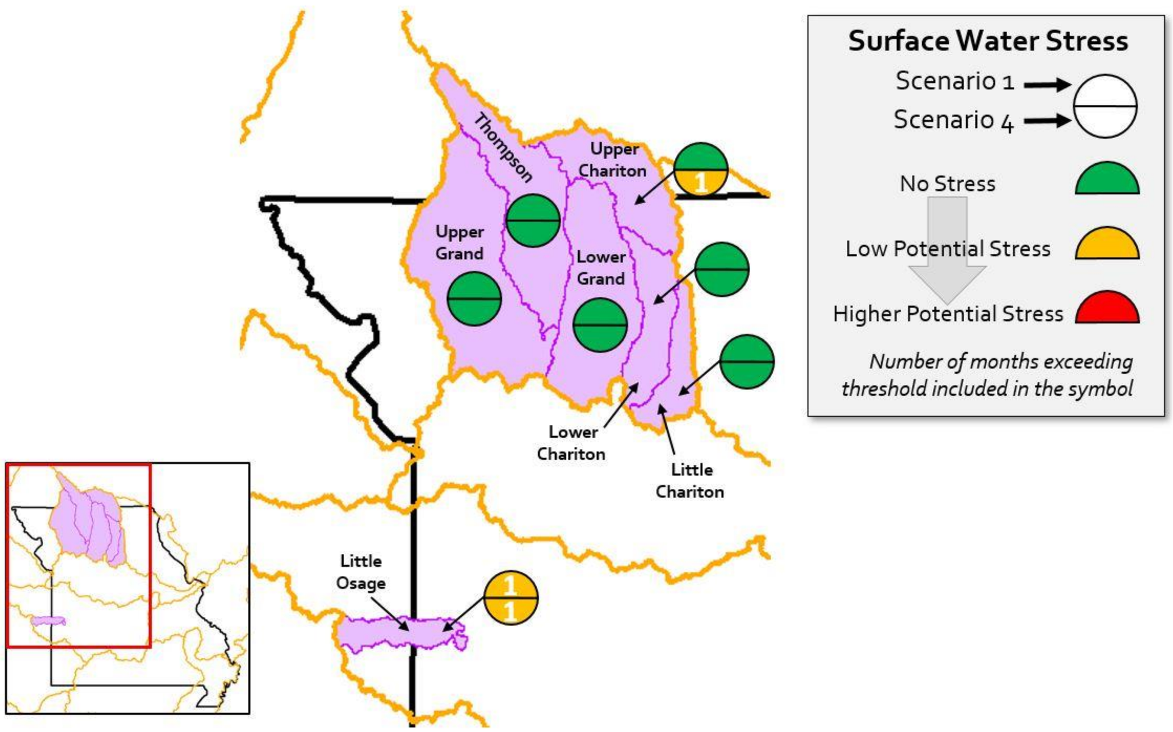


Figure 9-9. Scenario 4 Weak Economy/Low Water Stress for Average Hydrologic Conditions (Surface Water)

### 9.5.2 Drought Condition Surface Water Impacts

In all subregions and select subbasins, projected 2060 surface water demands were compared to surface water supplies under a drought condition. The drought condition (before adjustment by the specific scenario drivers) reflects average streamflow measured in a single year during the drought of record (either 1954 or 1956, whichever was drier for a particular subregion).

#### Scenario Results for Subregion Drought Conditions

A summary of the subregion surface water supply stress for each scenario in a drought condition is shown in **Table 9-5**. The Business-as-Usual, Substantial Agricultural Expansion, and Weak Economy/Low Water Stress scenarios all have the same number of subregions showing similar potential water stress, with one exception as explained following the table.

**Table 9-5. Subregion Surface Water Supply Stress Summary (Drought Conditions)**

| Potential Water Supply Stress Category | Number of Subregions in Each Category | | | |
|---|---|---|---|---|
| | Scenario 1 – Business-as-Usual | Scenario 2 – Strong Economy/ High Water Stress | Scenario 3 – Substantial Agricultural Expansion | Scenario 4 – Weak Economy/ Low Water Stress |
| Demand <50% of supply for entire year | 0 | 1 | 0 | 0 |
| Demand > 50% and < 100% of supply for 1 month or more | 1 | 1 | 1 | 1 |
| Demand > supply for 1 month or more | 8 | 7 | 8 | 8 |

**Figures 9-10** through **9-13** show the potential 2060 water supply stress for each subregion under drought conditions, as depicted using the notation in **Table 9-5**. The number of months exceeding the potential stress level for each subregion is listed in the yellow and red semi-circles.

The Business-as-Usual scenario results for each subregion are shown in **Figure 9-10** for the drought of record conditions. The low surface water flows of the drought of record combined with projected 2060 demands result in *Higher Potential Stress* level of stress in all subbasins except the Upper White. Supply gaps (when demand exceeds supply) range from 4 to 10 months.

The results for Strong Economy/High Water Stress, Substantial Agricultural Expansion, and Weak Economy/Low Water Stress scenarios for each subregion are shown in **Figures 9-11** through **9-13**. All results are shown below the Business-as-Usual results for easy comparison. Business-as-Usual, Strong Economy/High Water Stress, Substantial Agricultural Expansion, and Weak Economy/Low Water Stress scenarios show a similar level of *Higher Potential Stress* in nearly all subregions. As was the case under average conditions, the reduction in potential stress in the Lower Mississippi-St. Francis for the Strong Economy/High Water Stress scenario compared to the other scenarios is due to the assumptions made for the source of water (i.e., more groundwater use and less surface water use).

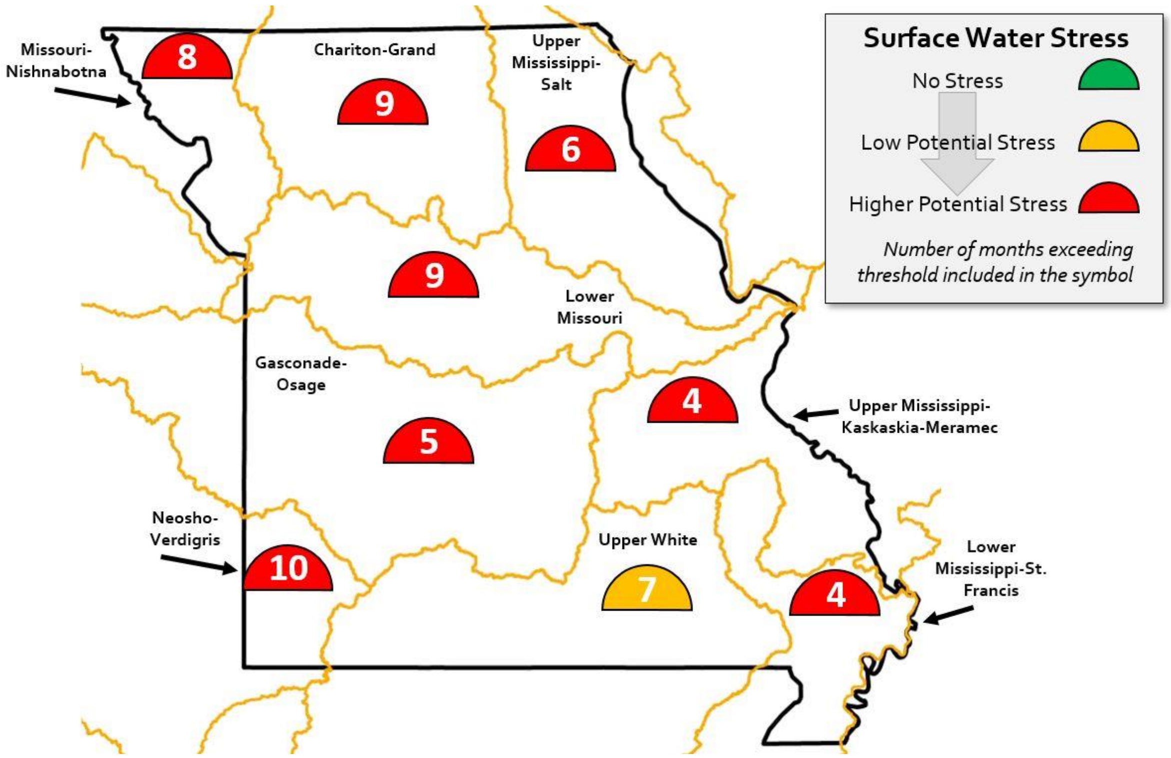


**Figure 9-10. Scenario 1 Business-as-Usual Results for Drought of Record Conditions (Surface Water)**

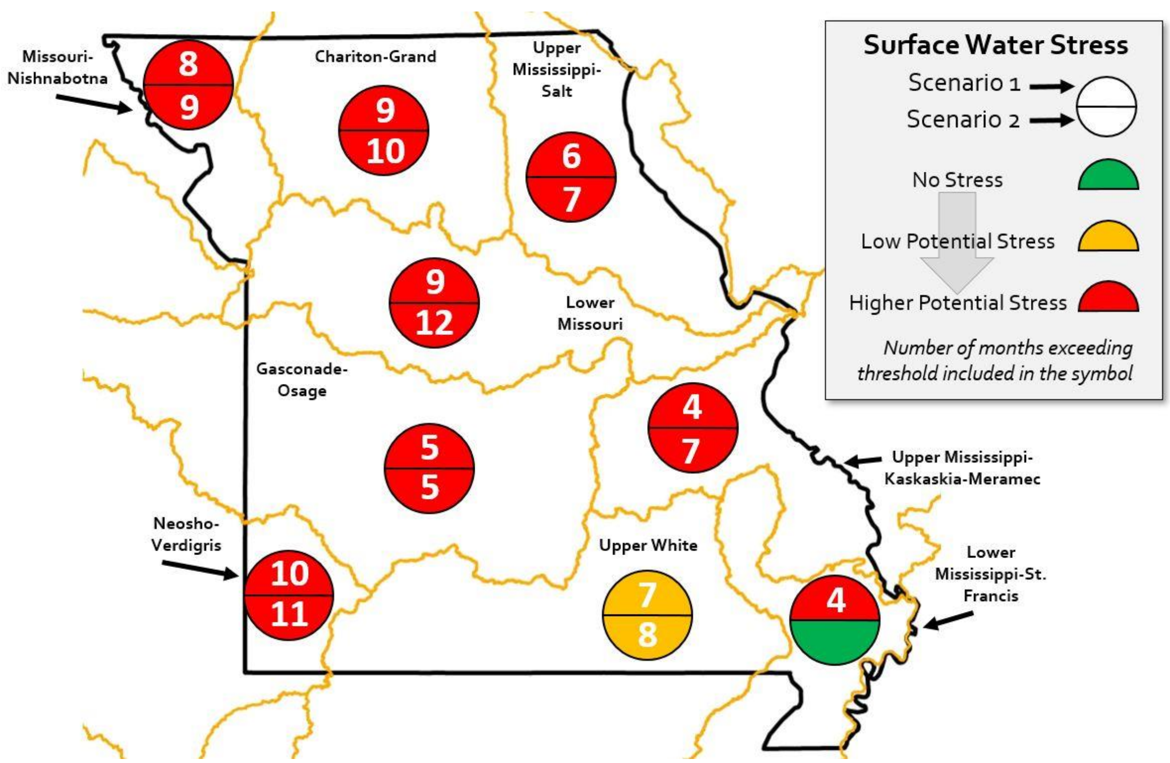


**Figure 9-11. Scenario 2 Strong Economy/High Water Stress Subregion Results for Drought of Record Conditions (Surface Water)**

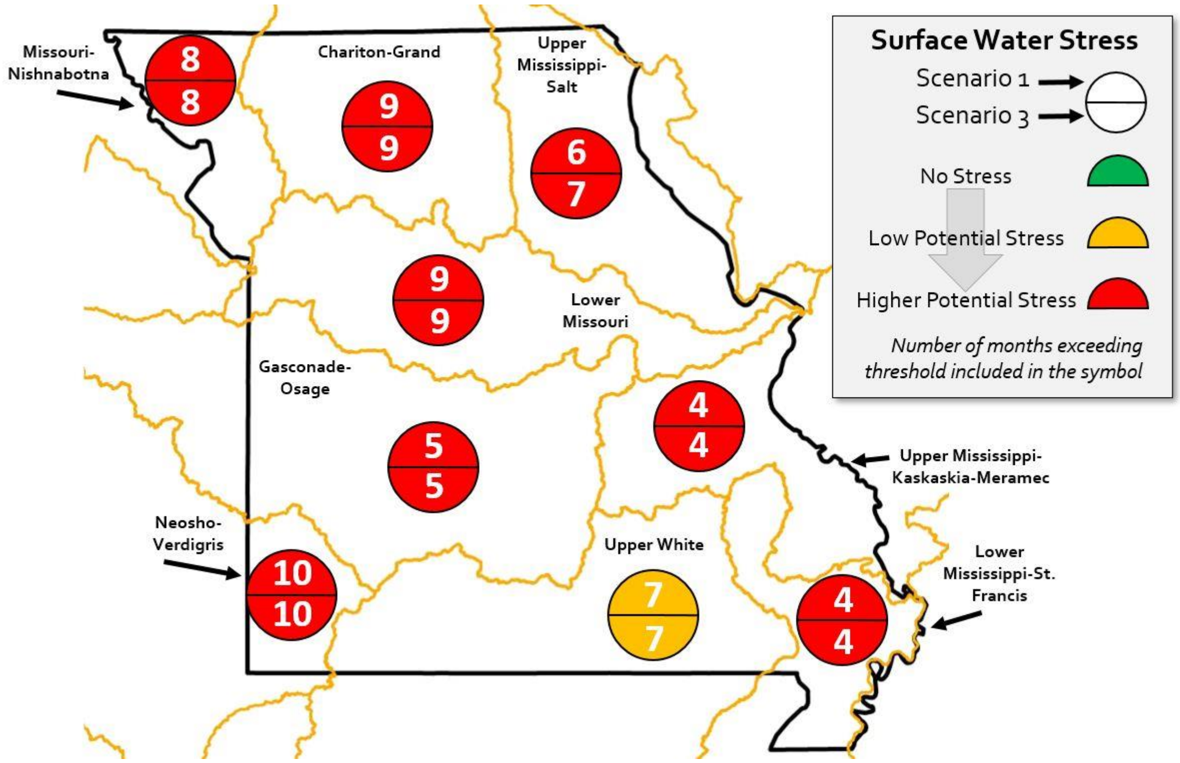


**Figure 9-12. Scenario 3 Substantial Agricultural Expansion Results for Drought of Record Conditions (Surface Water)**

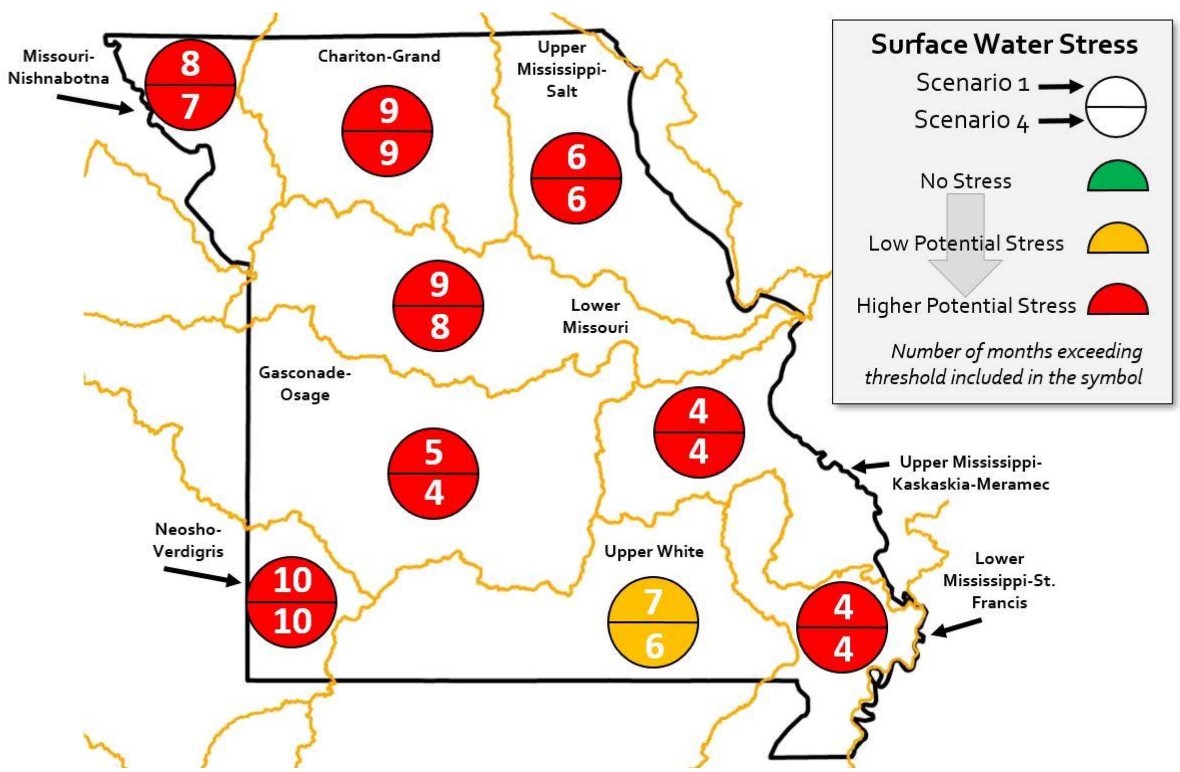


**Figure 9-13. Scenario 4 Weak Economy/Low Water Stress for Drought of Record Conditions (Surface Water)**

## Scenario Results for Subbasin Drought Conditions

A summary of the subbasin surface water supply stress for each scenario under drought conditions is shown in **Table 9-6**. The Business-as-Usual, Substantial Agricultural Expansion, and Weak Economy/Low Water Stress scenarios all show the same high potential for water supply stress.

**Table 9-6. Subbasin Surface Water Supply Stress Summary (Drought Conditions)**

| Potential Water Supply Stress Category | Number of Subbasins in Each Category | | | |
|---|---|---|---|---|
| | Scenario 1 – Business-as-Usual | Scenario 2 – Strong Economy/ High Water Stress | Scenario 3 – Substantial Agricultural Expansion | Scenario 4 – Weak Economy/ Low Water Stress |
| Demand <50% of supply for entire year | 0 | 0 | 0 | 0 |
| Demand > 50% and < 100% of supply for 1 month or more | 0 | 0 | 0 | 0 |
| Demand > supply for 1 month or more | 7 | 7 | 7 | 7 |

**Figures 9-14** through **9-17** show the potential 2060 water supply stress for each subbasin in a drought condition, as depicted using the notation in **Table 9-6**. The number of months exceeding the potential stress level for each subbasin is listed in the red semi-circles.

