# Northcentral Missouri
# Regional Water Source Evaluation

for the counties of

Adair, Chariton, Grundy, Linn, Livingston,

Macon, Mercer, Putnam, Schuyler, and Sullivan

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## Preface

The goal of the following analysis is to determine the ability for existing drinking water source(s) to provide sufficient, dependable raw water for the 10-county region of north-central Missouri. By grouping Public Water Systems (PWS's) utilizing the same raw water source(s), into clusters, the regional availability of water can be displayed more accurately. The 18 clusters are split into 3 groups for analysis: groundwater, surface water, and out-of-region clusters. These groupings are detailed below. This approach allows planners to identify instances when a supply source in one cluster has excess capacity during the drought of record (DOR) and another cluster has deficient supply. The first step is understanding the local need for water and identifying whether that need is being met. The second step is evaluating whether those systems with adequate water supply are capable of providing those with inadequate water supply. For the purposes of this evaluation the focus will remain on the first step.

The analysis to determine adequacy of a water source to serve a cluster is based on the following assumptions:

- Current daily raw water demands remain constant
- DOR recharge conditions
- Fifty years of sediment loading for surface water systems
- Water sources are sized according to current Missouri Dept. of Natural Resources design requirements
- Geologic and hydrogeological evidence
- Local history and information specific to water supply

Based on these assumptions, if a source is unable to supply the current daily demand, the cluster will be labeled as an inadequate source. Conversely, if a source is able to supply the current daily demand the cluster will be labeled as adequate.

This study was conducted using information from U.S. Geological Survey (USGS), Missouri Department of Natural Resources (MDNR), individual system interview data and the U.S. Department of Agriculture- National Resource Conservation Service (NRCS).

Staff from the engineering firms of Allstate Consultants and Olsson Associates collaborated on the production of this document. For more information, contact Aaron S. Jones, PE at ajones@allstateconsultants.net or Chad Johnson, PE at cjohnson@olssonassociates.com.

| Cluster ID | PWS Providing Water for Cluster |
|---|---|
| SW-1 | North Central Missouri Regional Water Commission |
| SW-2 | City of Brookfield & City Marceline |
| SW-3 | City of Unionville |
| SW-4 | Trenton Municipal Utilities |
| SW-5 | City of Kirksville |
| SW-6 | Macon Municipal Utilities |
| GW-1 | City of Keytesville |
| GW-2 | MO American Brunswick |
| GW-3 | Chillicothe Municipal Utilities |
| GW-4 | Livingston County PWSD #2 |
| GW-5 | Linn County Consolidated PWSD #1 |
| GW-6 | Linn-Livingston PWSD #3 |
| GW-7 | City of Meadville |
| GW-8 | City of Princeton |
| GW-9 | City of Salisbury |
| OR-1 | Rathbun Regional Water Association (surface water) |
| OR-2 | Clarence Cannon Wholesale Water Commission (surface water) |
| OR-3 | Livingston County PWSD #4 (groundwater) |