The Business-as-Usual scenario results for each subbasin are shown in **Figure 9-14** for the drought of record conditions. The low surface water flows of the drought of record, combined with projected 2060 demands, result in a higher level of stress in all subbasins. Supply gaps (when demand exceeds supply) range from 3 to 10 months. The results for the Strong Economy/High Water Stress scenario for each subbasin are shown in **Figure 9-15** and show more months of *Higher Potential Stress* than the Business-as-Usual scenario. Compared to the Business-as-Usual scenario, the Lower Chariton has the largest increase in *Higher Potential Stress*, from 3 to 8 months.

The Substantial Agricultural Expansion scenario results for each subbasin are shown in **Figure 9-16**. Except for the Little Osage subbasin, the results show either the same or fewer months of *Higher Potential Stress* compared to the Business-as-Usual scenario. The results of the Weak Economy/Low Water Stress scenario for each subbasin are shown in **Figure 9-17** and are nearly the same as the Business-as-Usual scenario.

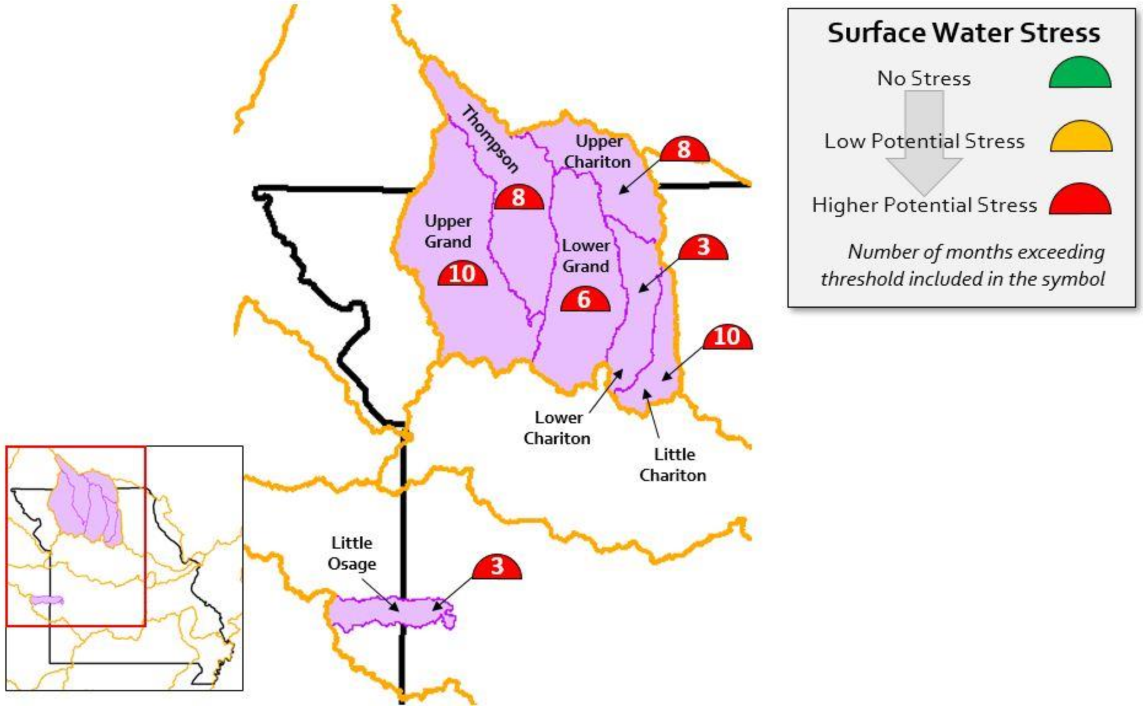


Figure 9-14. Scenario 1 Business-as-Usual Subbasin Results for Drought of Record Conditions (Surface Water)

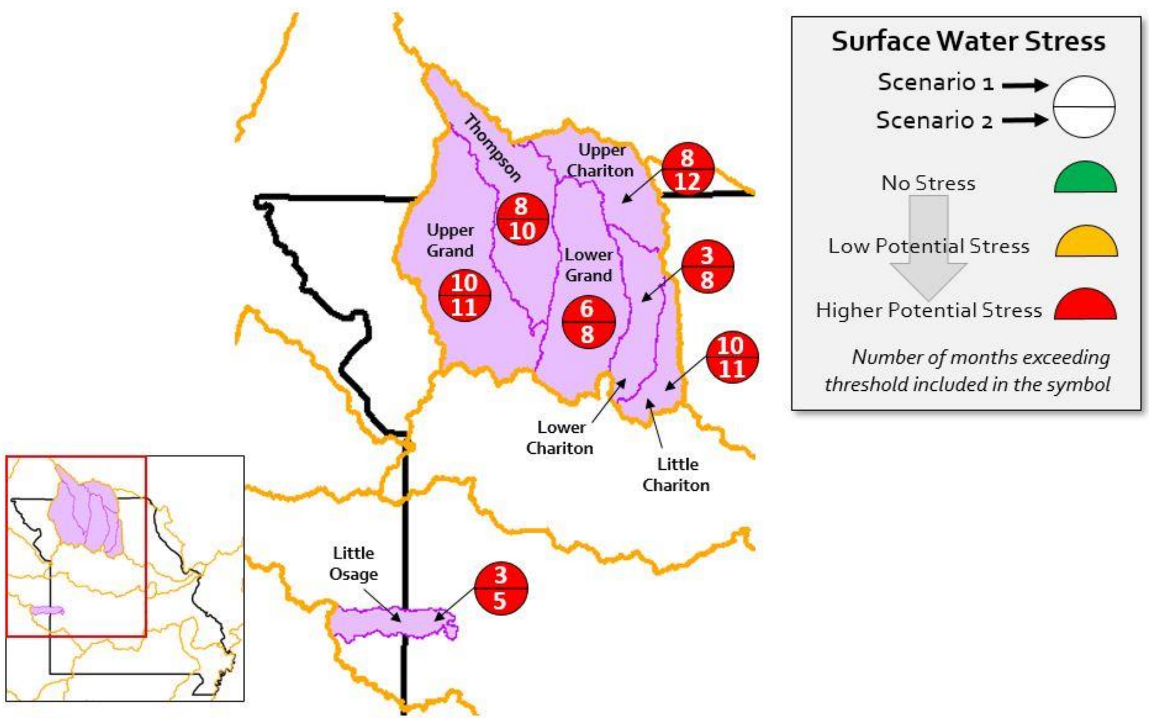


Figure 9-15. Scenario 2 Strong Economy/High Water Stress Subbasin Results for Drought of Record Conditions (Surface Water)

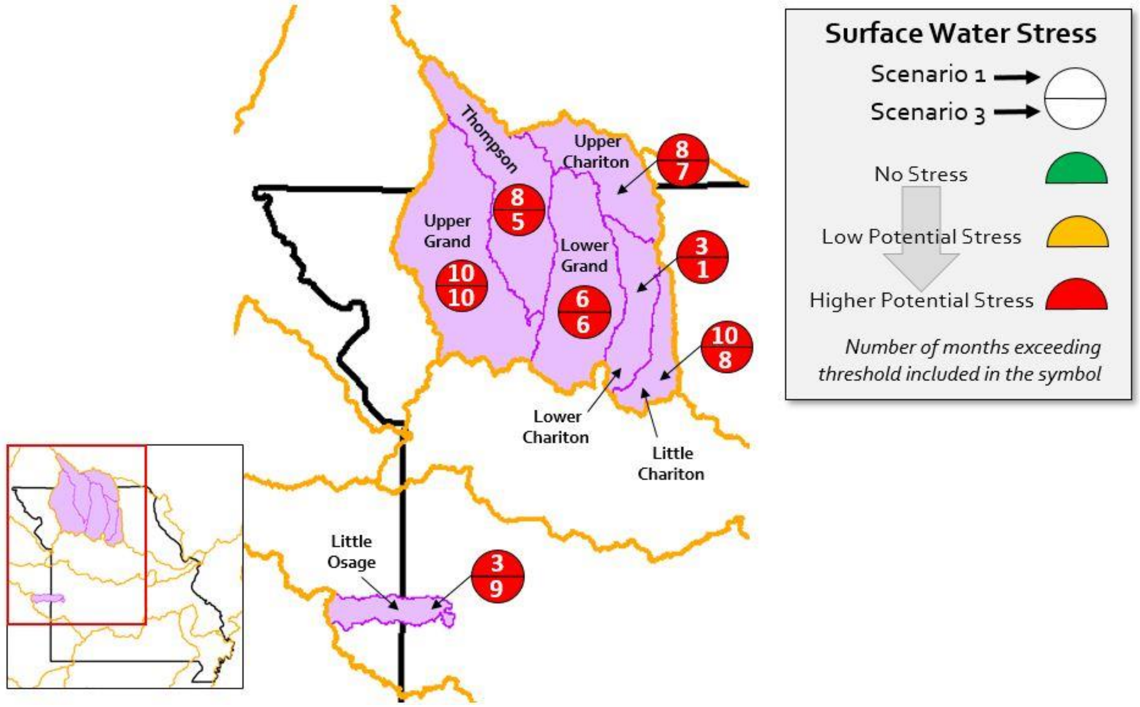


Figure 9-16. Scenario 3 Substantial Agricultural Expansion Subbasin Results for Drought of Record Conditions (Surface Water)

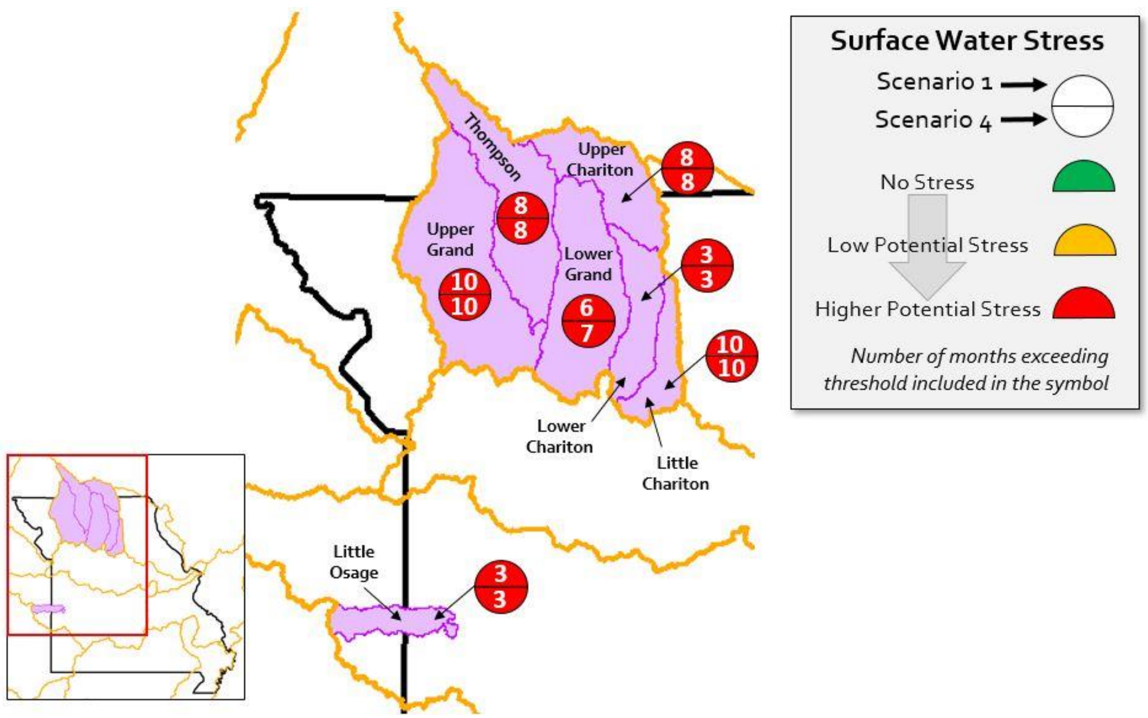


Figure 9-17. Scenario 4 Weak Economy/Low Water Stress Subbasin Results for Drought of Record Conditions (Surface Water)

### 9.5.3 Groundwater Impacts

#### Subregion Scenario Results

The method used to characterize, categorize, and graphically depict the level of potential groundwater supply stress under each scenario is shown in **Table 9-7**. The method differs from the method for evaluating potential water supply stress for surface water since groundwater availability is not as easily quantified. The method considers two factors: (1) whether there is already evidence of groundwater declines in a subregion or subbasin, and (2) whether groundwater withdrawals are expected to decrease, remain the same, increase, or substantially increase as a percentage of recharge from precipitation compared to current conditions. If no declining trend in groundwater levels exists and withdrawals as a percentage of recharge from precipitation are projected to decrease or remain relatively flat, *No Stress* was assigned. When no trend in groundwater levels exists and withdrawals as a percentage of recharge are expected to increase, *Low Stress* was assigned. *Low Stress* was also assigned if there have been observed groundwater declines in a subregion but projected withdrawals as a percentage of recharge are expected to remain flat or decrease. An increasing level of stress, as denoted by the yellow or red boxes, was assigned when there have been observed groundwater declines in a subregion and withdrawals as a percentage of recharge are expected to increase or substantially increase. The categorization of relative potential groundwater supply stress helps to compare impacts between different scenarios and identify options and strategies to mitigate or eliminate impacts.

**Table 9-7. Identifying Potential Water Supply Stress for Groundwater**

| Condition | Analysis | Current Groundwater Levels | Withdrawals as a Percent of Recharge from Precipitation | Potential Water Supply Stress | Key |
|---|---|---|---|---|---|
| Average | Annual | No Trend | Decrease | No Stress | |
| | | No Trend | Relatively Flat | | |
| | | No Trend<br>Declining | Increase<br>Flat or Decrease | Low Stress | |
| | | Declining | Increase | | |
| | | Declining | Substantial Increase | Increasing | |

Average annual hydrologic conditions were considered most when evaluating scenario impacts for groundwater. However, drought conditions were also examined in groundwater aquifers, especially the more heavily utilized aquifers in Missouri with significant amounts of storage. As such, short-term droughts (i.e., ones that occur over the span of a year or two) typically do not impact groundwater resources to the same extent as surface water resources. Exceptions to this might include thin, surficial aquifers with relatively little storage and/or shallow wells, which may experience reduced yield or become dry when groundwater levels drop only slightly.

Furthermore, the drought of record in the mid- to late 1950s did not impact groundwater resources to the same extent as surface water resources because of the timing of precipitation. During 1954 and 1956, much of the precipitation deficit occurred in the warmer months, when groundwater recharge is already low due to high evapotranspiration. In the cooler months, precipitation was close to average for both years. Since the majority of groundwater recharge occurs in the cooler months, recharge for both years was likely to be near average even though there was significantly less annual precipitation overall.

**Figure 9-18** shows the results of all four scenarios for groundwater. Low to increasing levels of potential stress are expected in six of the nine subregions for the Business-as-Usual scenario. Slightly higher levels of stress are expected for the Strong Economy/High Water Stress scenario, especially in the Lower Missouri subregion, because of substantial increases in projected withdrawals as a percentage of recharge. *No Stress* is expected in all subregions for the Substantial Agricultural Expansion and Weak Economy/Low Water Stress scenarios. Driving this result is the expected slight to moderate increase in recharge rates across the state as a result of the warmer temperatures and greater rainfall climate conditions used for the Substantial Agricultural Expansion and Weak Economy/Low Water Stress scenarios.

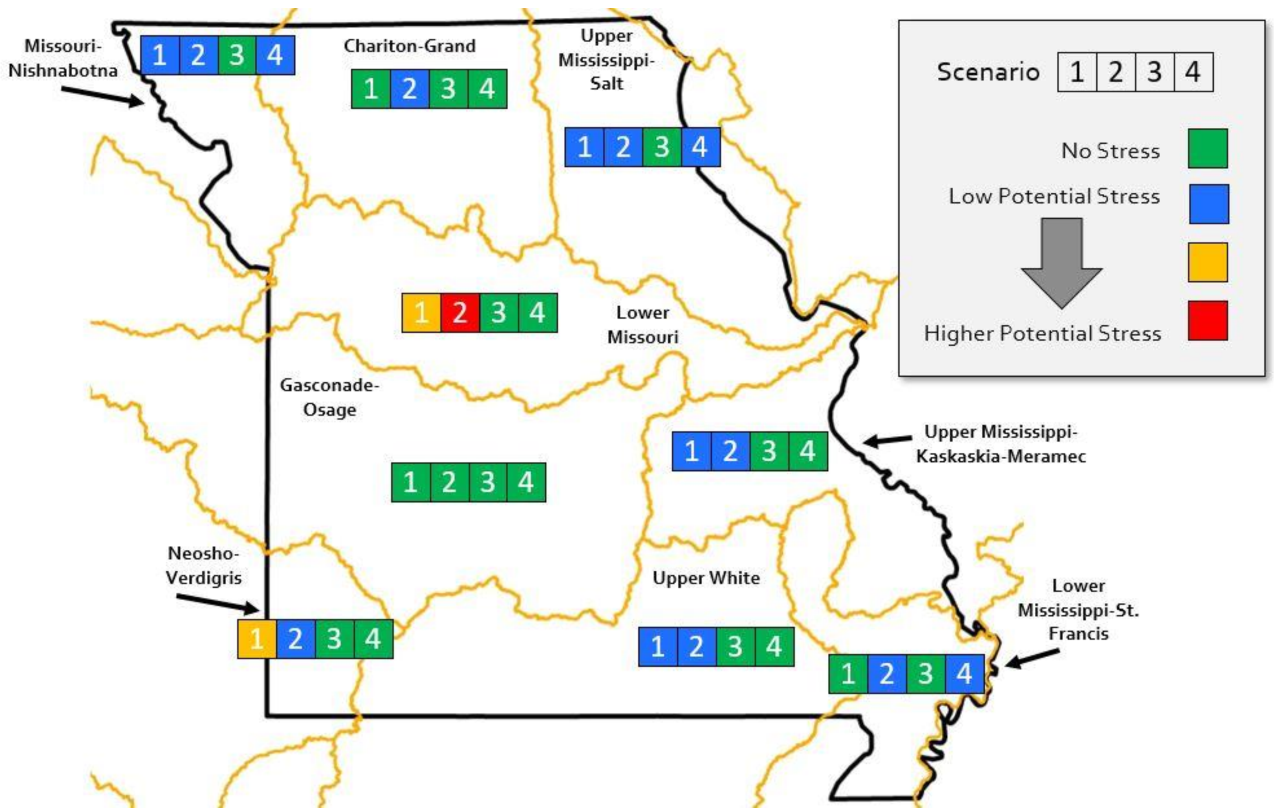


**Figure 9-18. Subregion Scenario Results for Average Conditions (Groundwater)**

The ensemble of global circulation models used for the warm/wet climate condition and applied to the Substantial Agricultural Expansion and Weak Economy/Low Water Stress scenarios suggest that precipitation will generally increase from November through May within a range of 1 to 19 percent depending on the month and location within Missouri. In the warmer months of June through October, the opposite is expected, with precipitation declines of between 1 and 18 percent. Since most groundwater recharge occurs in the cooler months, the increase in precipitation during these months is expected to result in an overall increase in average annual recharge. This result is expected even considering the projected 3–4°C increase in temperatures, which will increase evapotranspiration.