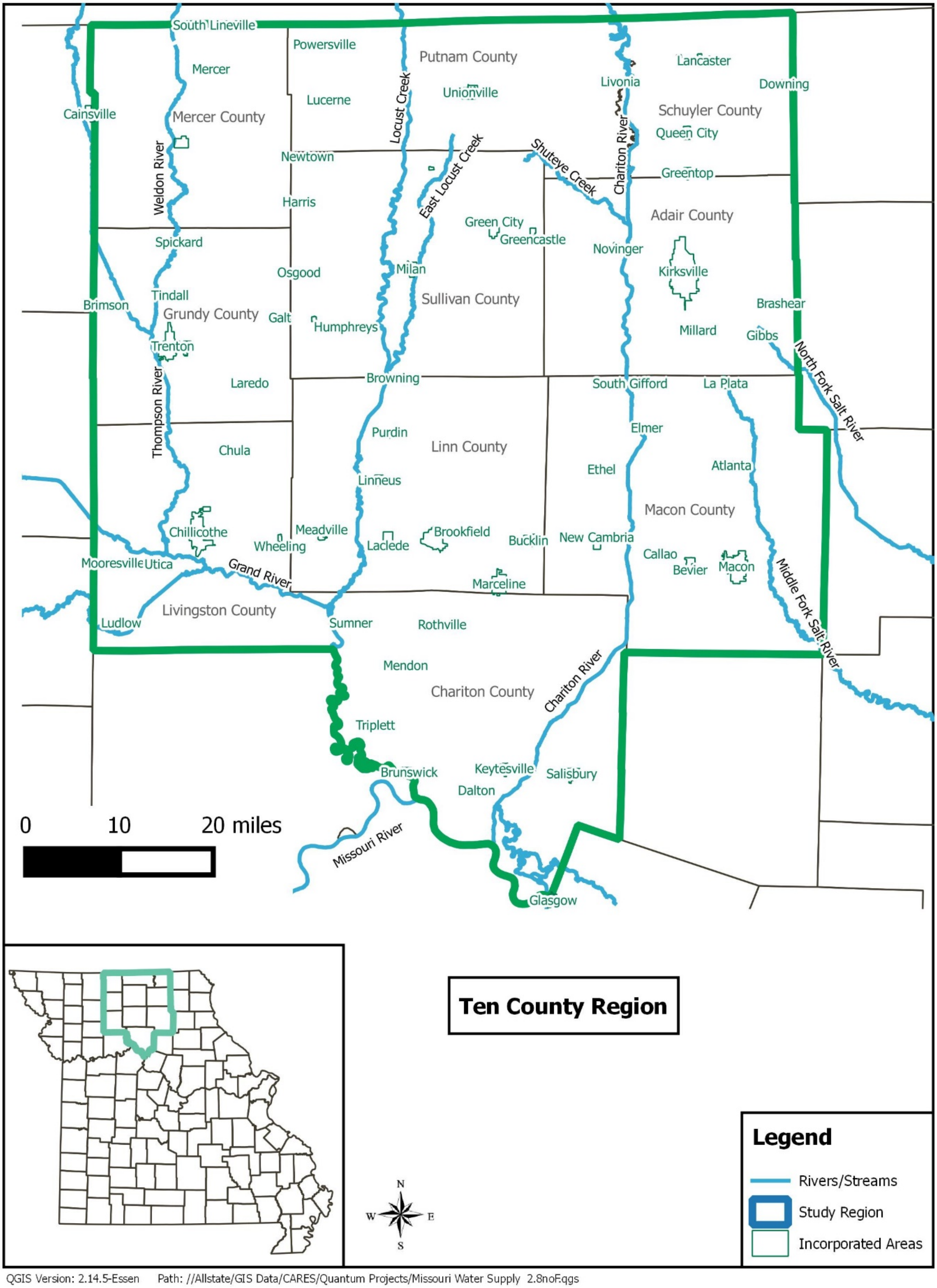



*Figure 1: Location Map for Region of Study.*

## Introduction to Region and Water Suppliers

The 10-county region of north-central Missouri includes the following counties: Adair, Chariton, Grundy, Linn, Livingston, Macon, Mercer, Putnam, Schuyler, and Sullivan. The residents and businesses of these counties are dependent upon the 19 water suppliers, within 18 clusters, to provide treated water daily. Figure 1, above, displays the region and communities within it.

Each cluster has a primary PWS that treats water from the source(s) and then transmits the treated water to other public water systems within the cluster. In some instances, a single PWS may be a part of two or more clusters. This is because the water system has multiple isolated systems for which the water is purchased from different providers. Note that Cluster SW-2 has two PWS's (City of Brookfield and City of Marceline) supplying individually treated water from different sources within the cluster. In this case, there is some interconnection between suppliers.

Generally speaking, the infrastructure needed to transport meaningful amounts of water between clusters is non-existent and development of the infrastructure is not viable for the limited amount of excess capacity that may exist within pockets in the region. The inability of current infrastructure to transport large volumes between adjacent systems, across cluster boundaries, is because of the original sizing of water mains and hydraulics. The existing water mains were sized by engineers based on maintaining adequate flow, water quality standards, and minimum pressures for individual systems.

There are six surface water clusters (SW-1-through SW-6), nine groundwater clusters (GW-1-through GW-9) and three out-of-region clusters (OR-1-through OR-3) that provide finished water in the 10 county region in North Missouri. In Figure 2, below, each segment of the pie corresponds to a producer suppling treated water within the 10 county region. The size of each segment is proportionate to the average daily demand produced by each system. A total of 13.723 million gallons per day (MGD) of treated water was produced in 2015, according to data provided by PWS's. This treated water demand data, is referenced through this evaluation. This graphic brings understanding to how regionalized the study region has become.

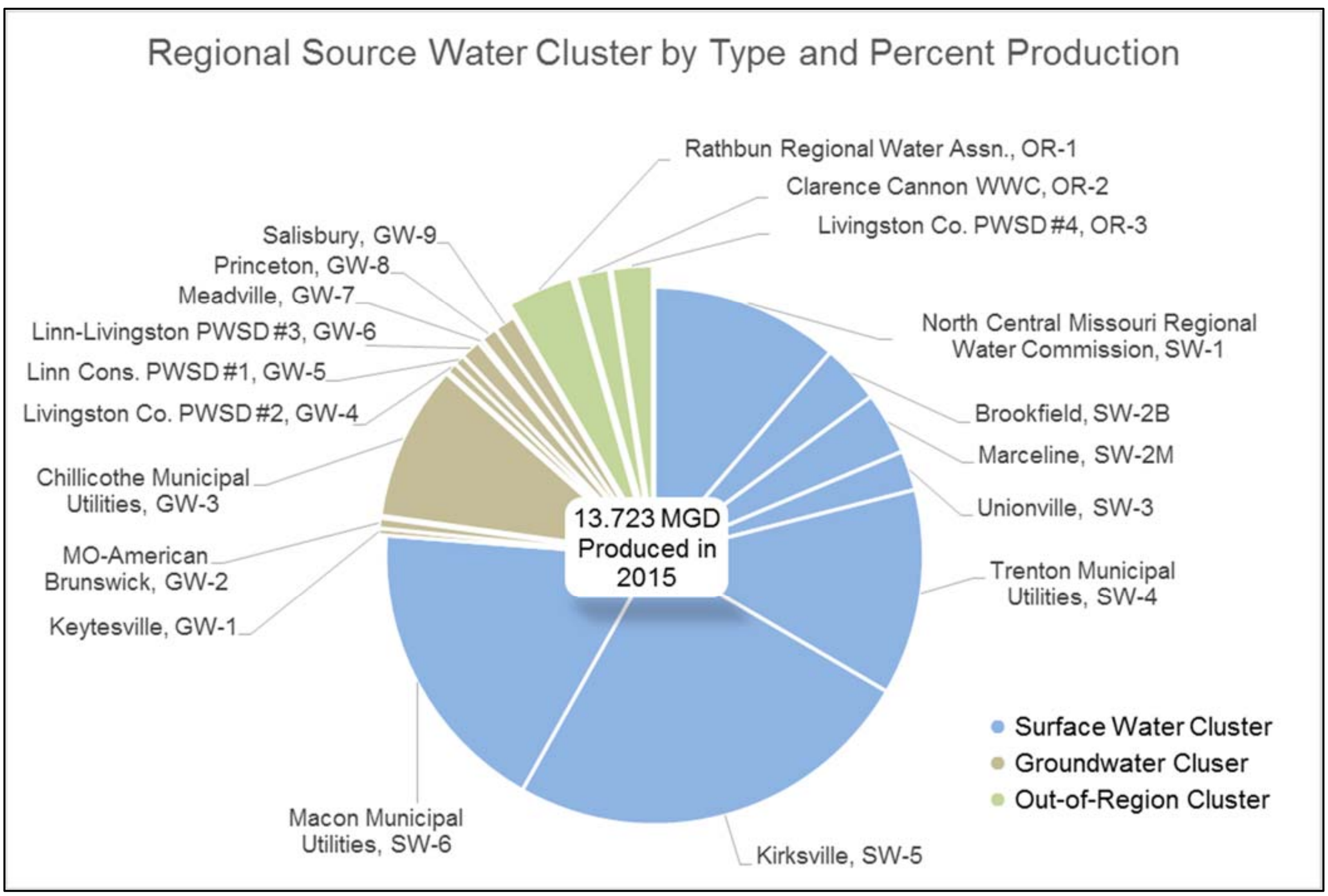



*Figure 2: Regional Source Water Clusters by Type and Percent Production*

## History of Water in Rural North Central Missouri

Water is not a new product or commodity, but the way it is accessed for consumption has change dramatically, in rural north central Missouri. Similarly, the impact of indoor potable water on the United States has been so profound the United States government included questions pertaining to residential plumbing facilities in decennial US Census Housing data, collected from 1940 to 1990 (U.S. Census 2016). Figure 3, below, reveals how rapid the evolution of residential plumbing occurred. The left axis depicts the percentage of residences lacking complete plumbing facilities. Although the intent of the graph is to show data for Missouri, the entire US is included for reference. Coupled with the number of Missouri residences with complete plumbing facilities, the graph captures not only the number of homes modified but also new construction residences with plumbing during a given period. The data shows that over 900,000 homes were built or modified to include complete plumbing facilities between 1950 and 1970. Complete plumbing facilities are defined as hot and cold piped water, a bath- tub or shower, and a flush toilet. (U.S. Census 2016)