The hot/dry climate condition that was applied to the Strong Economy/High Water Stress scenario reflects a similar seasonal pattern. The ensemble of global circulation models suggest that precipitation is expected to increase from November through May and decrease from June through September compared to current average conditions. An overall increase in annual recharge is expected in most areas.

## Subbasin Scenario Results

The same method used to characterize, categorize, and graphically depict the level of potential groundwater supply stress for subregions was used for the select subbasins. Again, only average annual conditions were considered when evaluating scenario impacts for groundwater. **Figure 9-19** shows the potential 2060 water supply stress for each subbasin under all scenarios under drought conditions. Scenarios 1, 2, 3, and 4 are Business-as-Usual, Strong Economy/High Water Stress, Substantial Agricultural Expansion, and Weak Economy/Low Water Stress, respectively. *No Stress* is expected in the Chariton Grand subbasins and low levels of potential stress are expected in the Little Osage subbasin in the Business-as-Usual scenario. Low levels of potential stress are expected for the Strong Economy/High Water Stress and Substantial Agricultural Expansion scenarios in all subbasins except for the Upper Chariton, where *No Stress* is seen for each scenario. The relatively low levels of stress expected in the Chariton Grand subbasins reflect the fact that groundwater is not heavily used in the subregion.

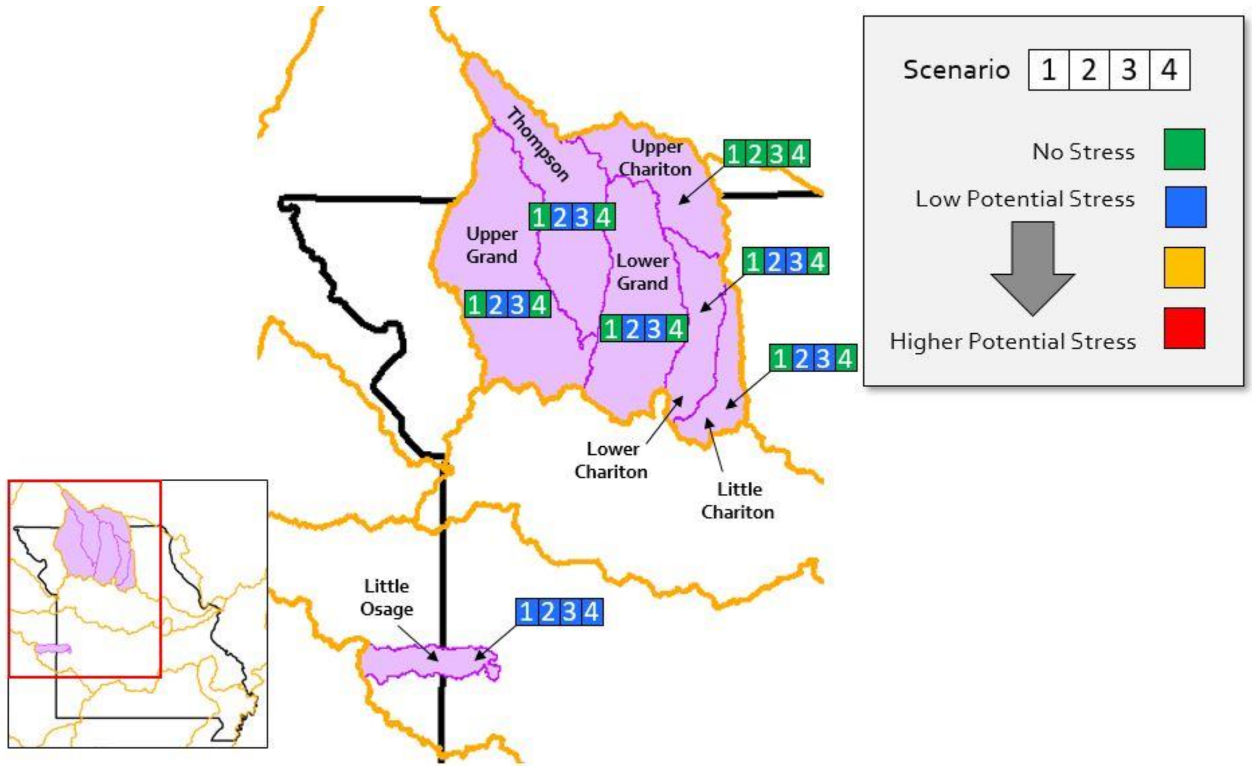


**Figure 9-19. Subbasin Scenario Results for Average Conditions (Groundwater)**

## 9.5.4 Missouri River Supply Constraint Potential Impacts

The uncertainty drivers applicable to the Missouri River were qualitatively evaluated to assess potential planning scenario impacts on the authorized purposes of the Missouri River. The authorized purposes of the Missouri River include flood control, navigation, water supply, irrigation, hydropower generation, water quality, fish and wildlife, and recreation. The uncertainty drivers that are applicable to the Missouri River include bed degradation, reduced supply, and prolonged water supply intake disruptions. **Table 9-8** assigns a severity of potential impacts to the Missouri River System authorized purposes for each uncertainty driver.

**Table 9-8. Potential Scenario Impacts to Missouri River Authorized Purposes**

| Missouri River System Authorized Purposes | Potential Impact of Missouri River Uncertainty Drivers | | |
|---|---|---|---|
| | Bed Degradation (All Scenarios) | Reduced Supply[1] (Strong Economy/High Water Stress and Substantial Agricultural Expansion Scenarios) | Prolonged Supply Disruption on River Intakes (Strong Economy/High Water Stress Scenario) |
| Flood Control | None | None | Not Applicable |
| Navigation | Low | Low | Not Applicable |
| Water Supply | Low | Low to Medium | Low to High |
| Irrigation | None | Low | Low |
| Hydropower | Not Applicable | Not Applicable | Not Applicable |
| Water Quality | Low | Medium | Not Applicable |
| Fish and Wildlife | None | Low to Medium | Not Applicable |
| Recreation | Low | Low | Not Applicable |

[1]The reduced supply driver includes: (1) upstream diversions out of the Missouri River Basin, (2) increased upstream demands, (3) climate changes resulting in a decrease in upstream snowpack, and (4) upstream reservoir sedimentation.

Continued bed degradation has the potential to impact critical infrastructure such as intakes for both water supply and hydropower generation. Piers for bridges may also become undermined, requiring costly repairs or replacement. Although not likely, water quality could be impacted if bed degradation exposes buried contaminants or alters the flow and interaction of groundwater and surface water by cutting through a confining unit.

The minimum releases required to support navigation generally exceed, by several orders of magnitude, the water supply demands on the Missouri River in Missouri; however, reduced flows can still indirectly impact the use of the Missouri River as a water supply. Coupled with bed degradation, lower flows can result in exposed water supply intakes. Water quality may degrade due to higher water temperatures, causing increased algal growth that lowers dissolved oxygen in the water, potentially impacting fish. Lower flows, which mix with nutrient-laden runoff, can result in more frequent and larger algal blooms. Lower flows can also result in more freezing in the winter. Ice jams in the Missouri have been known to temporarily disrupt the ability of water supply intakes to function properly.

In addition, disruptions to navigation could occur from reductions in Missouri River flows. These impacts could be direct, where navigation on the Missouri River itself is disrupted, or indirect, where impacts from bottlenecks occur. Flows from the Missouri River comprise 40 percent of total flows, on average, of the bottleneck reach on the Mississippi River. This reach extends from the rivers' confluence north of St. Louis to the confluence of the Mississippi River with the Ohio River near Cairo, Illinois. In 2012, drought conditions causing low flows in the Mississippi River bottleneck reach reduced commercial barge traffic, resulting in adverse economic impacts to the state. In this instance, Missouri River flow, which comprised over 70 percent of total flow in the Mississippi River in this reach, was critical to maintaining flow so that a minimal level of barge traffic could be supported.

Prolonged supply disruptions may occur as a result of a chemical spill or infrastructure failure (major mechanical failure, earthquake, etc.). A supply disruption would require that affected water users temporarily rely on an alternative source of water. This uncertainty driver evaluates the resiliency of water users to supply disruptions and helps identify potential vulnerabilities due to a lack of interconnections, lack of an alternative water source, or inability to quickly identify and connect to an alternative water source. To investigate this, four water suppliers with intakes on the Missouri River were contacted and surveyed to understand their level of resiliency to a supply disruption. The survey found that:

- The four water suppliers reported to have between 1 and 3 days of system storage. A disruption of greater than 1 to 3 days would require an alternative water source.
- Three of the four water suppliers had a backup source of water; however, these would often only provide water for 1 week of average system demands.
- Three of the four water suppliers had interconnections with neighboring systems; however, the ability to obtain water to satisfy average system demands was not guaranteed.
- All four water suppliers had an emergency response plan dictating steps to take in the event of temporary loss of access to their primary source of water.

Based on these results, the prolonged supply disruption driver was assigned a range of low to high impact (see **Table 9-9**), given the different levels of resiliency inherent to water suppliers with intakes on the Missouri River.

### 9.5.5 Reservoir Reallocation and Permitting for New Storage Reservoirs

The Business-as-Usual and Weak Economy/Low Water Stress scenarios assumed no reallocation of USACE reservoirs to increase water supply storage by 2060, and that the existing permitting process for new reservoirs would remain in place. No uncertainty drivers in the water supply constraints category were assigned to these two scenarios. The following outcomes might be expected, given the combination of these and other scenario drivers:

- Without an increase in water supply storage from existing reservoirs or new reservoirs, demands on groundwater resources would increase in southwest Missouri. In parts of southwest Missouri, withdrawals already exceed recharge from precipitation and the already observed long-term declines in Ozark Aquifer groundwater levels from predevelopment conditions would continue in localized areas. It is expected that areas near heavy pumping centers would experience reduced yield or dry wells, especially in shallower wells during extended drought periods.
- The limited surface water supply and reliance mostly on groundwater would limit growth in southwest Missouri unless infrastructure is developed to bring in water from outside the region. The USACE can only participate or assist when it comes to M&I storage, not irrigation. The Southwest Missouri Regional Water Commission's Phase I Water Demand Study (CDM Smith et al. 2012) projects a range of low-, medium-, and high-growth scenarios through 2060 based on different levels of water conservation for the 16-county region. Under the most aggressive level of conservation, total water demand in 2060 is projected to increase by 32 MGD (from 339 MGD in 2010 to 371 MGD) for the low-growth scenario, by 98 MGD for the medium-growth scenario, and by 205 MGD for the high-growth scenario. Given the already observed long-term groundwater level declines, it is unlikely that the Ozark Aquifer System could sustainably support the projected demands of the high- or even medium-growth scenarios, even with the slightly greater rainfall (and recharge) projected with the Weak Economy/Low Water Stress scenario. The low-growth scenario of the Phase I Water Demand Study would be a more likely outcome for the Business-as-Usual and Weak Economy/Low Water Stress scenarios. Under these scenarios, it is more likely that the Ozark Aquifer System could support the projected demands; however, the sustainability of the area's groundwater resources to support any increase in withdrawals is not assured. Localized problems with reduced yields and dry wells would still be expected.

The Strong Economy/High Water Stress and Substantial Agricultural Expansion scenarios included limited reallocation and a streamlined process for permitting new reservoirs as uncertainty drivers. Limited reallocation assumes that by 2060, 39 MGD of water supply storage is granted for Stockton Lake and Pomme de Terre Lake (combined) for use by members of the Southwest Missouri Regional Water Commission and/or their wholesale customers. The following outcomes might be expected, given the combination of these and other scenario drivers:

- The Southwest Missouri Regional Water Commission's Phase II Water Resource Study (CDM Smith et al. 2014) concluded that, as a region, there is sufficient surface water and groundwater in Southwest Missouri to meet future demands through 2060 during years of normal weather, provided the infrastructure and contractual agreements are in place to capture, store, treat, and deliver the available water. During drought periods, the 39 MGD increase in available water supply storage as a result of reallocation from Stockton Lake and Pomme de Terre Lake will help reduce future supply gaps. However, during times of drought, existing sources will be challenged to meet peak month demands region-wide and fall short by 6 MGD as early as 2030, growing to a deficit of 83 MGD in 2060. Even with reallocation, additional sources and strategies may be needed to meet future peak demands.
- Newly constructed reservoirs could supplement the supply that is added through reallocation and increase the region's ability to avoid shortages during a drought. New reservoirs, if located near high-demand areas, would reduce the pumping and conveyance infrastructure needed to distribute the additional water supply made available throughout the region from Stockton Lake and Pomme de Terre Lake. A streamlined permitting process would serve to reduce the time needed to develop the reservoirs, increasing the likelihood they would be available when needed.

### 9.5.6 Groundwater Limitations

As a driver of the Strong Economy/High Water Stress and Substantial Agricultural Expansion scenarios, it was assumed that the long-term groundwater level declines observed in localized areas within southwest Missouri will continue to become more widespread, resulting in a 30 percent reduction in projected 2060 groundwater withdrawal rates in the region. To implement this uncertainty driver, the 101 community water systems in the Neosho-Verdigris subregion using groundwater were assigned a 30 percent reduction in projected 2060 groundwater withdrawals. Average annual groundwater withdrawals by community water systems would decrease by 8 MGD, from 27 to 19 MGD. An 8 MGD increase in surface water withdrawals was assumed to be necessary to meet the community water system demands. The limited reallocation of Stockton Lake and Pomme de Terre Lake and the addition of new reservoirs, both of which are also drivers of the Strong Economy/High Water Stress and Substantial Agricultural Expansion scenarios, would help meet this demand. Conveyance infrastructure would also be needed to deliver the water to the communities impacted by groundwater withdrawal limitations.

### 9.5.7 Water Treatment Levels

The Strong Economy/High Water Stress scenario assumes that an increase in water treatment levels is necessary to provide water supply. The Substantial Agricultural Expansion scenario assumes that a more moderate increase in water treatment levels is necessary to provide water supply. A moderate or substantial increase in treatment levels would be driven by a degradation of source water quality and/or more stringent regulations. The primary impact would be higher treatment costs. An estimate of capital costs associated with different water treatment types for surface water sources is shown in **Table 9-9**. Capital and operating costs for surface water treatment can vary depending on water quality, treatment requirements, and location. The move from existing to moderate treatment levels, as would be the case for the Substantial Agricultural Expansion scenario, would require a one-time capital cost increase of $1 to $2 per gallon per day (GPD) of plant capacity. In this case, a 1 MGD water treatment plant would require a one-time capital cost increase of $1 to $2 million. The move from existing treatment levels to high treatment levels, as would be the case in the Strong Economy/High Water Stress scenario, would require a one-time capital cost increase of $5 to $8 per GPD. Operating costs would also increase—moderately for the Substantial Agricultural Expansion scenario depending on the additional treatment technologies used, and more significantly for the Strong Economy/High Water Stress scenario.

**Table 9-9. Treatment Cost Estimates for Varying Source Surface Water Characteristics**

| Treatment Type | Source Water Characteristics | Estimated Capital Costs (Cost/GPD) |
|---|---|---|
| Direct Filtration | Pristine water quality, consistent with few excursions. | $2–3 |
| Conventional | Moderate- to high-quality water, moderate to high frequency of excursions. | $3–4 |
| Conventional + Enhanced Coagulation | High natural organic matter (precursor material to disinfection by-products). | $3–4 |
| Conventional + Lime Softening | High hardness in source water. | $4–5 |
| Conventional + Ozone/Ultraviolet | High natural organic matter and/or increased levels of pathogens, increased levels of bromide, moderate to severe taste and odor, potential for contaminants of emerging concern. | $4–5 |
| Conventional + Granular Activated Carbon | Similar to Conventional + Ozone, but with lower risk of pathogens in source water. | $3–4 |
| Conventional + Membranes | High total organic carbon (TOC) and pathogens. | $4–5 |
| Conventional + Nanofiltration/RO | All of the above + TOC, softening, salinity, and contaminants of emerging concern. Not always effective for taste and odor. | $8–10 |

Because of variabilities in water quality, treatment requirements, location, and production capacity, the capital and operating costs for groundwater treatment can vary by an order of magnitude or more. For example, wells that require only chlorination for disinfection have low capital and operating costs to house the disinfection equipment, are relatively simple to operate and maintain, and often produce few or no residuals. Conversely, complex groundwater treatment systems with multiple processes can require manned operation, frequent maintenance, and extensive monitoring; consume high amounts of chemicals and power; require replacement membranes, ion exchange resins, or granular activated carbon; and produce residuals that are costly to process, transport, and dispose of. For contaminated groundwater supplies with complex, multiprocess facilities, costs can range from $5 to $20 per GPD of plant capacity. An overall estimate of capital costs associated with different water treatment types for groundwater sources are shown in Table 9-10.

**Table 9-10. Treatment Cost Estimates for Varying Source Groundwater Characteristics**

| Treatment Type | Source Water Characteristic | Estimated Capital Costs (Cost/GPD) | | |
|---|---|---|---|---|
| | | <1 MGD | 1–5 MGD | >5 MGD |
| No Treatment | Pristine water quality, absent of pathogens (coliforms). | – | – | – |
| Residual Disinfection | Pristine water quality with low levels of pathogens (coliforms). | $1–2 | $0.75–1.5 | $0.5–1 |
| Primary Disinfection + Residual Disinfection | Low to moderate levels of pathogens (coliforms). | $1–2 | $0.75–1.5 | $0.5–1 |
| Sequestering | Low to moderate levels of iron and/or manganese. | $1–2 | $0.75–1.5 | $0.5–1 |
| Corrosion Control (pH/Alkalinity or Inhibitor) | Corrosive waters with low pH, calcium (hardness), and/or alkalinity. | $1–2 | $0.75–1.5 | $0.5–1 |
| Air Stripping | Low to high levels of hydrogen sulfide, radon, or volatile organic compounds. | $2–4 | $1.5–3 | $1–2 |
| Oxidation/Advanced Oxidation | Low to high levels of hydrogen sulfide and other aesthetic or regulated constituents that can be destroyed by oxidation. | $2–5 | $2–3 | $1–2 |
| Oxidation + Pressure Filtration | Moderate to high turbidity levels, or iron, manganese, or arsenic. | $2–4 | $2–3 | $1–2 |

| Treatment Type | Source Water Characteristic | Estimated Capital Costs (Cost/GPD) | | |
|---|---|---|---|---|
| | | <1 MGD | 1–5 MGD | >5 MGD |
| Oxidation + Clarification + Filtration | Moderate to high levels of turbidity, iron, manganese, TOC, arsenic, radionuclides, and other aesthetic or regulated constituents. | $3–5 | $3–4 | $2–4 |
| Granular Activated Carbon Adsorption | Moderate to high levels of TOC and radon; low to high levels of synthetic organic compounds, volatile organic compounds, and per- and polyfluoroalkyl substances (PFAS), and other aesthetic or regulated constituents. | $3–4 | $2–3 | $1–2 |
| Ion Exchange | Moderate to high levels of iron, manganese, hardness, and TOC; low to high levels of arsenic, hexavalent chromium, PFAS, fluoride, or other aesthetic or regulated constituents including radionuclides. | $3–4 | $2–4 | $2–3 |
| Lime Softening + Filtration | Moderate to high levels of calcium and/or magnesium, hardness, and radionuclides. | $4–5 | $3–5 | $3–5 |
| Nanofiltration/RO | Moderate to high levels of salinity, hardness, organics, PFAS, metals, and other aesthetic or regulated constituents. | $5–10 | $4–8 | $3–6 |

## 9.6 Using Adaptive Management with Scenario Planning

Adaptive Management is a useful tool to continually assess and implement the results of scenario planning or similar tools. A combination of Scenario Planning with Adaptive Management was chosen to evaluate Missouri's water resources needs.

**Figure 9-20** shows an overview of the adaptive management framework for Missouri as a result of scenario planning. Identified projects have been incorporated in the present time frame. The figure shows that for each scenario, a different set of strategies will need to be implemented between now and the planning horizon of 2060.

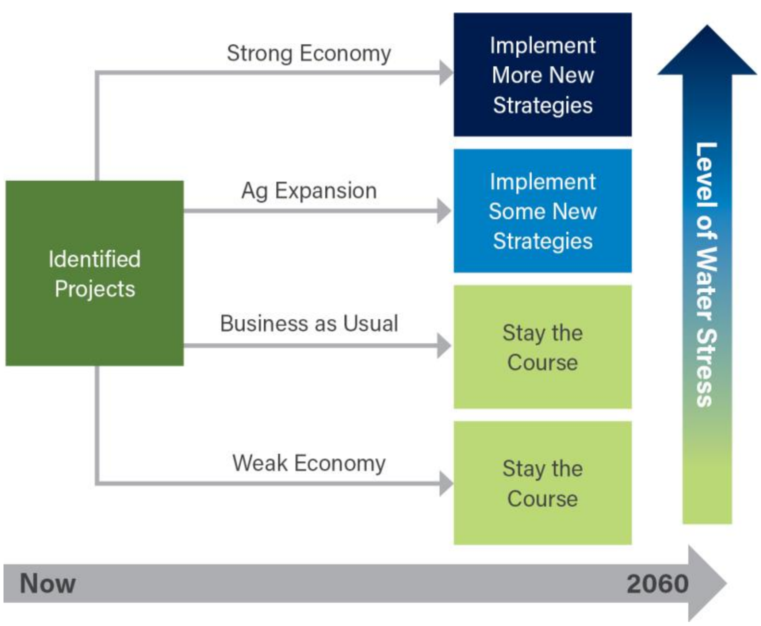


**Figure 9-20. Overview of Adaptive Management Framework for Missouri**

**Figure 9-21** shows the decision tree approach that is being used in the MWRP. Each risk trigger prompts an action in the future.

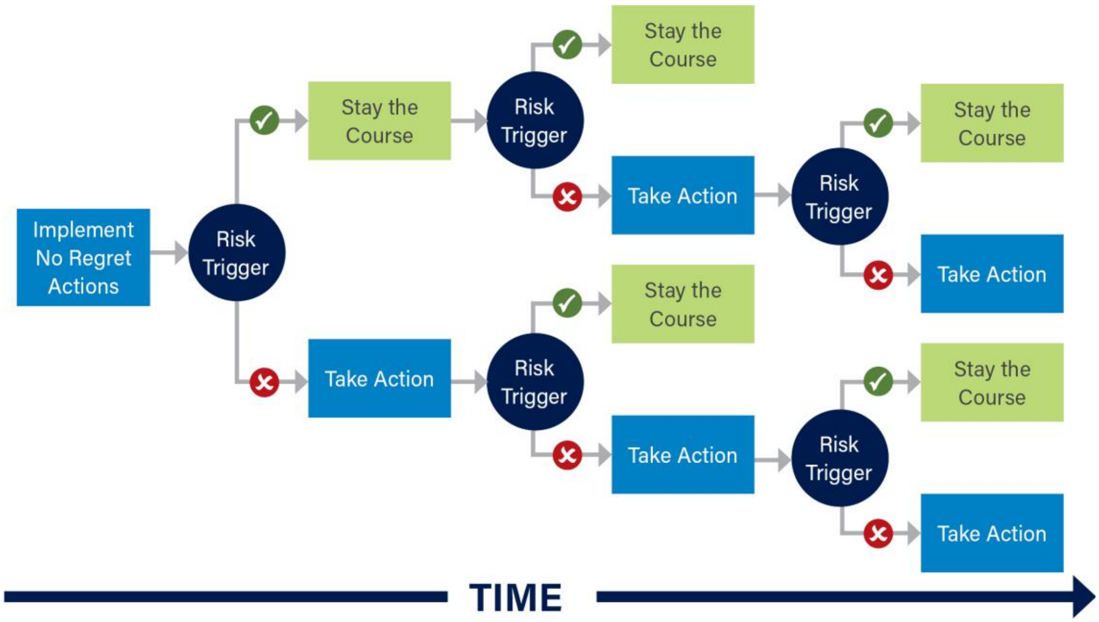


**Figure 9-21. Example of Adaptive Management using a Decision Tree Approach**

In order to develop a detailed adaptive management framework to meet M&I water needs, risk triggers from each scenario were used to represent future outcomes. The risk triggers are:

- Identified project implemented
- Reservoir regulation/reallocation
- M&I water demand growth
- Changing climate
- Supply and water quality constraints

Each risk trigger is represented as a dial in **Figure 9-22**. The actions correspond to the water supply options presented in **Section 7** for M&I.


**Figure 9-22. Example of Adaptive Management for Water Supply Planning – Municipal**

In order to develop a detailed adaptive management framework to meet agricultural water needs, risk triggers from each scenario were used to represent future outcomes. The risk triggers are:

- Identified Project Implemented
- Reservoir Regulation/Reallocation
- Agricultural Water Demand Growth
- Changing Climate
- Supply and Water Quality Constraints

Each risk trigger is represented as a dial in **Figure 9-23**. The actions correspond to the water supply options presented in **Section 7** for agriculture.

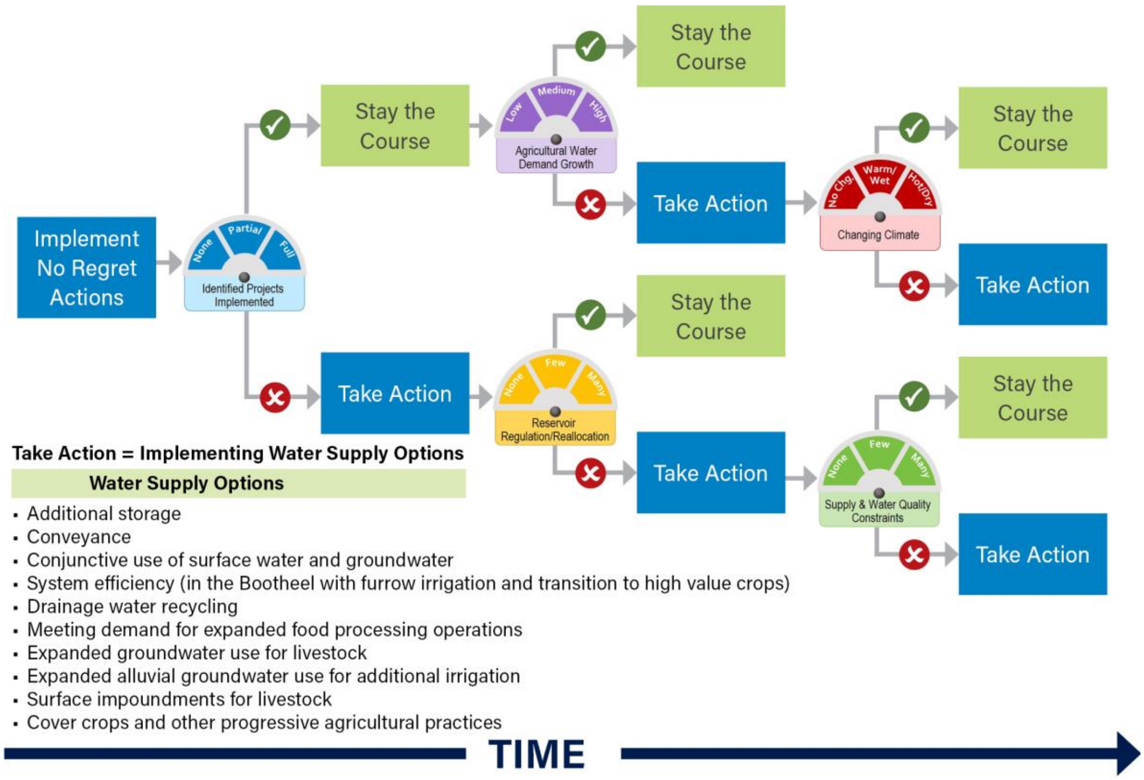


**Figure 9-23. Example of Adaptive Management for Water Supply Planning - Agricultural**

A range of possible outcomes are identified for each risk trigger as shown in **Figure 9-24**. Each dial represents a risk trigger. Options to address the range of outcomes are developed for each risk trigger.

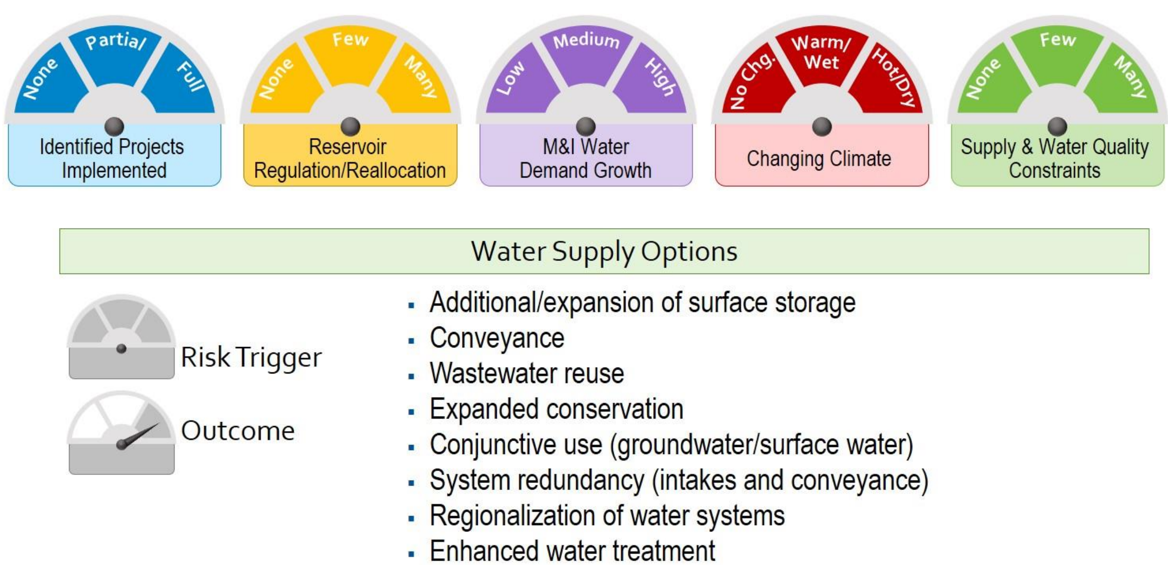


**Figure 9-24 Overview of M&I Adaptive Management Risk Triggers, Outcomes, and Water Supply Options**

### 9.6.1 Municipal and Industrial Options to Meet Future Needs

M&I options to address future water needs have been described in **Section 7** in detail. The options are represented as:

- Additional surface water storage, reallocation of existing storage, and expansion of existing storage facilities
- Conveyance
- Enhanced water treatment
- Wastewater reuse
- Expanded water use conservation
- Conjunctive use (groundwater/surface water)
- System redundancy (intakes and conveyance)
- Regionalization of water systems

**Figure 9-24** shows the full range of water supply options available for each associated risk trigger. The risk triggers are represented as dials with varying outcomes. For example, the identified projects and reservoir regulation/reallocation could be implemented fully, partially, or not at all. M&I water demand growth could be at a low, medium, or high level. Climate change conditions could vary from no change to existing climate conditions, to trending toward a warm/wet climate or a hot/dry climate. Finally, supply and water quality constraints, can be none, few, or many.

**Figure 9-25** shows risk triggers, outcomes, and associated water supply options for a scenario that is similar to the Strong Economy/High Water Stress scenario. A scenario was developed that was similar to but not exactly the same as the Strong Economy /High Water Stress, since the future is uncertain and there are many possible future scenarios as outcomes. The dials are set to represent an outcome for each risk trigger in a Strong Economy/High Water Stress scenario. For these risk trigger outcomes, the water supply options that could be implemented for each are presented in the same color as the risk trigger.


**Figure 9-25. Overview of M&I Adaptive Management Risk Triggers, Outcomes, and Water Supply Options for a Strong Economy/High Water Stress Similar Scenario**

**Figure 9-25** shows risk triggers, outcomes, and associated water supply options for a scenario that is similar to Weak Economy/Low Water Stress. When **Figure 9-25** is compared to **Figure 9-26** (which represents different conditions), it is apparent that varying scenarios warrant distinct water supply options for M&I.

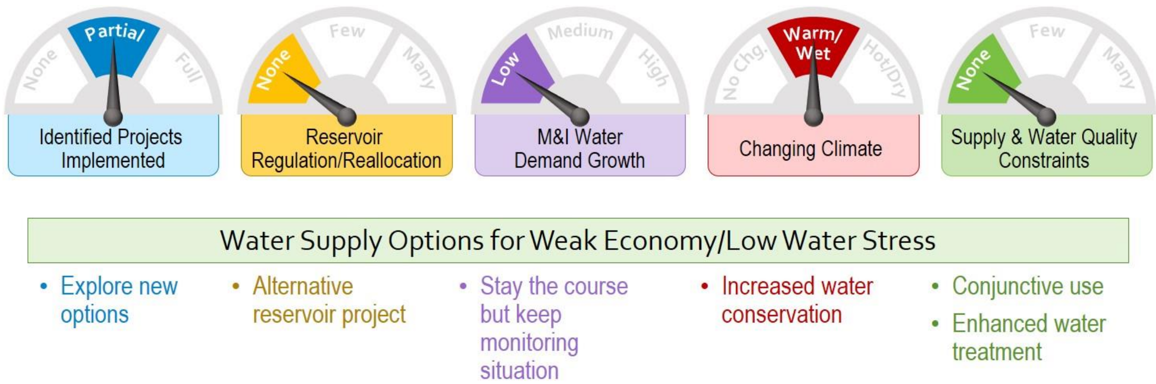


**Figure 9-26. Overview of M&I Adaptive Management Risk Triggers, Outcomes, and Water Supply Options for a Weak Economy/Low Water Stress Scenario**

## M&I Technical Workgroup

Since scenario planning and adaptive management is an exploratory exercise, the M&I technical workgroup developed two scenarios to test, as described below.

### Workgroup Scenario A

The technical workgroup chose to test the following risk trigger outcomes for Scenario A (a high water stress scenario): none of the identified projects are implemented, some reservoir reallocation occurs for increased water supply storage, M&I water demand growth is high, climate conditions are trending toward hot and dry, and many supply and water quality constraints exist. **Figure 9-27** shows these scenario risk triggers and outcomes.


**Figure 9-27. M&I Technical Workgroup Scenario A Risk Triggers and Outcomes**

The technical workgroup identified the following options to respond to this scenario outcome, where no identified projects were implemented:

- Increase conservation
- Pursue alternate projects
- Southwest Missouri: Add additional reservoirs/new impoundments and allocation in USACE reservoirs
- Enhance wellfields
- Increase reuse/recycle/conserve
- Increase regional connections
- Address water losses in distribution system (i.e., water recovery or system loss)
- Prioritize options based on feasibility

### Workgroup Scenario B

In the second scenario, the technical workgroup chose to test the following risk trigger outcomes: identified projects are fully implemented, reservoir reallocation is at a medium level, M&I growth is high, climate conditions are trending toward hot and dry, and many water supply and quality constraints exist. Scenario B is the same as Scenario A except that identified projects are fully implemented. **Figure 9-28** shows these scenario risk trigger outcomes.


**Figure 9-28. M&I Technical Workgroup Scenario B Risk Triggers and Outcomes**

To respond to the first risk trigger outcome (identified projects implemented at full level), the technical workgroup chose to consider the following options:

- It was recognized that in southwest Missouri, small communities are not paying into existing projects and therefore will not benefit from them. As such, the option to build infrastructure to meet demands of smaller communities was considered.
- In southeast Missouri, build infrastructure to access the existing supply.
- In northern Missouri especially, monitor potential declining storage in existing sources (reservoirs) and evaluate the feasibility of dredging to recover storage where needed.
- Water loss recovery.

To respond to the M&I demand growth risk trigger at the high level and climate trending toward hot/dry conditions, the technical workgroup identified the following options:

- Minimize system loss
- Regionalization
- Conservation
- Water restrictions
- Greater reuse

The technical workgroup recognized that by coupling many supply and water quality constraints with hot/dry climate conditions and high M&I water demand growth, an outcome could be increased diversions from the Missouri River in the Upper Missouri River Basin, and thus, less water available in the Missouri River to support Missouri's needs, especially during a drought. This was recognized as a particularly severe outcome and emphasized the need for additional strategies and options that protect and preserve Missouri River flow upstream of the state.

The technical workgroup also recognized that larger communities moving toward addressing their water supply issues, will, in turn, help smaller communities. For example, if larger communities are successful in developing regional surface water supply sources, they will not draw as heavily on groundwater resources. This may benefit smaller, nearby communities that rely on the same groundwater source.
These implementation options may change as future circumstances and conditions change.