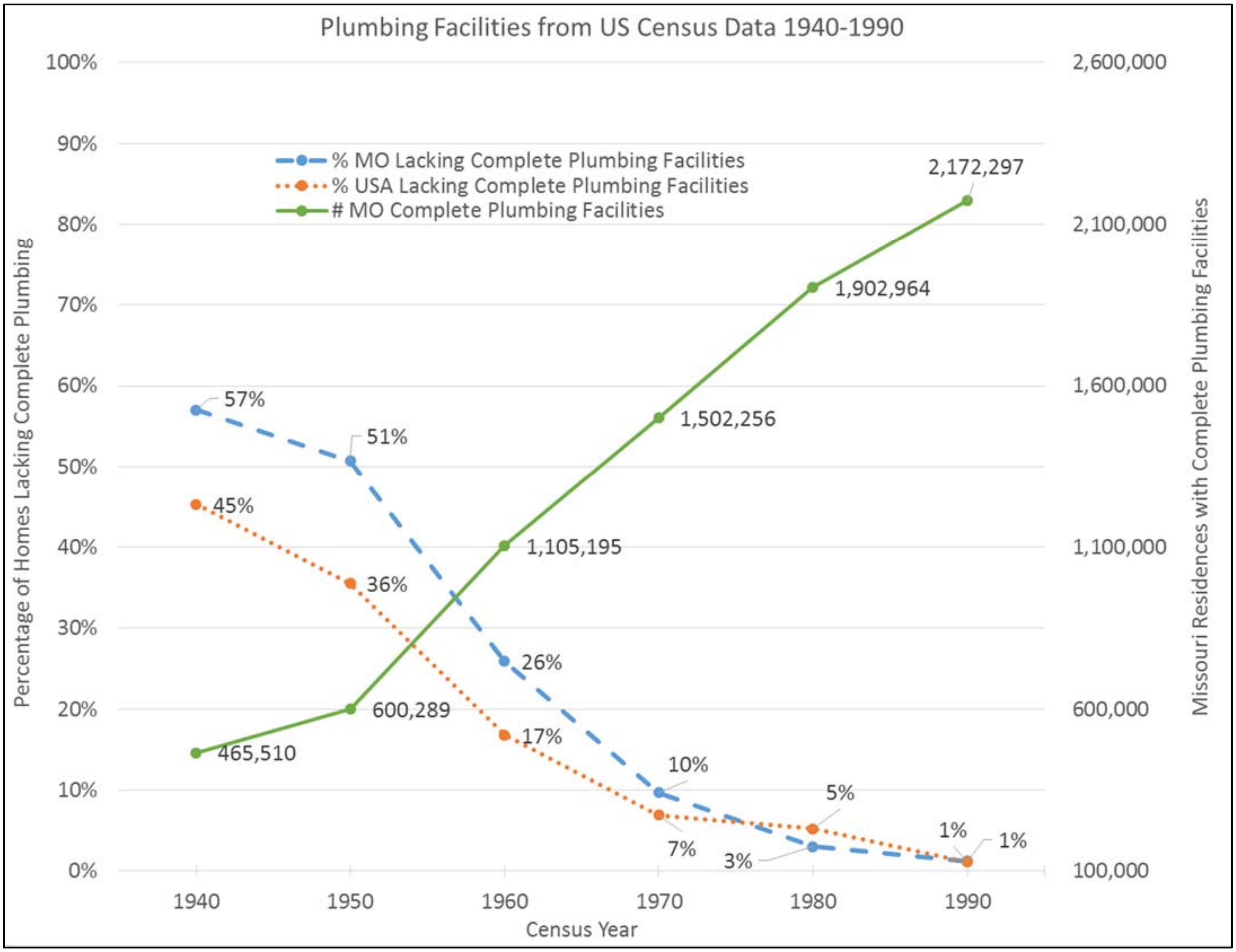



*Figure 3: Plumbing Facilities in Missouri and US from U.S. Census data 1940-1990. (U.S. Census Bureau 2016)*

The indoor plumbing trend was not exclusive to urban residents, many small rural communities provided available water to residents near town when possible. Many rural homes operated cisterns and had a pump and pressure tank that was utilized to force water into the home's bathroom and kitchen. At that time homes did not have automatic dishwashers and automatic clothes washers, as a general rule, as they used too much water and they would run the cistern dry. Families typically used a bathtub full of water for multiple family members for bathing and residential bathroom showers were a rare thing. When the water level in the cistern became depleted, pumps located in cellars or a home basement would lose prime. Periodically, the homeowner would clean the cistern and dump bleach in it. Impurities in the cistern would enter the cistern from barn roof gutter drains, house roof gutter drains, surface water conduits, and pond water being pumped in to the cistern. Items that might be cleaned from a cistern could include silt; bird feces; bird feathers; dead animals such as rabbits, rats, cats, birds, snakes, etc.; algae from the ponds; grass clippings; and other such items. Farmers were constantly cleaning out bird nests from gutters and down spouts to keep impurities out of the home's water supply. Some of the better cistern set ups included roof gutter drains dumping into barrels or cylinders filled full of sand that would provide some filtering prior to entering the cistern.

Prior to rural water districts expansions in the late 1960's, residential water in north central Missouri was limited to cisterns and shallow wells. Many of the old cisterns and residential wells were located for ease of access which was typically as close to the home and barn as possible. Many of the old hand dug wells and cisterns have been abandoned and/or collapsed. Remnants of the old cisterns and hand dug wells with windmills can still be seen scattered across north Missouri but many of the old windmills have been torn down.