## 9.6.2 Agricultural Options to Meet Future Needs

The following is a list of options to address water supply needs for agriculture. These are described in **Section 7** in more detail. The options are presented as:

- Additional storage
- Conveyance
- Conjunctive use of surface water and groundwater
- System efficiency
- Drainage water recycling
- Meeting demand for expanded food processing operations
- Expanded groundwater use for livestock
- Expanded alluvial groundwater use for additional irrigation
- Surface impoundments for livestock

To develop an adaptive management framework specific to agricultural water needs, risk triggers from each scenario were used to represent future outcomes. The risk triggers are:

- Identified Project Implementation
- Reservoir Regulations/Reallocation
- Agricultural Water Demand Growth
- Changing Climate
- Supply and Water Quality Constraints

**Figure 9-29** shows the full range of agriculture-specific water supply options available for each associated risk trigger. The risk triggers are presented as dials with varying levels of outcomes. For example, the identified projects and reservoir reallocation could be implemented fully, partially, or not at all. Agricultural water demand growth could be at a low, medium, or high level as discussed in **Section 8**. Climate change conditions could vary from no change to existing climate conditions or trending toward a warm/wet climate or a hot/dry climate. Finally, supply and water quality constraints, as explained in **Section 8,** can be none, few, or many.

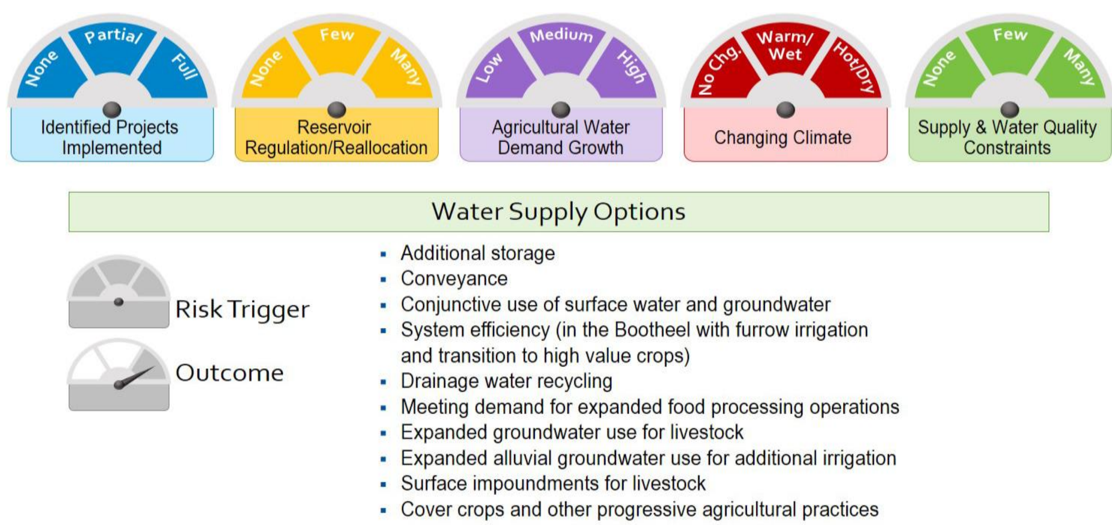


**Figure 9-29. Overview of Agricultural Risk Triggers, Outcomes, and Water Supply Options**

**Figure 9-30** shows risk trigger outcomes and associated water supply options for a scenario similar to Substantial Agricultural Expansion. The dials are set on this figure to represent an outcome of the risk trigger in a scenario associated with substantial agricultural expansion. The water supply options that could be implemented for each trigger are presented below, in the same color as the risk trigger.


Water Supply Options for Substantial Agricultural Expansion

- Drainage water recycling
- Meeting demand for expanded food processing operations

- Alternative reservoir project

- Expanded groundwater use for livestock
- Surface impoundments for livestock

- System efficiency in the Bootheel

- Conjunctive use of surface water and groundwater
- Surface impoundments for livestock

**Figure 9-30. Overview of Agricultural Risk Triggers, Outcomes, and Water Supply Options for a Substantial Agricultural Expansion Scenario**

**Figure 9-31** shows risk trigger outcomes and associated water supply options for a scenario similar to the Strong Economy/High Water Stress Scenario. When **Figure 9-30** is compared to **Figure 9-31**, it is apparent that varying scenarios warrant distinct water supply options for agriculture.


Water Supply Options for Strong Economy/High Water Stress

- Drainage water recycling
- System efficiency (in the Bootheel with furrow irrigation and transition to high value crops)

- Alternative reservoir project

- Expanded groundwater use for livestock
- Expanded alluvial groundwater use for additional irrigation
- Surface impoundments for livestock

- System efficiency in the Bootheel
- Additional storage
- Conveyance
- Cover crops and other progressive agricultural practices

- Surface impoundments for livestock

**Figure 9-31. Overview of Agricultural Risk Triggers, Outcomes, and Water Supply Options for a Strong Economy/High Water Stress Scenario**

### Agriculture Technical Workgroup

The agriculture technical workgroup focused on identifying responses to various risk triggers affecting agriculture in Missouri. The specific actions described below were offered as potential options for the Substantial Agricultural Expansion and the Strong Economy/High Water Stress scenarios.

Destocking was identified as the only practical option during an extended drought to recover some value from livestock. It was noted that drought conditions most typically limit the food supply of livestock before there is a shortage of water for livestock consumption. While not identified by the technical workgroup, early weaning is also recognized as a technique to reduce forage demand, recognizing that feed material may be in short supply (University of California Cooperative Extension 2019).

As a long-term strategy to deal with drought, water hauling has limited impact. The demand for most livestock operations is much greater than what can economically and feasibly be hauled.
Regarding farm ponds, impoundments, and additional storage:

- Most farm ponds are small and tend to dry up quickly during an extended drought. Larger impoundments, especially those with a large drainage area, are needed to help maintain livestock operations.
- Maintenance and protection of impoundments is important. Currently, most are not managed well.
- In developing water supply impoundments, there are no cost sharing opportunities available for water supply purposes like there are for erosion control. Many impoundments were specifically built to combat erosion and capture sediment, which reduces water supply storage. The value impoundments bring to the agricultural economy needs to be better recognized when considering cost sharing.
- Watersheds need to be managed better to maintain storage volumes.

Building additional conveyance specifically for agricultural uses is likely to be too expensive.
On the opposite end of the spectrum, having too much water (flooding) was also discussed as a concern and an impediment to productive agriculture. For example:

- Too wet of a spring can reduce yields significantly since corn and other crops with long growing periods need to be planted early.
- Heavy rains and flooding exacerbate the sedimentation and filling of impoundments and farm ponds reducing their storage capacity.
- Controlled drainage was mentioned as a strategy, especially in the Bootheel, for moving excess water off of fields and allowing them to dry more quickly.
- Climate change and extreme weather events might be the most important uncertainty driver for agriculture.

## 9.7 Summary

The scenario planning process for the resources described in this section organizes known uncertainty risk drivers into four plausible scenarios, which bound potential future outcomes. Varying outcomes related to economic growth, changes in water demands, future climate variability, water treatment levels, supply constraints, and regulations were combined to form a cohesive narrative for each scenario. The scenarios do not account for every combination of uncertainties; however, they were developed to show the potential range of impacts.

The scenarios were evaluated under years representing average hydrologic conditions and years representing drought conditions. The average conditions are useful for summarizing the results of the scenario planning process because water stress may occur in a year with normal water availability. Issues that arise under average conditions best indicate a shift in baseline conditions, which could cause persistent struggles to meet water needs while also worsening the impact of a drought.

These results, which were made possible by adjusting the water budgets, show that, in general, the highest risk observed comes from the Strong Economy/High Water Stress scenario, which has higher demands due to a strong economy but reduced supply because of climatic conditions. The Substantial Agricultural Expansion scenario also indicates future vulnerability due to a strong economy even with an increased water supply because of increases in precipitation. A strong economy is a benefit to Missouri; however, the results of the scenario planning process indicate that it poses an increased likelihood of increased water stress and potential water shortages. Careful tracking and planning of increases in water demands due to economic growth will be key to maintaining a sustainable and resilient supply of water in Missouri as the economy grows.

Identifying and assessing potential impacts of Missouri River supply constraints, reservoir reallocation and permitting, groundwater limitations, and water treatment levels provide further evidence of potential outcomes under each scenario. For example, a high degree of reallocation of USACE reservoirs to meet existing water demands in the southwest portion of the state is important to maintaining an adequate water supply, minimizing shortages, and eliminating potential supply gaps. Should reservoir reallocations not occur, as assumed in the Business-as-Usual and Weak Economy/Low Water Stress scenarios, the Neosho-Verdigris, western portion of the Upper White, and southern portion of the Gasconade-Osage subregions are likely to experience higher risk of future water supply stress.

**Figure 9-32** shows the relative level of surface water and groundwater stress for each scenario by subregion for both average and drought conditions. The subregions in the central and northern part of Missouri are expected to have the highest likelihood for water supply gaps under the Strong Economy/High Water Stress scenario. In the Lower-Mississippi-St. Francis subregion, the most stress and highest potential for gaps are expected under the Substantial Agricultural Expansion Scenario; however, the assumptions behind the supply source (groundwater versus surface water) to meet the increased demands of this scenario play a large role in determining that potential. In the Neosho-Verdigris subregion, the highest potential for stress and gaps occurs under average conditions with the Strong Economy/High Water Stress and Substantial Agricultural Expansion scenarios. Under drought conditions, the Business-as-Usual and Weak Economy/Low Water Stress scenarios would be expected to show the highest level of stress because of no reservoir reallocations and the assumption that no new reservoirs are constructed.

Under drought conditions, there is little to no difference in the results in all scenarios. A high potential for surface water supply stress during multiple months of the year would be expected regardless of the variations in demand, climate conditions, and water supply constraints of the scenarios. This result suggests the increasing need for effective water conservation plans; additional or interconnected supplies, especially in areas where groundwater availability is limited; adequate infrastructure; interconnections to distribute water effectively from system to system; and regionalization of systems where economically and technically feasible.

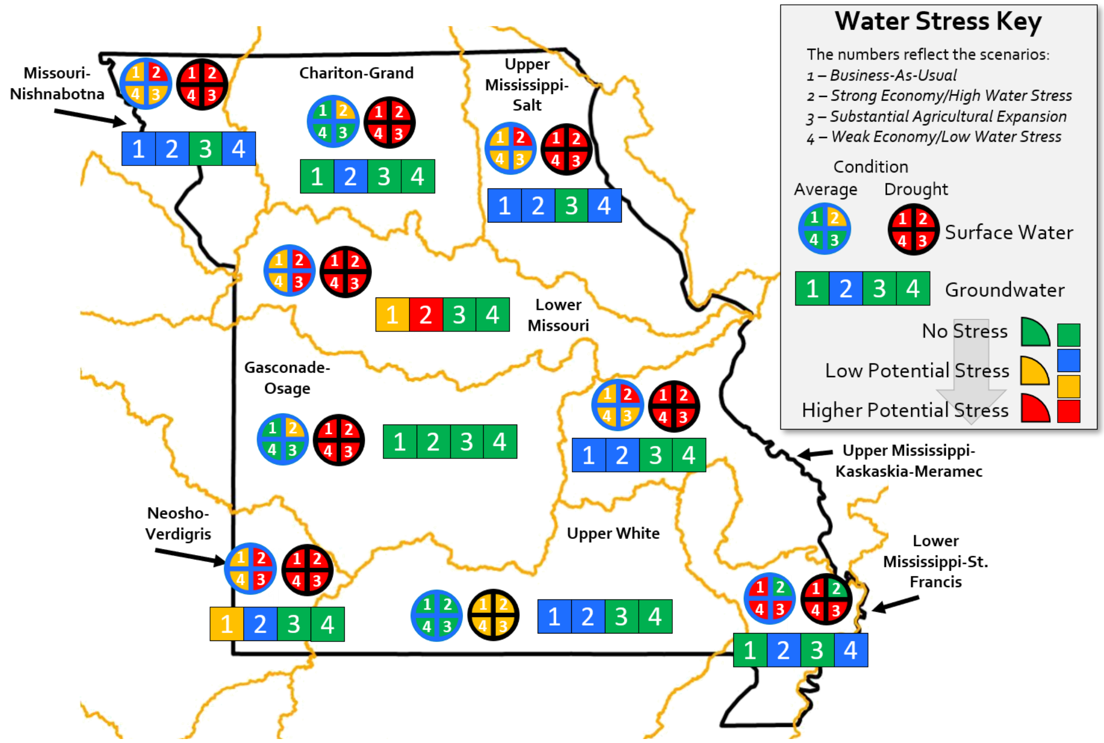


**Figure 9-32. Scenario Results Showing Stress Level in Each Subregion for Average and Drought Conditions**

The analyses suggest that most groundwater users are generally less likely to experience increasing stress than surface water users. Exceptions to this may be groundwater users with shallow wells in a surficial, nonalluvial aquifer. These wells may experience reduced yield or become dry from increased competition for water and/or drought. Driving this result is the expected slight to moderate increase in recharge rates across the state as a result of the warmer temperatures and greater rainfall conditions used for the Substantial Agricultural Expansion and Weak Economy/Low Water Stress scenarios. Since most of the recharge occurs in the cooler months, the increase in precipitation during these months is expected to result in an overall increase in average annual recharge. Even during the hotter temperature/lower precipitation (relative to the other scenarios) condition of the Strong Economy/High Water Stress scenario, groundwater recharge is expected to increase over current conditions due to the timing of precipitation. The increase in recharge under all scenarios will continue to replenish the relatively large amount of potable water stored in Missouri's aquifers. However, as noted elsewhere, localized areas (such as those in the southwestern part of the state) may continue to experience declining aquifer levels from localized overuse, ultimately resulting in shortages.

## 9.7 References Cited

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# Section 10 Findings and Recommendations

## 10.1 Introduction

The water resources of Missouri are largely influenced by climate, physiography, and geology. Each of these factors varies broadly across the state. The amount of precipitation increases from the northwest, where it varies significantly by season, to the southeast, where it occurs more evenly throughout the year. The rolling plain landscape in the north contrasts with the more rugged and hilly nature of the Ozarks and the flat lowlands of the Bootheel. Missouri exhibits such a wide range of geology that seven distinct groundwater provinces have been defined, each with unique hydrogeologic characteristics that influence the quality and quantity of groundwater.

Because of these variations, the availability and usability of water is not the same throughout the state. Accounting for this fact, the assessment of the state's water resources was performed primarily at the hydrologic subregion level. In this section, key findings of the Missouri WRP are summarized by grouping the subregions that have similarities into four major regions—northern, central, southwestern, and southeastern. However, certain key findings and recommendations apply to the entire state, and these are presented and discussed first.

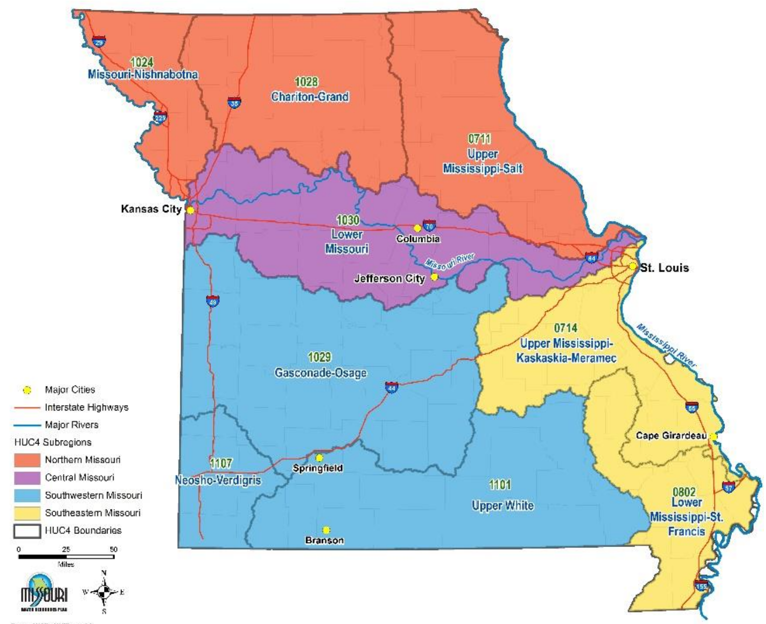


**Figure 10-1. Missouri Major Regions**

### Overview of Section 10 Findings and Recommendations

This section is organized as follows:

- Section 10.2 Statewide – summarizes key findings and recommendations that are applicable statewide.
- Section 10.3 Northern Missouri Region – summarizes key findings and recommendations for the portion of the state north of the Missouri River Valley.
- Section 10.4 Central Missouri Region – summarizes key findings and recommendations for portions of the state along the Missouri River, from Kansas City to St. Louis.
- Section 10.5 Southwestern Missouri Region – summarizes key findings and recommendations for southwestern Missouri, including much of the Ozark Plateau.
- Section 10.6 Southeastern Missouri Region – summarizes key findings and recommendations for southeastern Missouri, including the Bootheel.
- Section 10.7 Summary of Recommendations – provides a comprehensive list and discussion of all recommendations.

## 10.2 Statewide

At a large scale, Missouri has an abundant supply of water above and below the ground. Precipitation falling within the state provides over 15 trillion gallons of runoff water to rivers, lakes, and streams. More than twice that amount of water—38 trillion gallons per year—enters the state from the Missouri and Mississippi rivers. Precipitation infiltrating the ground replenishes aquifers that contain an estimated 500 trillion gallons of potable groundwater storage within the state (Miller and Vandike 1997).

Total consumptive demand in Missouri is estimated to be 3,180 MGD. Water demand across the state is driven by agriculture irrigation (65 percent), which supports 1.75 million irrigated acres of farmland. Missouri's 6.12 million residents and numerous businesses and industries account for most of the remaining consumptive demand for water (29 percent). Approximately 22 percent of the consumed water is supplied by surface water, with the remaining supplied by groundwater (mostly alluvial areas associated with aquifers adjacent to rivers and streams). An additional 6.3 billion gallons of water is withdrawn each day but not consumed, mostly from surface water sources, to support thermoelectric power generation. With population expected to grow to 7.48 million and increases in irrigated acres, consumptive demands are projected to increase by 18 percent (or 582 MGD) by 2060. Additional water users rely on water in lakes, streams, and rivers for nonconsumptive uses such as hydropower, thermoelectric power, navigation, recreation, wetland nourishment, aquaculture, and fish hatcheries. Future nonconsumptive demands are more difficult to estimate than consumptive uses.