Surface runoff and livestock waste above and around the well or cistern allowed surface water to enter the water supply. Water quality testing performed by agencies such as University of Missouri Extension, Missouri Department of Health, MDNR, and USDA-NRCS concluded that many of the shallow wells and cisterns were high in nitrates. Elevated nitrate levels utilized for human and livestock water posed health risks such as Blue Baby Syndrome, stillborn calves and stillborn pigs. This water quality testing further increased the need and desire for safe potable water systems to be provided to rural areas (Sievers and Fulhage 1992).

"Groundwater contamination is possible, and numerous cases of groundwater pollution have been documented. However, most are local problems caused by private septic systems, agricultural runoff from livestock confinements, fertilizer, and other agricultural chemicals, such as, pesticides and herbicides" (Miller and Vandike 1997).

Rural water districts in Missouri started in the mid-1960's in the counties surrounding the urban areas of Kansas City and St. Louis. Districts began when people formed steering committees and groups to push for rural water. These systems would allow the rural residents to discontinue using pond water, cistern water, and individual wells for drinking water purposes. The first rural water districts were formed prior to organized design criteria, with private funds by individuals wanting potable water; Plastic and poly vinyl chloride (PVC) pipe allowed the distribution system construction to be more economical than cast iron or ductile iron pipe.

The first rural water districts utilized small-diameter water mains ranging from 3/4-inch to 2 1/2 – inches to fill up cisterns with a yard hydrant. Design criteria for the sizing pipes for rural water systems was initially non-existent in the early to middle 1960's. PVC pipe allowed cheaper pipe to be installed, but many of the larger engineering companies would not specify or allow its use. Agencies such as the State of Missouri worked with Engineers and communities to develop PVC water pipe design criteria such as early glue joint pipe and now slip joint pipe. Engineers within the Missouri Department of Health (currently MDNR) reviewed plans and specifications for the PWS's and began researching the amount of rural water users compared with the gallons of water utilized. From this research and data, it was determined that a near straight line could be plotted on semi-log paper thus the formula for rural water systems was developed in about 1970:

$$Q = 12C^{0.515}$$

Where: $Q$ = water demand in gallons per minute

$C$ = number of residential users

This formula was utilized for years in hand calculations for rural water districts all over the state of Missouri and beyond. The formula calculates water supply for residential household use only and does not account for fire flows (MDNR 2013).

These new public entities (i.e. water districts) allowed people to pass bond issues to fund initial phases of the water district. The next expansion phases of the water district development required people to take on more debt to help out their neighbors in obtaining potable water from a rural water district. This was accomplished through funding by USDA- Rural Development (formerly USDA-FmHA), MDNR, and Community Development Block Grant (CDBG) as districts began to materialize by utilizing low-interest loans and grants. PVC pipe, pumping stations, and elevated finished water storage reservoirs began to be constructed in the rural areas as a pathway to successful rural water districts. This method of rural people helping out each other through the acceptance of debt allowed the rural water districts began to grow and expand.

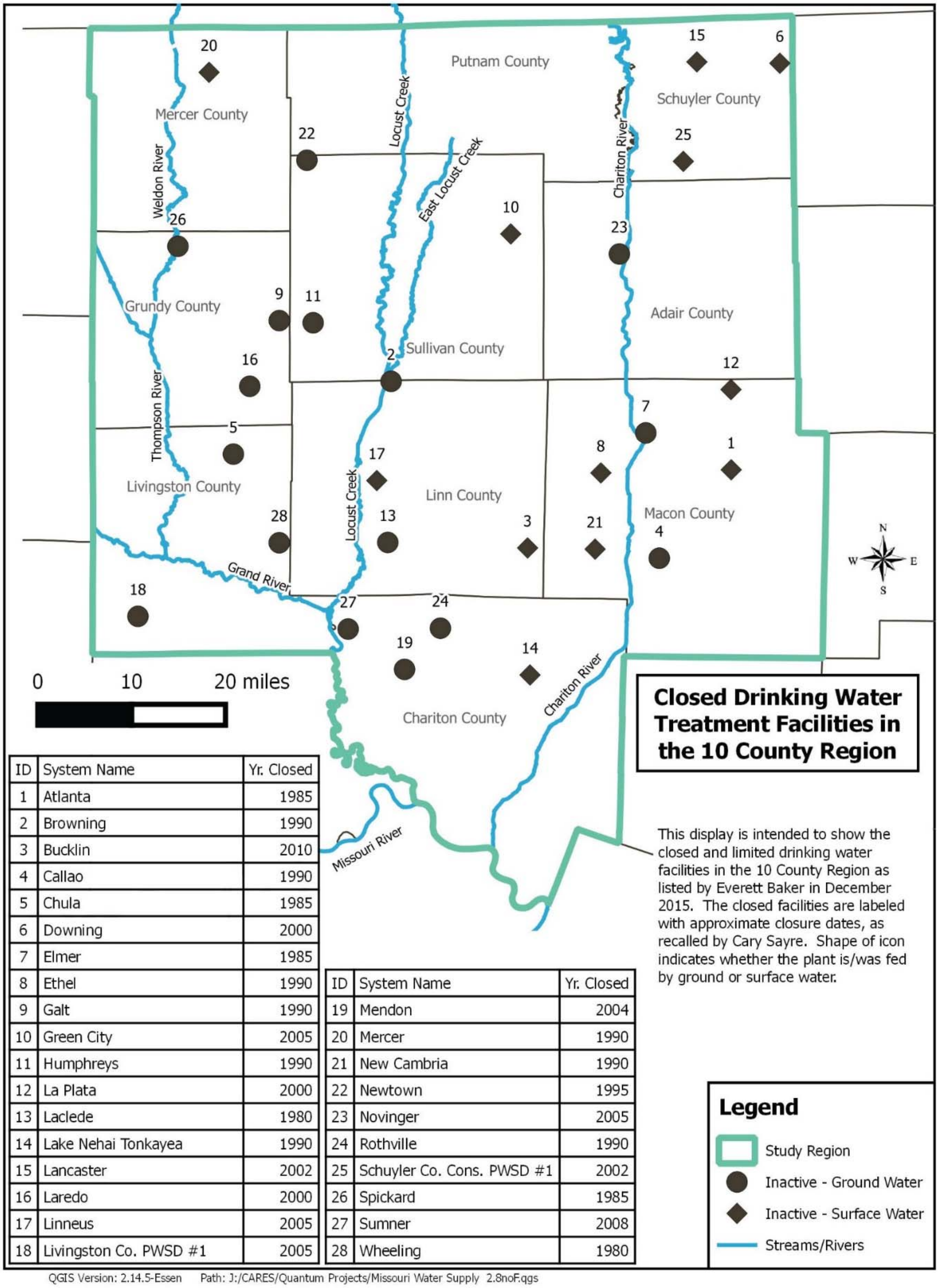
In part, research from the University Extension indicated farmers' livestock utilizing safe potable water for livestock can result in greater livestock production and profit. Often times, utilizing the rural water district water supply was more dependable and required less maintenance than the farmers operating and maintaining their own wells, cisterns, pump and pressure tanks, pond float and pump system, or any other type of water supply system. Many farmers currently utilize rural water for at least a portion of their livestock watering needs.

Through time, the drinking water standards and criteria have become more stringent. Trihalomethanes, disinfection, turbidity, security and other such drinking water standards have caused many PWS's to consolidate with larger systems. The closure or consolidation of the 28 treatment facilities since 1980 is one of the most compelling data trends for rural water systems in the region. The complete listing with a summary of factors for closure, including both surface and groundwater sources, is found in Appendix C. Figure 4, below, depicts the location of the systems now purchasing water from an adjacent system after moving away from their own water source and closing their treatment plants. The aggregation of water systems, or development of unintended regional water supplies, to suppliers with larger capacity has impacted the ability of remaining sources to ensure adequate, reliable raw water for all customers. The impacts of unintended regional water supplies has not been sufficiently evaluated within the 10-county area. The analysis contained herein will evaluate existing water sources and evaluate the need for a regional solution for providing adequate, reliable water. In many cases throughout north Missouri, the raw water supply source capacity was not increased at the same order of magnitude that the drinking water demands increased through the addition of rural water expansion and consolidation.

The first example, the City of Bucklin's lake was constructed in the mid-1930's to be a raw water supply reservoir for the City and to fill steam engines for the adjacent railroad. Bucklin began selling treated water to the local rural water district during the early 1980's. The reservoir silted in through the years and the more current U.S. Environmental Protection Agency's (EPA) drinking water standards became too stringent for the City to comply without a tremendous cost. The City of Bucklin closed their water plant in 2010, no longer sell water to the water district, and now both the city and rural users obtain their water from the City of Marceline via Chariton-Linn PWSD #3. This consolidation created additional strain on City of Marceline's water supply system, from raw water source availability, to the treatment, operation, and maintenance capacities.

The second example references the letter in Appendix B, shows an example of a supply system, Linn County Consolidated PWSD #1, in search of another well site after their existing well had been influenced by high iron. The drillers' letter states after 11 test wells that "We don't feel a suitable formation for a well to produce at least 50 GPM has been encountered." This was in an area adjacent to Locust Creek.

In summary, rural public water supplies and even indoor plumbing has only been prevalent in Missouri since around the 1950's. Originally, rural water suppliers were formed to improve health conditions. As those benefits were realized systems rapidly outgrew water source supply capacity. With the public dependent upon a single supply, a need for quality standards was introduced in the Safe Drinking Water Act. These standards became more than some communities could achieve or afford, so reliance upon adjacent supplies began. Figure 4, below, identifies the 28 closed systems in the region since 1980. In an area where source water is scarce, regionalization has led to the current conditions of widespread dependency on a few sources. Only three of the 18 clusters provide water to their one district or community; the remainder provide wholesale water.




| ID | System Name | Yr. Closed |
|---|---|---|
| 1 | Atlanta | 1985 |
| 2 | Browning | 1990 |
| 3 | Bucklin | 2010 |
| 4 | Callao | 1990 |
| 5 | Chula | 1985 |
| 6 | Downing | 2000 |
| 7 | Elmer | 1985 |
| 8 | Ethel | 1990 |
| 9 | Galt | 1990 |
| 10 | Green City | 2005 |
| 11 | Humphreys | 1990 |
| 12 | La Plata | 2000 |
| 13 | Laclede | 1980 |
| 14 | Lake Nehai Tonkayea | 1990 |
| 15 | Lancaster | 2002 |
| 16 | Laredo | 2000 |
| 17 | Linneus | 2005 |
| 18 | Livingston Co. PWSD #1 | 2005 |
| 19 | Mendon | 2004 |
| 20 | Mercer | 1990 |
| 21 | New Cambria | 1990 |
| 22 | Newtown | 1995 |
| 23 | Novinger | 2005 |
| 24 | Rothville | 1990 |
| 25 | Schuyler Co. Cons. PWSD #1 | 2002 |
| 26 | Spickard | 1985 |
| 27 | Sumner | 2008 |
| 28 | Wheeling | 1980 |

*Figure 4: Closed Drinking Water Treatment Facilities in the 10 County Region, based on (MDNR- Baker)*

## Overview of Surface Water Cluster Evaluations

Water supply systems in north central Missouri rely on a variety of surface water sources, including in-stream reservoirs, off-stream reservoirs, and streamflows. Evaluation of these surface water sources, requires analysis of either the Reservoir Operation Study Computer Program (RESOP) for instream reservoirs, or the 7 day average low flow rate that occurs once in 10 years on average (7 Q10) of streamflows combined with capacities of off-stream reservoirs. These methods were analyzed against the available rain gauge data from this period, 1952-1959, as the DOR, which is the longest duration and most intense drought in Missouri on file.

### RESOP Method

The MDNR approved method for instream reservoir analysis is the NRCS's RESOP, which is used to calculate "optimized demand" as described in NRCS Technical Release 19.

> *Optimize Demand -- indicates that the lowest storage will be checked against the lower limit and the demand modified until the maximum demand is reached and no deficiency occurs. (NRCS 1987)*

To avoid confusion with the word demand, in this evaluation optimized demand will be referred to as reservoir yield capacity and defined as:

> <u>Reservoir Yield Capacity</u> is the calculated volume of raw water that can be withdrawn daily from a reservoir to maintain a minimum volume in the reservoir to meet other purposes, and meet water source design guidelines.