Although water supplies generally exceed demands now and into the future throughout most of the state, history has shown that in certain areas, supplies can be stressed during droughts. Water budget analyses at the subregion level and for select subbasins using past drought conditions and accounting for future demands demonstrated the potential for water supply stress and gaps in supply and demand in nearly all regions of the state.

Even with generally abundant supplies, making water available for beneficial use can sometimes be a challenge in parts of Missouri. Timing is an important influence on the availability of water, since peak demands often coincide with the driest times of the year and multiyear droughts can lower aquifers and drain reservoirs that typically provide adequate supply.

Water is also not always available where it is needed and must be transported over large distances which increases the cost to users. Maintaining adequate flows on the state's waterways for nonconsumptive uses such as power generation and navigation is also important. Flows are also needed to preserve water quality (assimilative capacity), ensure the viability of existing water supply intakes, and protect fish and wildlife needs.

***Key Finding: As water resource challenges evolve and emerge, there will be an increasing need for additional, high-quality data and improved data sharing among water users, managers, researchers and regulators.***

Effective water planning and assessment relies heavily on abundant, high-quality data. Data characterizing both water availability and use are the cornerstones of identifying the reliability of a supply, and supporting decisions to build water infrastructure. While numerous agencies including MoDNR and USGS have programs to collect, review, and report on water resource data, additional effort is needed to fill data gaps and improve the quality of data being collected. Enhancing and improving water use data collected through MoDNR's major water users program and other programs is necessary to better understand, establish, and protect Missouri's growing demand for water. Since groundwater withdrawn for crop irrigation accounts for the single largest consumptive use category in the state, improvements in estimating or directly measuring and reporting groundwater withdrawals will establish a more reliable baseline of use and help identify potential future gaps. An expanded monitoring well network is important in this regard, especially where local or regional declines are of concern. Additional and more precise groundwater withdrawal data, coupled with an expanded groundwater monitoring network, can be used to enhance the accuracy and predictability of the USGS Ozark Plateaus groundwater model—a key tool for water planners and managers. Other water resource studies, especially those focused on a watershed or subbasin level, would also benefit from improved data collection. While the water budget analysis of the Missouri WRP focused on subregions and a few key subbasins, additional data and analyses are needed in many areas to better address water supply reliability at a localized scale. Expanding the stream gage network will help fill in data gaps at a local level and improve estimates of surface water availability and water supply reliability. Water use data is also important for quantifying and protecting Missourian's rights to water in interstate disputes.

Recommendations that address the challenges associated with this key finding include:

- Improve data and information collection to better support decision-making, future water planning, and to protect Missourians' rights to utilize both surface water and groundwater.
- Focus resources to pursue water-related studies where additional information is needed to address water supply availability and reliability at a watershed, regional or metropolitan level.
- Improve coordination between MoDNR divisions and programs and across other state agencies.

***Key Finding: The growing need to repair and replace aging infrastructure will require careful planning, effective management, and creative funding solutions to ensure water rates remain affordable.***

Community public drinking water systems serve over 5 million customers in Missouri. While water mains serving these customers often last 80 to 100 years, the development of drinking water distribution systems in Missouri started 150 years ago, leaving many systems with components over 100 years old (Metro Water Infrastructure Partnership 2014). Therefore, there is a growing need to repair and replace aging infrastructure. In addition to challenges associated with aging infrastructure, utilities must continue to expand and upgrade their systems because of changing regulations, increasing population, and to support regionalization of water supply systems. Investment and upkeep in this infrastructure are necessary not only for Missouri to meet current and projected future water demands, but also to promote economic development throughout the state.

Recommendations that address the challenges associated with this key finding include:

- Continue to leverage existing state and federal programs to finance water and wastewater infrastructure.
- Offer and promote programs to educate utilities on effective rate setting that allows for replacement and expansion of infrastructure.

***Key Finding: An extended and/or severe drought would generate a high potential for water supply stress during multiple months of the year regardless of the potential future variations in demand, climate conditions, and water supply constraints.***

In general, the water budgets demonstrate that Missouri has an abundant supply of water for consumptive uses during years of average precipitation; however, experience has shown that shortages can occur during periods of extended or severe drought. Analysis that incorporates future demands and variations in supply availability demonstrate that this problem is not going away, and suggests the increasing need for effective water conservation plans; enhanced data collection to identify and assess trends in streamflow and water availability; evaluation of existing surface storage capacity and new storage (especially in areas where groundwater availability is limited); adequate infrastructure to deliver water to where it is needed; interconnections to enhance resiliency and distribute water effectively from system to system, regionalization of systems (where economically and technically feasible), and better drought planning and management.

Recommendations that address the challenges associated with this key finding include:

- Prepare for droughts by updating the state drought plan and encouraging water supply systems to develop drought contingency plans.
- Document and monitor regional projects that improve water supply reliability.
- Improve data and information collection to better support decision-making, future water planning, and to protect Missourians' rights to both surface water and groundwater.
- Focus resources to pursue water-related studies where additional information is needed to address water supply availability and reliability at a watershed, regional or metropolitan level
- Encourage and promote water conservation as a viable option within a water supply portfolio to meet M&I water supply needs. Effective and sustained water conservation programs help defer investment in additional sources.
- Optimize use of existing reservoir storage and develop additional reservoir storage where existing supplies are limited.
- Promote and support regionalization and consolidation, especially in areas where technical, managerial, and economic resources are limited, and source waters are difficult to develop.
- Using the adaptive management approach, continue to monitor and assess key risk triggers and identify support (through funding or other means) for projects that mitigate risk to water resources.

***Key Finding: Groundwater users are generally less likely to experience increasing stress (reduced yields or dry wells) than surface water users under drought conditions.***

Statewide, there is an estimated 500 trillion gallons of usable quality groundwater stored in aquifers, although it is not evenly distributed (Miller and Vandike 1997). Where groundwater is used, analysis that accounts for future variations in supply and demand suggests that there is more resiliency to droughts in groundwater resources than surface water resources, primarily due to the vast amounts of groundwater in storage. Additionally, climate projections suggest that the timing of precipitation in Missouri may change in the future. Since most of the recharge to groundwater occurs in the cooler months, projected increases in precipitation during these months are expected to result in an overall increase in average annual recharge to aquifers and an increase in groundwater availability. Even under climate scenarios that point to warmer temperatures and lower precipitation, groundwater recharge may increase over current conditions because of the timing of precipitation. These factors highlight the potential benefit of augmenting surface water supplies with groundwater, especially to mitigate the effects of drought. Conjunctive use of surface water and groundwater can maximize the benefits and reliability of both surface water and groundwater sources of supply.

Recommendations that address the challenges associated with this key finding include:

- Support integrated water resource planning in areas where water shortages exist and solutions are limited or unclear.

***Key Finding: While a strong economy is a benefit to Missouri, it brings an increased likelihood of water stress and potential water shortages.***

Analysis suggests that even under average hydrologic conditions, a strong economy would result in 2060 surface water demands that are greater than available supply from streamflow (not accounting for reservoir storage) in five of nine subregions, for one or more months. Under drought conditions, 2060 surface water demands would exceed available supply in seven subregions, for five or more months. These findings suggest that careful tracking and planning of increases in water demands from economic growth will be key to maintaining a sustainable and resilient supply of water as the economy grows.

Recommendations that address the challenges associated with this key finding include:

- Improve data and information collection to better support decision, future water planning, and to protect Missourians' rights to water.
- Document and monitor regional projects that improve water supply reliability.
- Using the adaptive management approach, continue to monitor and assess key risk triggers and identify support (through funding or other means) for projects that mitigate risk to water resources.

***Key Finding: Nonconsumptive demands for power generation, commercial navigation, water-based outdoor recreation, aquaculture, and fish and wildlife, while more difficult to quantify, are important to Missouri and its growing economy.***

Nonconsumptive demand refers to water that is withdrawn from the source or remains in place to support the demand but is not consumed and ultimately remains available for other uses. While the water required for these sectors is more difficult to quantify, the importance of clean, abundant water to support these uses cannot be overstated. As consumptive demands increase and less water remains in a stream, river, lake, or aquifer, nonconsumptive needs may be the first to be compromised, particularly during drought conditions. During periods that are critical to spawning or other important biological processes, for example, streams that could typically support a diverse range of fish and wildlife may lose that ability if withdrawals to support public water supply or irrigation result in significantly reduced flows.

Recommendations that address the challenges associated with this key finding include:

- Manage water resources to optimize the opportunities for nonconsumptive water needs such as navigation, power generation, recreation, aquaculture, and fish and wildlife.

***Key Finding: An adaptive approach to coordinated, long-term water planning and management is vitally important, especially given expected future variation in climate conditions, water demand, and other factors.***

Analysis determined that, outside of drought, the highest risk to not meeting future water needs is associated with potential variations in climate that result in less precipitation and reduced availability of surface water coupled with a strong economy that accelerates growth and water demand. The future, however, is unknown, and there are many potential "water futures" that could unfold in Missouri. Actions that may be taken to address reduced availability of surface water and increased demands from high growth are not likely to be the same as those needed under a different future scenario. To identify which water future is most likely to occur, risk triggers can be developed and monitored over time. If it appears that a risk trigger is occurring, specific actions are identified to be implemented; otherwise, the current strategy can stay the course. This adaptive approach is vital to ensuring that appropriate long-term strategies are implemented at the right time.

Recommendations that address the challenges associated with this key finding include:

- Using the adaptive management approach, continue to monitor and assess key risk triggers and identify support (through funding or other means) for projects that mitigate risk to water resources.
- Increase coordination between MoDNR divisions and programs and across other state agencies.
- Provide continued funding for Missouri WRP implementation.

## 10.3 Northern Missouri Region

The Northern Missouri Region includes the Missouri-Nishnabotna, Chariton-Grand, and Upper Mississippi-Salt subregions. Mean annual precipitation in this region is the lowest in the state. The region is characterized by glaciated, flat to rolling plains that slope gently toward the Missouri and Mississippi river valleys. Agriculture is the dominant land use of the region, with 70 percent of land used for pasture, hay, and cultivated crops.

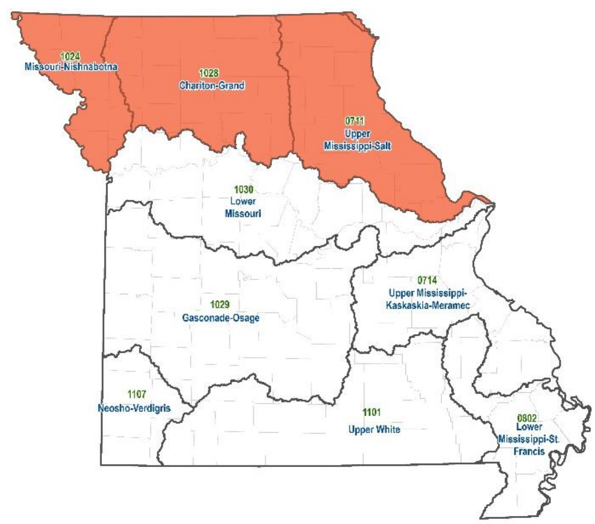


**Figure 10-2. Northern Missouri Region**

Total consumptive demand in the Northern Missouri Region is estimated to be 308 MGD. Water demand in the region is driven by public drinking water systems (60 percent) and agriculture (29 percent). Approximately 53 percent of the consumed water is supplied by surface water, with the remaining supplied by groundwater (mostly alluvial). An additional 2.2 billion gallons of water is withdrawn each day, most of which is from surface water sources, to support thermoelectric power generation. Population growth across northern Missouri is projected to vary. The counties around Kansas City (Clay and Platte) and St. Charles (Lincoln, St. Charles, and Warren) are projected to grow significantly by 2060. Andrew, Clinton, DeKalb, Holt, Ralls, and Randolph counties are projected to have moderate growth. The remaining counties are projected to have only slight increases or decreases in population by 2060.

Groundwater resources are less available in the northern half of the state, primarily because much of the groundwater is highly mineralized, limiting its use without extensive treatment. Additionally, water-bearing layers in both the northeastern and northwestern groundwater provinces are significantly deeper and more difficult to access. The Mississippian Aquifer and Pennsylvanian-age units have low yields compared to the shallower alluvial, glacial, and preglacial fill, which offer higher quality and usable groundwater but are limited in thickness and extent. The usable glacial drift deposits are more prevalent in the western portion of the region. In the eastern half, the glacial drift deposits are limited.

The Northern Missouri Region includes alluvial deposits of the Missouri and Mississippi rivers that store approximately 2.5 trillion gallons of potable water. The largest amount of storage is in Holt County, where the Missouri River Alluvial Aquifer underlies an area of about 182 square miles. Water from the alluvial aquifer is generally used by rural water districts, towns, and cities including Kansas City, St. Charles, and St. Joseph. High-yield water wells along the Missouri and Mississippi rivers are also used for irrigation.

South of the freshwater-saline transition zone in Audrain, Lincoln, Montgomery, St. Charles, and Warren counties, the Cambrian-Ordovician Aquifer stores over 23 trillion gallons of potable water and serves as the primary source for self-supplied domestic and nonresidential water users.

Reservoirs are an important component of the region's overall water supply system because of the limited availability of potable groundwater, lower average rainfall, and history of drought. Forty-four water supply reservoirs have been constructed to provide a source of water for cities and towns, with most of the reservoirs in the Chariton-Grand subregion.

***Key Finding: Declining populations place additional financial stress on utilities to replace aging infrastructure.***

Most of the public drinking water and wastewater systems in northern Missouri serve small communities that are projected to have little to no growth or even declines in population by 2060. In these areas, communities are faced with financial challenges to maintain and operate aging water and wastewater infrastructure while experiencing a shrinking tax base. In northwest Missouri, for example, a study found that with decreasing populations in parts of the region, the tax base falls short of covering imminent water infrastructure improvement costs (CDM Smith 2010). The total cost of addressing the current wastewater needs alone for rural communities in Missouri was estimated to be more than $170 million (MoDNR 2011). Households in the Northern Missouri Region currently pay the highest drinking water and wastewater rates in the state.

Regionalization is another viable solution to alleviating northern Missouri's infrastructure needs. The region's many small water systems frequently encounter water supply challenges as a result of limited technical, economic, and/or managerial resources. Regionalization can take the form of the joint operation of water treatment plants, combining of managerial resources, consolidation, or the creation of an association or nonprofit that has operational ability to apply for state and federal financing. Many funding opportunities including state revolving funds are tailored toward supporting regionalization initiatives and regional projects. Financially, a larger system operates with more revenue from producing and selling higher volumes of water, while overhead costs for expenditures such as electricity, personnel, testing, chemicals, and maintenance are spread over the larger operation. With higher revenues and lower costs, larger systems can more sustainably fund needed maintenance. The Joint Municipal Utility Commission Act of 2002 provides authority for water municipalities, public water supply districts, or nonprofit water companies to contract together to establish a joint utility commission and pursue and fund water projects such as reservoirs, pipelines, wells, water treatment plants, and other facilities. The Clarence Cannon Wholesale Water Commission serves as a successful example of regionalization. The Commission purchases raw water from Mark Twain Lake, treats that water, and distributes it to water providers that then serve nearly 73,000 people across 14 counties in northeast Missouri.

Recommendations that address the challenges associated with this key finding include:

- Promote and support regionalization and consolidation, especially in areas where technical, managerial, and economic resources are limited, and source waters are difficult to develop.
- Continue to leverage the existing state and federal programs to finance water and wastewater infrastructure.
- Offer and promote programs to educate utilities on effective rate setting that allows for replacement and expansion of infrastructure.

***Key Finding: Limited water supplies leave communities susceptible to shortages during droughts.***

Outside of areas with access to the alluvial aquifers of the Missouri and Mississippi rivers or the Cambrian-Ordovician Aquifer, the Northern Missouri Region is highly vulnerable to drought—more so than any other region of the state. Streams and smaller reservoirs can easily become depleted during extended drought. In the Missouri-Nishnabotna subregion, the water budget analysis shows that combined withdrawals on tributaries to the Missouri River approach or exceed median dry year streamflow in three months and drought of record year streamflow in five months. The potential for a similar, multimonth shortage under dry year and drought of record year streamflow conditions exists for tributaries to the Mississippi River in the Upper Mississippi-Salt subregion. In the Chariton-Grand subregion, a supply gap exists in one or more months in each of the subregion's six subbasins under dry year and drought of record year streamflow conditions. There is the potential for surface water supply gaps in all three subregions of the Northern Missouri Region that do not have access to the Missouri or Mississippi rivers. Even during short duration droughts like those experienced in 2012 and 2018, emergency measures to tap into additional sources of supply have been necessary to meet Municipal and Industrial (M&I demands. Treatable groundwater supplies are limited to begin with, and generally cannot be relied upon to meet needs beyond limited use for domestic purposes.

A variety of options and strategies can be pursued to address the water supply challenges common to M&I users in the Northern Missouri Region. In both the southeastern and west-central part of the region, allocated but unused water supply storage exists in three federally owned reservoirs. Coupled with a conveyance project, these supplies could be used to address the water supply challenges of the region. Mark Twain Lake, Long Branch Lake, and Smithville Lake have 13,750, 20,000 and 75,700 acre-feet, respectively, of water supply storage space currently available for water supply contract. Conveyance would be needed to move the water to the areas of most need and study would be needed to determine if this is a cost-effective option.

Development of additional surface water storage is another option, whether it be development of new on-channel or off-channel reservoirs or expansion or revitalization of existing reservoirs, though the process is expensive and lengthy. Two new reservoir projects in the region are already well into the planning process: East Locust Creek Reservoir in Sullivan County and Little Otter Creek Lake in Caldwell County. Each is aimed at establishing additional, reliable sources of supply to address water shortages, especially in cases of severe drought.

Regionalization, as previously discussed, is an effective option for developing sustainable solutions to water supply challenges. Small water providers often possess limited technical, economic, and/or managerial resources to solve complex water supply issues. As water providers unite through a commission or form larger water systems, resources are pooled, and water supply development costs are spread among a larger tax base.

Additional conveyance is another option to address the water supply challenges of the Northern Missouri Region. Conveyance is often closely tied to regionalization efforts, since delivery of water to communities is typically the greatest hurdle to overcome in regionalization. An example of a conveyance project that is currently being implemented in northern Missouri is the 36-mile water transmission main from St. Joseph to Cameron, Maysville, and Stewartsville. USDA Rural Development funding was obtained to implement the conveyance project that sources reliable water supply from Missouri American Water in St. Joseph.

Water reuse and conservation, both of which can effectively reduce the demand placed on a limited supply, are also options. Economically viable opportunities for water reuse in the Northern Missouri Region may be possible where centralized wastewater treatment facilities exist near large nonpotable industrial or irrigation demands. Water reuse feasibility studies can be performed to identify potential customers and their water quality requirements and determine the cost-effectiveness and technical viability of a water reuse program. Additionally, indirect potable reuse may be viable depending on the location of wastewater treatment plants and water supply intakes. Water conservation can be expanded to further limit the potential for water shortages. Conservation-focused rate structures, distribution system water loss prevention and leak detection programs, and more restrictive plumbing codes are some of the more common water techniques that promote water conservation.

Finally, integrated water resource planning can be used to identify and implement water management solutions that are effective in the Northern Missouri Region. Integrated planning identifies strategies to diversify and develop alternative water supplies, protect the environment, and increase resiliency during droughts and from climate change. Grants could be provided to specifically support this type of holistic planning, focusing on areas of northern Missouri where shortages exist, solutions are limited or unclear, and communities lack resources to find the most cost-effective and sustainable solutions.

Recommendations that address the challenges associated with this key finding include:

- Prepare for droughts by updating the state drought plan and encouraging water supply systems to develop drought contingency plans.
- Focus resources to pursue water-related studies where additional information is needed to address water supply availability and reliability at a watershed, regional or metropolitan level.
- Support integrated water resources planning in areas where water shortages exist, and solutions are limited or unclear.
- Encourage and promote water conservation as a viable option within a water supply portfolio to meet M&I water supply needs. Effective and sustained water conservation programs help defer investment in additional sources.
- Optimize use of existing reservoir storage and develop additional reservoir storage where existing supplies are limited.
- Promote and support regionalization and consolidation, especially in areas where technical, managerial, and economic resources are limited, and source waters are difficult to develop.

***Key Finding: There is a limited water supply for livestock production and few options to maintain ample supply during a drought.***

While the Northern Missouri Region is generally thought of as a row crop region, it does contain considerable numbers of livestock that depend upon sufficient water for animal health and nutrition. In the Chariton-Grand, livestock water demand is projected to increase from 14.7 to 21.6 MGD over the next 40 years.

Generally, northern Missouri relies on surface water to supply 85 to 90 percent of livestock watering demands.

The surface water impoundments used by producers to water livestock in the Northern Missouri Region are susceptible to both short-term and moderate droughts. During the 2018 drought, significant impacts to livestock production were reported across the Northern Missouri Region. Producers generally turned to hauling water, looked to already stressed rural water providers for supply or pumped water over relatively long distances to supplement livestock water during droughts. When water could not be secured, producers turned to selling livestock (Dailey 2018). As reported after the 2012 drought by a cattle producer in Polk County, "If you are out of hay, you can buy it. It may be expensive, but you can get it. But, if you are out of water, you're out of business." (Office of Missouri Governor 2013). While emergency support for water hauling or access, watering variances, and hay access are available to assist producers economically during a drought, long-term solutions are needed that proactively improve drought resiliency and support a vibrant and secure agricultural industry.

Options to address livestock producer water needs include creating new surface water impoundments, setting up emergency connections, installing on-farm storage infrastructure (e.g., distribution lines and tanks), creating new wells where groundwater is of sufficient quality and quantity, or restoring existing surface water impoundments through sediment removal. To further meet the water supply needs of Missouri's agriculture industry, future collaboration is needed between local agencies, state agencies (e.g., MoDNR, Missouri's Soil and Water Conservation Districts, the Missouri Rural Water Association, and the University of Missouri's Extension Program), and federal agencies (e.g., USDA). A predisaster cost share program could be established and agencies could provide technical guidance and oversight.

Recommendations that address the challenges associated with this key finding include:

- Invest in improving the reliability of water supply for livestock, CAFO, and pasture production during periods of drought.

## 10.4 Central Missouri Region

The Central Missouri Region consists of the Lower Missouri subregion. The amount of precipitation falling in the Central Missouri Region is typically higher than the Northern Region but lower than in southern Missouri. The key feature of the Central Missouri Region is the Missouri River and its associated valley; however, it includes a surprising amount of physical and hydrogeologic diversity and includes parts of three physiographic provinces and six groundwater provinces. Approximately 83 percent of land use is near evenly divided between pasture and hay, cultivated crops, and deciduous forest. Kansas City, St. Louis and other developed land, account for most of the remaining land uses.

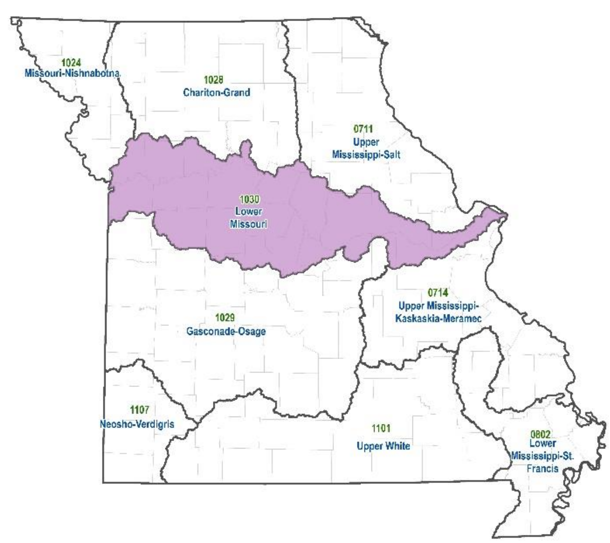


**Figure 10-3. Central Missouri Region**

Total consumptive demand in the Central Missouri Region is estimated to be 363 MGD. Water demand in the region is driven by major water systems (76 percent). Approximately 64 percent of the consumed water is supplied by surface water, with the remaining supplied by groundwater (60 percent from the Missouri River

Alluvial Aquifer and 33 percent from the Ozark or Cambrian-Ordovician aquifers). An additional 2.1 billion gallons of water is withdrawn each day, most of which is from surface water, to support thermoelectric power generation. With the planned retirement of two of four generating units at the Labadie power plant in Franklin County around 2036, thermoelectric power water demands are projected to decline by 26 percent. Across the Central Missouri Region, population and associated water use are projected to increase overall but vary significantly by county. The counties projected to grow significantly by 2060 include Boone (73 percent), St. Charles (72 percent), Clay (61 percent), and Warren (31 percent). Groundwater withdrawals to support population growth are projected to increase by 29 percent.

The Missouri River and Missouri River Alluvial Aquifer are the major sources of water in this subregion. Approximately 50 percent of the population of the state receives their drinking water directly from the river or from the associated alluvium. Nonconsumptive uses are also vital to the state's economy. Seven power generation facilities withdraw water from the river; barges move several million tons of goods and materials each year; water-centered recreation activities abound along the river; and various species of mammals, birds, reptiles and amphibians depend on the habitat offered by the Missouri River and its associated floodplain. Missouri River flows are also critical to maintaining navigation in the Mississippi River below St. Louis, especially when drought conditions exist in the Upper Mississippi River Basin.

In addition to the Missouri River Alluvial Aquifer, the Ozark Aquifer (south of the Missouri River) and Cambrian-Ordovician Aquifer (north of the Missouri River) are significant groundwater sources. Surface water users in the northern and southern parts of the subregion, who lack easy access to the Missouri River or its associated alluvium, must rely on tributaries to the river or groundwater, where available. These users may experience water supply stress during drought years.

***Key Finding: Localized zones of bed degradation, flooding, ice jams, and chemical spills all pose risks to Missouri River water supplies and the ability to sustain uninterrupted service.***

As so many Missourians receive their drinking water from the Missouri River or its associated alluvium, its ability to serve as a reliable and resilient water supply is vitally important. Several types of challenges and disruptions have the potential to threaten the supply. Localized bed degradation, which is the lowering of the river's channel over time, threatens to expose water intakes making them more vulnerable to reduced winter flows and ice jams. Upstream flooding degrades the quality of water entering Missouri, making treatment more difficult and expensive. During the late winter and spring, ice jams present a challenge as they can reduce flows available at water supply intakes. Chemical spills can temporarily restrict or limit the use of water from the river and require that water users temporarily rely on alternative sources of water.

Water suppliers that depend on the Missouri River should focus on options and strategies that improve resiliency. This includes developing system redundancy such as backups that can relieve the primary systems in the event of a failure, duplication of intakes and conveyance mains, emergency connections to other water systems, and secondary water supply sources.

Recommendations that address the challenges associated with this key finding include:

- Focus resources to pursue water-related studies where additional information is needed to address water supply availability and reliability at a watershed, regional, and metropolitan level.
- Continue to work with USACE to support navigation and protect vital water supplies along the Missouri and Mississippi rivers to ensure Missouri's water needs are met.

***Key Finding: Changing climate conditions, increasing upstream uses, and sedimentation of reservoirs may impact Missouri River flows for water supply, navigation, energy production, recreation, and other uses.***

Development in the Missouri River Basin upstream of Missouri is expected to continue, necessitating the need for more water. Both public supply and industrial demands are forecasted to increase, and an increase in irrigated crop acreage is likely. Furthermore, development fueled by existing state and tribal water rights may result in additional withdrawals in the basin and/or directly from the Missouri River. The ongoing sedimentation of Missouri River system reservoirs may also reduce flow into Missouri during droughts. These issues, along with the potential for changing climate conditions that may result in less annual flow or longer periods of drought, emphasize the need for the state to continue to advocate for equitable and effective Missouri River system management and protect the numerous uses of the river that are vital to public health, energy production, navigation, recreation, and fish and wildlife.

Recommendations that address the challenges associated with this key finding include:

- Continue to work with USACE to support navigation and protect vital water supplies along the Missouri and Mississippi rivers to ensure Missouri's water needs are met.
- Continue dialogue with neighboring states and USACE with respect to interstate water issues.

***Key Finding: Communities without easy access to the Missouri River or Missouri River Alluvial Aquifer are susceptible to shortages during droughts.***

Surface water users in the northern and southern parts of the region must rely on tributaries to the Missouri River. Withdrawals on the tributaries exceed median dry year flows in 5 months of the dry year and in 8 months of the drought of record year. The results suggest the potential for a surface water gap in certain parts of the region, and emphasize the importance of reservoir storage, connection to more reliable supplies, interconnections with other systems, conjunctive use of groundwater, or a combination of methods to bridge potential supply gaps. Additional data, including stream gages on streams tributary to the Missouri River, are needed to help better evaluate surface water availability in these areas.

Recommendations that address the challenges associated with this key finding include:

- Prepare for droughts by updating the state drought plan and encouraging water supply systems to develop drought contingency plans.
- Focus resources to pursue water-related studies where additional information is needed to address water supply availability and reliability at a watershed, regional or metropolitan level.
- Support integrated water resources planning in areas where water shortages exist, and solutions are limited or unclear.
- Encourage and promote water conservation as a viable option within a water supply portfolio to meet M&I water supply needs. Effective and sustained water conservation programs help defer investment in additional sources.
- Optimize use of existing reservoir storage and develop additional reservoir storage where existing supplies are limited.

## 10.5 Southwestern Missouri Region

The Southwestern Missouri Region includes the Gasconade-Osage, Neosho-Verdigris and Upper White subregions. Mean annual precipitation in this region is slightly higher than the Central and Northern regions. The region lies primarily with the Ozark Plateaus physiographic province, with only the northwestern portion in the central lowlands. Deciduous forest is the dominant land use of the region (45 percent), followed by pasture and hay (33 percent).

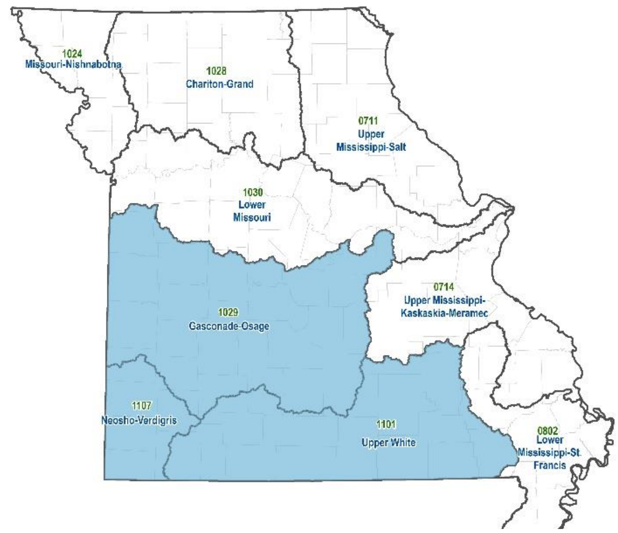


Figure 10-4. Southwestern Missouri Region

Total consumptive demand in the Southwestern Missouri Region is estimated to be 571 MGD. Water demand in the region is driven by major water systems (21 percent) and agriculture (71 percent). Nearly 60 percent of the major water systems demand is supplied by groundwater. The Ozarks region is projected to have the highest growth in population across the state, which translates to an increase in major water systems demand of 41 percent by 2060. The counties projected to grow significantly by 2060 include Christian (119 percent), Taney (70 percent), Camden (55 percent), Polk (52 percent), and Newton (51 percent). Additionally, the Southwestern Missouri Region has a high nonconsumptive demand, with substantial withdrawals for hydropower, aquaculture and wetlands.

For the most part, the region has abundant surface and groundwater resources. Surface water withdrawals typically remain at least an order of magnitude below median dry year flows throughout the year. The relatively consistent streamflow even during dry periods is, in part, because of the thousands of springs and outlet points in the Salem Plateau and Springfield Plateau portions of the subregion, which provide consistent base flow to streams. Although surface and groundwater resources are generally plentiful in the region, the potential for shortages is a concern in growing areas such as Springfield, which sits on the drainage divide between the Upper White and Gasconade-Osage subregions, and in the southwest corner of the state where a long-term lowering of water levels has been observed in localized portions of the Ozark Aquifer. Localized stress may still occur due to over-pumping or poor quality, especially in the western counties of the subregion on the saline side of the freshwater-saline transition zone.

***Key Finding: Projected increases in demands on groundwater resources will result in localized declines in Ozark Aquifer levels.***

Results from the application of the USGS Ozark Plateaus Aquifer System groundwater flow model suggest that increases in public supply, self-supplied nonresidential, and livestock demands, particularly in Christian and McDonald counties by 2060, may result in approximately 200-foot localized declines in Ozark Aquifer groundwater levels. Smaller localized declines may occur in Dade and Taney counties due to projected increases in irrigation and self-supplied nonresidential withdrawals from the Ozark Aquifer. The potential for these declines was also identified as part of the Southwest Missouri Water Resources Study (CDM Smith et al. 2014). The Tri-State Water Resource Coalition, which commissioned the study, and the Southwest Missouri Regional Water Commission, have been working on a variety of solutions to address growth and water supply challenges in the southwestern portion of the region. Additional conveyance, new reservoir construction, reallocation of existing USACE reservoirs, and regionalization are just some of the solutions being pursued.

Recommendations that address the challenges associated with this key finding include:

- Improve data and information collection to better support decision-making, future water planning, and to protect Missourians' rights to both surface water and groundwater.
- Support integrated water resources planning in areas where water shortages exist, and solutions are limited or unclear.
- Support regional planning groups to collaboratively address water resource challenges specific to a river basin, subregion, or subbasin.
- Promote and support regionalization and consolidation, especially in areas where technical, managerial, and economic resources are limited, and source waters are difficult to develop.
- Optimize use of existing reservoir storage and develop additional reservoir storage where existing supplies are limited.
- Continue to leverage the existing state and federal programs to finance water and wastewater infrastructure.
- Offer and promote programs to educate utilities on effective rate setting that allows for replacement and expansion of infrastructure.

***Key Finding: Successful reallocation of USACE reservoir storage is critical to the region's growth; however, even with reallocation, additional options that include both new sources and conservation may be needed to meet future demands during drought.***

The Southwest Missouri Water Resource Study showed that the region will experience an estimated 40 percent increase in water demand over the next 50 years. Water supply gaps are expected to develop during severe drought conditions for the public supply, self-supplied residential, and self-supplied nonresidential sectors. Additionally, the infrastructure to capture, store, treat, and deliver water for at-risk communities is currently not in place to meet projected demands, especially during severe drought. Based on this analysis, 10 of the 16 counties within the study were projected to encounter water supply deficits during drought conditions if additional supplemental water supply allocations are not in place. While reallocation of existing USACE reservoirs is already being pursued as a solution, new sources may need to be identified and conservation efforts may need to be increased to mitigate against impacts from drought and high growth. A proposed new reservoir for the Joplin area to store water from Shoal Creek and help address a projected shortfall in the area's long-term water supply is one of the new source options being pursued.

Recommendations that address the challenges associated with this key finding include:

- Encourage and promote water conservation as a viable option within a water supply portfolio to meet M&I water supply needs. Effective and sustained water conservation programs help defer investment necessary to develop additional sources of supplies.
- Support integrated water resources planning in areas where water shortages exist, and solutions are limited or unclear.
- Optimize use of existing reservoir storage and develop additional reservoir storage where existing supplies are limited.

***Key Finding: Nonconsumptive uses, including recreation, aquaculture, and hydropower associated with or supported by USACE reservoirs and other managed public waterbodies, are vital to the region's economy and growth.***

When enhancing existing water supplies and considering new sources to support the growing population, the importance of nonconsumptive uses in the region must not be overlooked. Recreation is one of the most important nonconsumptive uses of this region. Outdoor recreation is among Missouri's largest economic sectors, fed by the recreationalists who purchase gear, equipment, and licenses, and spend money on transportation, food, and lodging in local economies. The impact of outdoor recreation and the resources that support it add positive value to the local, state, and national economies. As the region grows, the water needed to fully support recreation and other nonconsumptive uses should be quantified, managed, and monitored.

Because there are several state and federal agencies that manage and operate the public's outdoor recreational water resources, coordination among those agencies to quantify the region's nonconsumptive needs and optimize their use is essential.

Recommendations that address the challenges associated with this key finding include:

- Manage water resources to optimize the opportunities for nonconsumptive water needs such as navigation, power generation, recreation, aquaculture, and fish and wildlife.
- Increase data and information collection to better support decision-making and tracking for demands, groundwater, surface water, and infrastructure.
- Improve coordination between MoDNR divisions and programs and across other state agencies.

***Key Finding: Groundwater resources in the West-Central groundwater province (northwestern portion of the region) are generally scarce and of poor quality.***

Most public supplies in the northwestern portion of the region (Osage Plains) depend on surface water sources provided by rural water districts. Groundwater that is easily accessed is typically highly mineralized and unsuitable for use without extensive and often cost-prohibitive treatment. Therefore, options and strategies to mitigate against drought and support growth are centered on surface water supplies and include expansion or reallocation of existing sources, development of new reservoirs, regionalization, conveyance, and conservation. Water reuse is also an option that may have promise in this area and can be weighed against the cost of developing new sources or building conveyance to bring water from distant sources. Integrated water resource studies can be performed to help identify and evaluate the most promising of these options.