The term Normal Demand will be defined as:

> <u>Normal Demand</u> is the average daily quantity of water used by customers, based on an annual period.

The RESOP calculates the reservoir yield capacity by using initial volume, water supply volume, rainfall, runoff, and evaporation parameters. If daily water supply withdrawals (normal demand) are greater than reservoir yield, the results will be a shortage of water during a DOR. The evaluation contained herein will characterize system clusters with a normal demand greater than the calculated water source yield capacity, as an inadequate source. The system clusters with a normal demand less than its calculated yield capacity will be characterized as an adequate source.

> Normal Demand (raw water) < Reservoir Yield Capacity → Adequate Source

> Normal Demand (raw water) > Reservoir Yield Capacity → Inadequate Source

Some of the evaluated reservoirs serve multiple purposes such as recreational, drinking water supply, and flood control. In the case of a water supply and recreational use reservoir, a minimum volume, or lower limit, must be established to maintain aquatic habitat and recreational uses. Other examples of lower limit volumes include physical intake inlet elevations and water quality thresholds. Note that these limitations and thresholds are different for each source. These lower limits were not included in the Missouri Water Supply Study of 2013 (MDNR 2013), so that analysis assumes that quality drinking water can be withdrawn from the lake until the lake is dry. The Missouri Water Supply Study provided the background data and base RESOP models for this evaluation, but this new, more detailed analysis was completed to better quantify water availability in the 10-County region by accounting for added sediment over the next 50 years, and reasonable limits on acceptable lake levels.

Given the sensitivity and security of information regarding specific design details of public water supply inlet structures, systems interviewed asked for those details to be omitted from this evaluation. Some systems within the study region shared their inlet elevations and discussed which inlets were typically used. One system referenced water analysis conducted on the entire water column and noted water from the lowest inlet elevation was "oxygen deprived and therefore highly reactive during jar testing." By conducting routine jar testing the systems staff determined that they could use less chemical to treat water 4 to 6 feet below the water surface.

Water inlet elevations vary by source, as well as by water quality horizons. This evaluation could not reasonably consider all variables that affect each supply in the region and, therefore the assumption of the lower one-third reservoir elevation was made to account for inaccessible water and water quality limitations, and is based on the knowledge of systems within the study region. Note the one-third elevation, from the spillway to the lowest pool elevation, is not equal to one-third of the reservoir volume. Bathymetric evaluations by USGS from the Missouri Water Supply Study of 2013 were used for calculations.

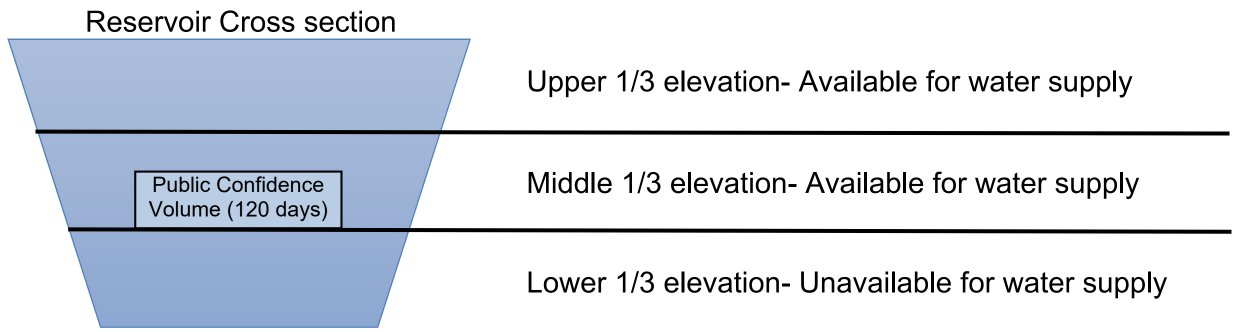



*Figure 5: Reservoir Cross section (not to scale)*

When evaluating a source for quantity and reliability the Minimum Design Standards for Missouri Community Water Systems states the following in Chapter 3 Section1.1a:

> "Reservoir storage volume shall provide a reasonable surplus for reserve storage. A reasonable amount of surplus reserve storage should be considered in order to maintain public confidence in the reliability of supply at predicted depletion levels during a prolonged severe drought. A minimum of 120 days surplus reserve storage should be considered."

This public confidence volume should be accounted for in the portion available for water supply, as shown in the Middle 1/3 elevation in Figure 5. This volume is calculated by multiplying the normal demand by 120 days. This quantity of million gallons must then be converted to acre-feet and added to the lower limit of RESOP analysis when calculating reservoir yield capacity. An example of the impact of public confidence is included in the following Cluster SW-5 report.

In order to provide a thorough investigation of the water supply dependability in the 10-county region, the RESOP analyses were updated for differing assumptions. RESOP input parameters for lake volumes were also modified for sediment to reflect the volume of reservoir capacity reduced by the accumulation of sediment over the next 50 years. Some of the RESOP graphs show this as adjustment for sediment, which is the reservoir levels assuming normal demand stays constant, but shifted to account for the reduced reservoir volume due to sedimentation over 50 years.

To accurately model extreme conditions the scenarios considered must reflect conditions when no pumping will be allowed. These no pumping conditions have been observed in actual pumping data sets. As an example the largest streamflow in the region is the Thompson River which provides water for Cluster SW-4. The USGS recorded the daily flows in the Thompson River observation station at Trenton, MO. The data shows a four consecutive-month period (November 1955 to February 1956) when average monthly flows (from daily flow calculations) in the Thompson River were below the base flow of 9 cfs, therefore no pumping could be allowed during this time. See Cluster Report SW-4 for more information. Through observed data and because other streamflows smaller than that of the Thompson River are used to supplement in-stream reservoirs, (which prohibited pumping during the DOR), the capacity from pumping will not be considered as a dependable source of water.

An important note about RESOP analysis is that unless the start of a DOR was accurately predicted and pumping was reduced prior to the beginning of the drought, in the case that normal demand exceeds reservoir yield, the reservoir would not actually be able to produce the reservoir yield because it would be drawn down by the normal demand before conservation measures could be implemented. In other words, the normal demand needs to be below the reservoir yield, or the reservoir yield could not actually be achieved. So, in these cases, the reservoir yield overestimates the available water.