Recommendations that address the challenges associated with this key finding include:

- Encourage and promote water conservation as a viable option within a water supply portfolio to meet M&I water supply needs. Effective and sustained water conservation programs help defer investment in additional sources.
- Support integrated water resources planning in areas where water shortages exist, and solutions are limited or unclear.
- Optimize use of existing reservoir storage and develop additional reservoir storage where existing supplies are limited.
- Promote and support regionalization and consolidation, especially in areas where technical, managerial, and economic resources are limited, and source waters are difficult to develop.

## 10.6 Southeastern Missouri Region

The Southeastern Missouri Region includes the Upper Mississippi-Kaskaskia-Meramec and Lower Mississippi-St. Francis subregions. Mean annual precipitation in this region is the highest in the state. Seasonal variation in precipitation is minimal due to the influence of subtropical air masses throughout the year. The southern portion of the region lies in the Coastal Plain physiographic province and the northern portion lies within the Ozark Plateaus. Deciduous forest, primarily in the north and western areas of the region, is the dominant land use (41 percent), followed by cultivated crops (26 percent) and pasture and hay (16 percent), which are more common in the Bootheel.

Total consumptive demand in the Southeastern Missouri Region is estimated to be 1,910 MGD. Water demand in the region is driven by agriculture irrigation (86 percent), most of which is alluvial groundwater supplies used in the Bootheel counties of Butler, Dunklin, Mississippi, New Madrid, Pemiscot, Scott, and Stoddard. Groundwater withdrawals to support crop irrigation are projected to increase by 17 percent by 2060. Major water systems demand is significant as well, because of the high population areas of St. Louis City and St. Louis County. Across the region, population and associated water use is projected to increase overall, but that growth varies significantly by county. The counties projected to grow significantly by 2060 include Jefferson (45 percent), Ste. Genevieve (32 percent), St. Francis (36 percent), and Wayne (36 percent). Surface water withdrawals to support major water systems are projected to grow by 26 percent.

Outside of the St. Francois Mountains area, water supplies, both at the surface and below ground, are generally abundant and capable of meeting demands even during prolonged droughts. Most of the Bootheel relies heavily on the groundwater stored in the Southeast Lowlands Alluvial Aquifer. The Mississippi River and associated alluvium, with its vast upstream drainage area, offers a near limitless supply. The tributaries feeding the Mississippi River from the west are supported by groundwater discharge and runoff from precipitation, which varies little by season and is the highest in the state.

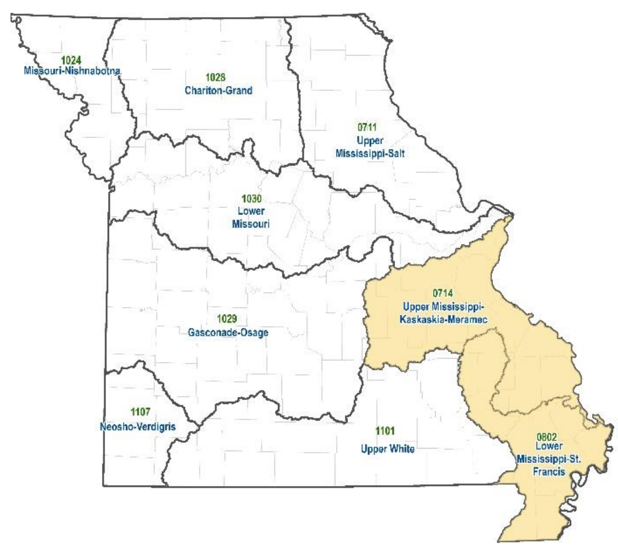


Figure 10-5. Southeastern Missouri Region

***Key Finding: While water resources in this region are plentiful, especially in the Bootheel, approximately 50 percent of all consumptive demands in the entire state occurs here.***

Long-term monitoring of observation wells in and north of the Bootheel suggests that recharge from the Ozark Aquifer system, the Mississippi River, and precipitation remain greater than the amount of water that is withdrawn to support agriculture and all other uses. However, continued monitoring is prudent given the significant groundwater declines observed south of Missouri in eastern Arkansas within the Mississippi embayment system. There, groundwater mining is occurring, which depletes the amount of water stored in the aquifer.

Recommendations that address the challenges associated with this key finding include:

- Improve data and information collection to better support decision-making, future water planning, and to protect Missourians' rights to water.
- Track ongoing agriculture industry initiatives to anticipate future agricultural water supply needs.

***Key Finding: Investment in new infrastructure will be needed to replace aging infrastructure and accommodate future growth.***

As previously noted, there is a growing need to repair and replace aging infrastructure. In addition to challenges associated with aging infrastructure, utilities must continue to expand and upgrade their systems due to changing regulations and increasing population. Three counties within the region, Jefferson, St. Francois, Wayne, and Ste. Genevieve, are expected to grow by 46, 36, 36, and 32 percent, respectively, between 2016 and 2060. Investment and upkeep in this infrastructure are necessary not only for Missouri to meet current and projected future water demands, but to promote economic development throughout the region.

Recommendations that address the challenges associated with this key finding include:

- Continue to leverage existing state and federal programs to finance water and wastewater infrastructure.
- Offer and promote programs to educate utilities on effective rate setting that allows for replacement and expansion of infrastructure.

***Key Finding: In the St. Francois Mountains, groundwater resources are relatively scarce but often the only option for rural water supply.***

Unlike most of the region, water supplies in the St. Francois Mountain area are somewhat limited, more difficult to access, and costly to distribute. Groundwater is relatively scarce compared to most other parts of the state due to the presence of igneous bedrock that lacks significant voids and fractures to store and transmit water. It is also the most difficult and costly area in Missouri to construct water lines because of the presence of shallow bedrock. The combination of few source options, the small amount of storage, and the high cost to tap distant sources limits avalailable strategies and solutions to those that focus primarily on demands, such as enhanced conservation and effective drought planning.

Recommendations that address the challenges associated with this key finding include:

- Prepare for droughts by updating the state drought plan and encouraging water supply systems to develop drought contingency plans.
- Encourage and promote water conservation as a viable option within a water supply portfolio to meet M&I water supply needs. Effective and sustained water conservation programs help defer investment in additional sources.

***Key Finding: Flow from the Missouri River is critical to maintaining navigation in the Mississippi River, from St. Louis to the confluence with the Ohio River.***

St. Louis is the third largest inland waterway port in the United States, averaging 20 million tons of commerce passing through each year. The Missouri River, which enters the Mississippi River just north of St. Louis, supplies substantial flow to the Mississippi River. In an average year, the Missouri River supplies 42 percent of the total Mississippi River flow and as much as 72 percent during droughts, making the Mississippi River vulnerable to flow reductions in the Missouri River. Droughts have resulted in low flows on the Missouri River that have threatened to reduce the Mississippi River channel below the minimum depth required for navigation. The state must continue to emphasize the importance of Missouri River flow support to navigation in the Mississippi River and advocate for decision-making that considers this beneficial use.

Recommendations that address the challenges associated with this key finding include:

- Continue to work with USACE to support navigation and protect vital water supplies along the Mississippi and Missouri rivers to ensure Missouri's water needs are met.
- Continue dialogue with neighboring states and USACE with respect to interstate water issues.
- Manage water resources to optimize the opportunities for nonconsumptive water needs such as navigation, power generation, recreation, aquaculture, and fish and wildlife.

## 10.7 Summary of Recommendations

Throughout the development of the Missouri WRP, analysis and synthesis has led to several key findings. These key findings have identified both challenges and opportunities related to water resources in Missouri, which lead to the following recommendations. The recommendations are grouped by type: planning, implementation, funding, and data. The region or regions of the state that would benefit the most if the recommendation were implemented follows each recommendation.

**Wakonda State Park near La Grange in northeast Missouri**

## Planning

**Prepare for droughts by updating the state drought plan and encouraging water supply systems to develop drought contingency plans.** statewide

- Update the state's drought mitigation and response plan. Include specific actions to take and resources available.
- Encourage water supply systems to develop and implement drought contingency/management plans. Effective plans are developed before drought occurs and help identify trigger points and responses to extend critical water supplies, identify alternative water sources, establish interconnections, develop education programs and demand reduction strategies, define implementation and enforcement mechanisms, and address water conservation during drought conditions.
- Continue MoDNR's program of conducting yield studies of Missouri's drinking water reservoirs based on updated bathymetric surveys. These studies and surveys give water systems an accurate and updated assessment of how long their water supplies will last during a drought, and give them an estimate of the sedimentation rate in their reservoirs.

**Support regional planning groups to collaboratively address water resource challenges specific to a river basin, subregion, or subbasin.** statewide

To best accomplish the task of understanding and planning for water resource concerns and challenges, support regional planning groups to identify and address the unique needs and issues faced within a river basin or subregion. These regional groups should be nonregulatory and consist of local stakeholders and appropriate agency representatives. It is possible that regional planning commissions can fill this role. The goal of the regional groups will be to guide planning initiatives, collaborate on issues of mutual interest, and provide associated local and regional input directly to MoDNR and other water management agencies. MoDNR should consider assisting stakeholders in developing a framework for the regional planning groups, including delineation of the geographic boundaries, membership, organization, duties and responsibilities, funding mechanism, and extent of authority. Where resources are shared across multiple states, regional planning groups should not be constrained by state boundaries.

**Focus resources to pursue water-related studies where additional information is needed to address water supply availability and reliability at a subbasin, regional or metropolitan level.** statewide

Studies that should be considered include:

- Reliability of local water supply
- Bathymetry of water supply reservoirs
- Evaluation of aging water infrastructure and water loss
- Cost-effectiveness and viability of reuse in Missouri
- Cost-effectiveness and viability of advanced treatment techniques (i.e., reverse osmosis) to treat brackish groundwater in northern Missouri
- Methods to maximize the use and efficiency of water needed to support Missouri's agriculture
- Interaction between the Missouri and Mississippi rivers' alluvial aquifer and the river flow and water quality

**Track ongoing agriculture industry initiatives to anticipate future agricultural water supply needs.** statewide

Recognizing Missouri's successful and vital agriculture industry, continue to work with representatives of the agriculture industry to maximize and protect water supplies. Continue to support and understand future agricultural initiatives including the expansion of agricultural-based food processing and the associated water needs.

**Support integrated water resources planning in areas where water shortages exist, and solutions are limited or unclear.** statewide

Promote and support integrated water resource planning to identify and implement water management solutions on a local or regional scale to increase self-reliance and water security. Integrated planning identifies strategies to diversify and develop alternative water supplies, while protecting the environment, and increasing resiliency to droughts and climate change. Where localized groundwater level declines and shortages exist in northwest and southwest Missouri, water providers may benefit from the coordinated conjunctive use of both surface and groundwater to meet demands. Track and monitor localized declines in the Ozark Aquifer in southwest Missouri. Grants could be provided to support planning initiatives that incorporate these principles.

## Implementation

**Encourage and promote water conservation as a viable option within a water supply portfolio to meet municipal and industrial (M&I) water supply needs. Effective and sustained water conservation programs help defer investment in additional sources.** statewide

Potential measures that should be considered include:

- Encourage local plumbing codes for water efficiency.
- Promote conservation-focused rate structures.
- Increase awareness of the cost effectiveness of replacing aging infrastructure and implement incentives that reduce water losses through leak detection and distribution system renovation.
- Initiate and develop education programs that modify and improve consumer water use habits.
- Establish statewide conservation guidelines for drought conditions.

**Optimize use of existing reservoir storage and develop additional reservoir storage where existing supplies are limited.** northern and southwest Missouri

Portions of Missouri would benefit from additional storage to maintain water supplies during prolonged shortages or drought. Potential measures that should be considered include:

- Utilize storage already available for M&I use in federal reservoirs
- Conduct bathymetric surveys
- Evaluate when and where dredging may be feasible
- Reallocate storage in federal reservoirs where storage is not allocated for M&I supply
- Evaluate new reservoirs
- Expand existing reservoirs

Missouri River

**Promote and support regionalization and consolidation, especially in areas where technical, managerial, and economic resources are limited, and source waters are difficult to develop.** statewide; northern and southwest Missouri

Regionalization, in either structural or nonstructural form, refers to the alliance of two or more water systems to improve planning, operation, and management of the systems. Regionalization has proven successful in working toward solutions to water and wastewater infrastructure and supply challenges across northern and southwest Missouri. This may also include the sizing of conveyance based on supply availability. The state could further advance regionalization by implementing a campaign targeted at the areas of need that includes dissemination of information and roundtable events, and by designating a representative to answer questions and guide water systems through the process. Projects that include regionalization as a component could be given funding priority.

**Invest in improving the reliability of water supply for livestock, concentrated animal feeding operations and pasture production during periods of drought.** northern Missouri

Local, state, and federal agencies should continue to work together with livestock producers to invest in restoring existing surface water impoundments and creating new impoundments, and/or developing additional infrastructure such as emergency connections for on-farm storage tanks or new groundwater wells as a proactive approach to alleviating future shortages. Local, state, and federal agencies should work jointly to create new cost sharing opportunities including grant programs, where gaps exist for investing in resilient livestock water supply. This is of critical importance in northern Missouri where drought threatens livestock water supplies.

**Continue to work with USACE to support navigation and protect vital water supplies along the Missouri and Mississippi rivers to ensure Missouri's water needs are met.** northern and central Missouri

Coordinate with USACE in continued monitoring of localized bed degradation along portions of the Missouri River and track impacts to water supply intakes for municipal needs and navigation on the river.

**Continue dialogue with neighboring states, and federal agencies with respect to interstate water issues.** statewide

In addition to water from precipitation falling within the state, Missouri relies on flows entering the state. Missouri also provides flow to rivers leaving the state. State and regional water planning groups should continue to maintain a dialogue on water related challenges and opportunities to meet current and future water needs.

**Manage water resources to optimize the opportunities for nonconsumptive water needs such as navigation, power generation, recreation, aquaculture, and fish and wildlife.** statewide

Missouri should continue to manage water resources to optimize opportunities for navigation, power generation, recreation, aquaculture, and fish and wildlife. The state should consider a program to quantify nonconsumptive needs and focus efforts on quantifying water needs that are more difficult to estimate.

**St. Francois State Park**

**Document and monitor regional projects that improve water supply reliability.** statewide

MoDNR should continue to document and monitor regional water supply projects that improve reliability, resiliency, and sustainability. MoDNR should evaluate the effects and implications of the projects on the water resources within the state. The state should develop and maintain a list of these projects.

**Using the adaptive management approach, continue to monitor and assess key risk triggers and identify support (through funding or other means) for projects that mitigate risk to water resources.** statewide

The Missouri WRP details a variety of possible future scenarios, identifies various risk triggers, and presents an adaptive management framework to address future water needs as they arise. Risk triggers have been developed and should continue to be refined to monitor changes in water demands, climate variability, water treatment needs and levels, supply constraints, and reservoir regulation and allocation. Local, state, and regional agencies and water managers should continue to review, follow, and update this framework to address the challenge of balancing underperformance and overinvestment of water infrastructure.

**Increase coordination between MoDNR divisions and programs and across other state agencies.** statewide

In Missouri, water issues are overseen by several agencies within the state. Recognizing the benefits of coordinated planning, state agencies should work together to share information and avoid duplication on water-resources-related activities, as opportunities arise.

### Funding

**Continue to leverage existing state and federal programs to finance water and wastewater infrastructure.** statewide

To meet Missouri's significant drinking water and wastewater infrastructure needs, water and wastewater utilities should continue to leverage existing state and federal programs to supplement local funding and grants. MoDNR's Financial Assistance Center (FAC) offers grants and loans to utilities for planning, financing, and constructing water infrastructure projects. Projects that may need funds beyond what can be offered by FAC may consider using the Multipurpose Water Resource Fund. The Multipurpose Water Resource Fund focuses on funding projects that provide a long-term, reliable public water supply, treatment, or transmission facility in an area that exhibits significant need. In addition to assisting utilities with current fund opportunities, MoDNR should continue to identify and track emerging federal funding opportunities. These funding opportunities should be promoted in order to raise awareness throughout the state.

**Offer and promote programs to educate utilities on effective rate setting that allows for replacement and expansion of infrastructure.** statewide

MoDNR and other agencies should continue to offer or promote training to utilities and communities that focuses on effective rate setting and establishment of asset management programs. Regional water infrastructure funding workshops are offered through MoDNR's FAC. Trainings should continue to address the unique needs of both small and large water and wastewater providers. Utilities need to establish rates that remain affordable but account for infrastructure replacement and expansion. Asset management provides utility managers information on capital assets, the timing of investments, and allows for more informed rate setting to ensure financial capacity for needed replacement, repair, rehabilitation, and expansion of infrastructure.

**Provide continued funding for Missouri WRP implementation.** statewide

The state legislature has appropriated $1 million annually for Missouri WRP implementation activities. This funding will help MoDNR address water resources challenges throughout the state and help the communities that face those issues. Such reliable funding is invaluable to maintaining the momentum of the program and should be continued.

### Data

**Increase data and information collection to better support decision-making and to understand and defend Missouri's rights to water.** statewide

Focus resources on the following:

- Enhance and improve the data collected through MoDNR's major water users program and other programs to better establish and track Missouri's demand for water.
- Enhance data reporting with respect to agricultural groundwater use and agricultural irrigation demands. Identify opportunities to improve measurement and reporting.
- Continue to maintain the groundwater well observation network. Expand the network to fill data gaps where significant local or regional water level declines are expected or observed.
- Expand the streamflow gage network in partnership with USGS to address data gaps, especially in northern Missouri where drought impacts have been observed and surface water is the primary source of supply.
- Continue efforts to expand soil moisture monitoring infrastructure in Missouri.
- Engage with USGS to review, validate, update, and enhance, where necessary, the Ozark Aquifer System groundwater model to better support local and regional water resources planning.
- Collect data to better characterize water and wastewater infrastructure (e.g., size, extent, age) across the state to identify funding needs, evaluate resiliency, and promote economic growth and development.
- Collect data to better understand existing interconnections between water systems. This may include GIS data of water infrastructure to identify existing and potential future interconnections.

## 10.8 References Cited

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# Appendices

Appendix A – Groundwater Province Stratigraphic Sections

Appendix B – Detailed Methodology and Data Sources for Demands

Appendix C – Demands by County and Source

Appendix D – Detailed Methodology for Water Budgets

Appendix E – Subregion Summaries and User Guide

Appendix F – Subbasin Summaries

Appendix G – Scenario Planning Methodology and Calculations

Appendix H – Streamflow, Precipitation, and Land Use and Land Cover Trends in Missouri

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