In the case when a PWS uses multiple reservoirs for raw water supply an additional calculation is needed to identify the proportion of total normal demand on each source. The proportional demand approach was used in this evaluation similar to the approach by MDNR in the Missouri Water Supply Study of 2013. This calculation was only used in Cluster SW-5 and detailed calculations are included in its report.

### 7 Q10 Method

For systems in the region that rely on streamflow, the Minimum Design Standards for Missouri Community Water Systems stipulates in Chapter 3 Section 1.1.f:

> "When a river or stream is to be used as the sole source of water, the flow in the river or stream shall exceed the current registered and future downstream uses, instream flow recommendations, usually the 7 day Q 10 flow rate, and the design year future water system demand. Historical data must be used to determine that stream flows are adequate. Where the nearest gauging station is downstream of the intake site, a drainage area ratio or other approved method to represent the intake location must adjust the flow data. Data from an upstream station may be used. For streams where data does not cover the DOR, data from similar streams may be used to correlate or predict stream flows, with department approval" (MDNR 2013).

The 7Q10 is the 7 day average low flow rate that occurs once in 10 years on average. So, by definition, the flow in the stream during the DOR will be below the 7 day Q 10 flow rate. The 7 day Q 10 flow rate represents a moderate drought of the kind that occurs once in 10 years. This leaves no capacity for the water system to pump from the stream during any drought more severe than the 10 year return period drought.

In the north-central region of Missouri several systems use a combination of streamflow and reservoirs to provide water. An important step in evaluating the dependability of a source, is considering cases when augmenting (pumping) a source with water from streamflow is not an option. The Missouri Water Supply Study describes this circumstance in the following excerpt:

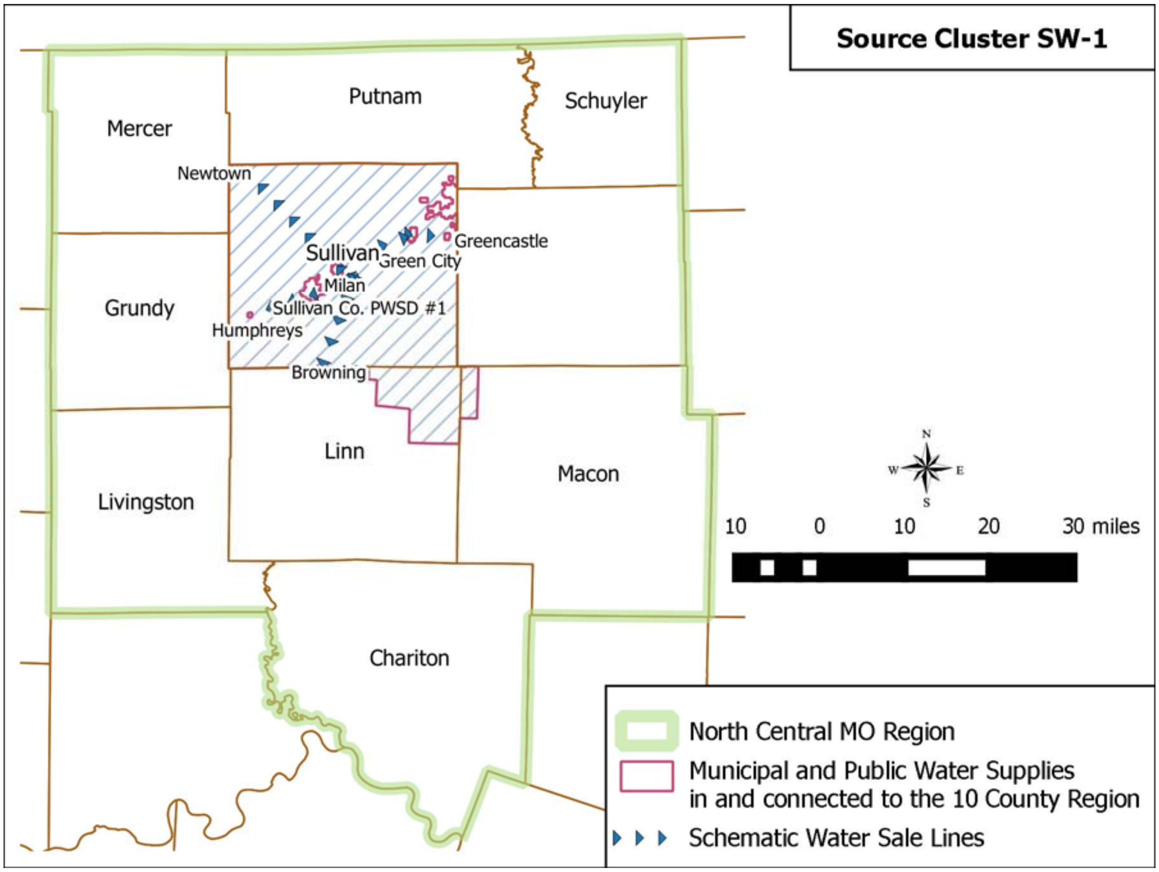
> "Several of the examined water supply systems are from a collection of surface water sources, which can include several small lakes in series or tandem and often supplemented by in-stream diversion pumps. These analyses were made for some of the most critical supplies. Cities usually use two sources to supply their needs. These sources are lakes and flowing streams. Water stored in lakes comes from rainfall runoff to the lakes. Many of the lakes are too small in size and drainage area to satisfy local needs. As a result, the supply provided by the lakes must be supplemented by other sources. A common practice is to pump from streams into the lakes during high stream flows in an attempt to keep water levels in lakes near full. During droughts one can expect the streams to dry up or stream flow to be so low that pumping cannot be achieved" (MDNR 2013).

The following surface water cluster reports provide information on specific systems and sources within each of the six clusters, as well as the determination of a source to be adequate or inadequate.

# Surface Water Cluster Reports SW-1 to SW-6

# Cluster SW-1

**Sources Inadequate**




There are currently two lake sources for Cluster SW-1, operated by the North Central Missouri Regional Water Commission (NCMRWC) near Milan, Missouri. The cluster map above shows the service area for this cluster and the Production and Demand table on the next page details systems dependent upon these sources for all water supply needs. The demands listed are average daily treated water usage, based on an annual period. NCMRWC currently produces approximately 0.572 MGD of treated water and sells another 0.923 MGD raw water to Premium Standard Farms, which operates its own treatment facility for industrial purposes. The single treatment facility is designed to produce 2.4 MGD and enough land is owned by the NCMRWC to expand the facility to an ultimate approximate capacity of 6.5 MGD treated water.

Since 1985 four communities in this cluster have abandoned water treatment activities. Green City was mandated by the MDNR to cease treatment activities in 2004. The Inactive Sources table on the next page identifies those communities and briefly describes the reasoning for closure.

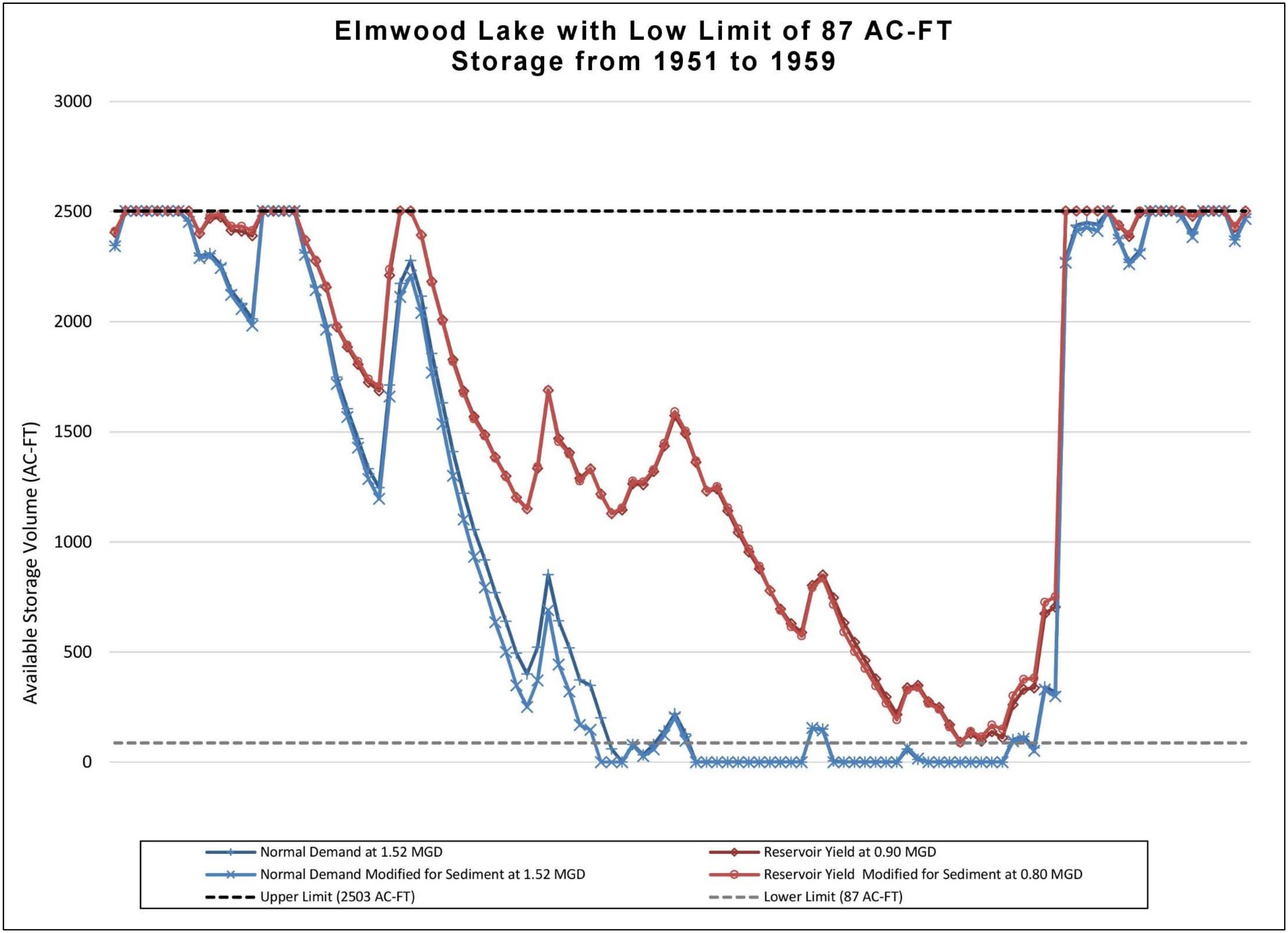
Assessing the two reservoir sources, Elmwood Lake and Milan Lake (Golf Course Lake), it is important to note that pumping from Locust Creek is necessary to maintain current demand. Both the 194-acre Elmwood Lake and 41 acre Milan Lake are supplemented with pumping from Locust Creek during normal and dry periods to maintain adequate levels. During wet periods pumping is conducted as needed. As both sources continue to decay and silt, the available source water capacity continues to decline. This reduction of capacity threatens health, safety, and economic sustainability of communities dependent upon this supply. Modeling conservative scenarios over the next 50 years, with siltation and drought of record conditions, RESOP analysis shows that the Elmwood Lake and Milan Lake, respectively, could daily yield 0.800 and .140 MGD of raw water. Cluster SW-1's total raw water yield capacity is 0.940 MGD, which is 0.744 MGD less than the average daily raw water demand under current conditions, therefore the sources for Cluster SW-1 are inadequate. USGS Low Flow data shows the 7Q10 is less than 0.24 MGD which means that the stream will be unable to provide sufficient flow in a DOR.

| 2015-2016 Cluster Average Daily Production and Demand (Treated Water Quantities) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Source Cluster | Tier System | | | | | MGD Produced | % purchase from supplier | Total MGD Consumed |
| | 1st | 2nd | 3rd | 4th | 5th | | | |
| SW-1 | North Central Missouri Regional Water Commission | | | | | 1.572 | | n/a |
| | | Green City | | | | | 100% | 0.122 |
| | | | Green Castle | | | | 100% | 0.034 |
| | | Milan | | | | | 100% | 0.180 |
| | | Sullivan County PWSD #1 | | | | | 100% | 0.274 |
| | | | Browning | | | | 100% | 0.017 |
| | | | Humphreys | | | | 100% | 0.007 |
| | | | Newtown | | | | 100% | 0.016 |
| | | Premium Standard Farms (Raw Water Industrial Customer) | | | | | 100% | 0.923 |

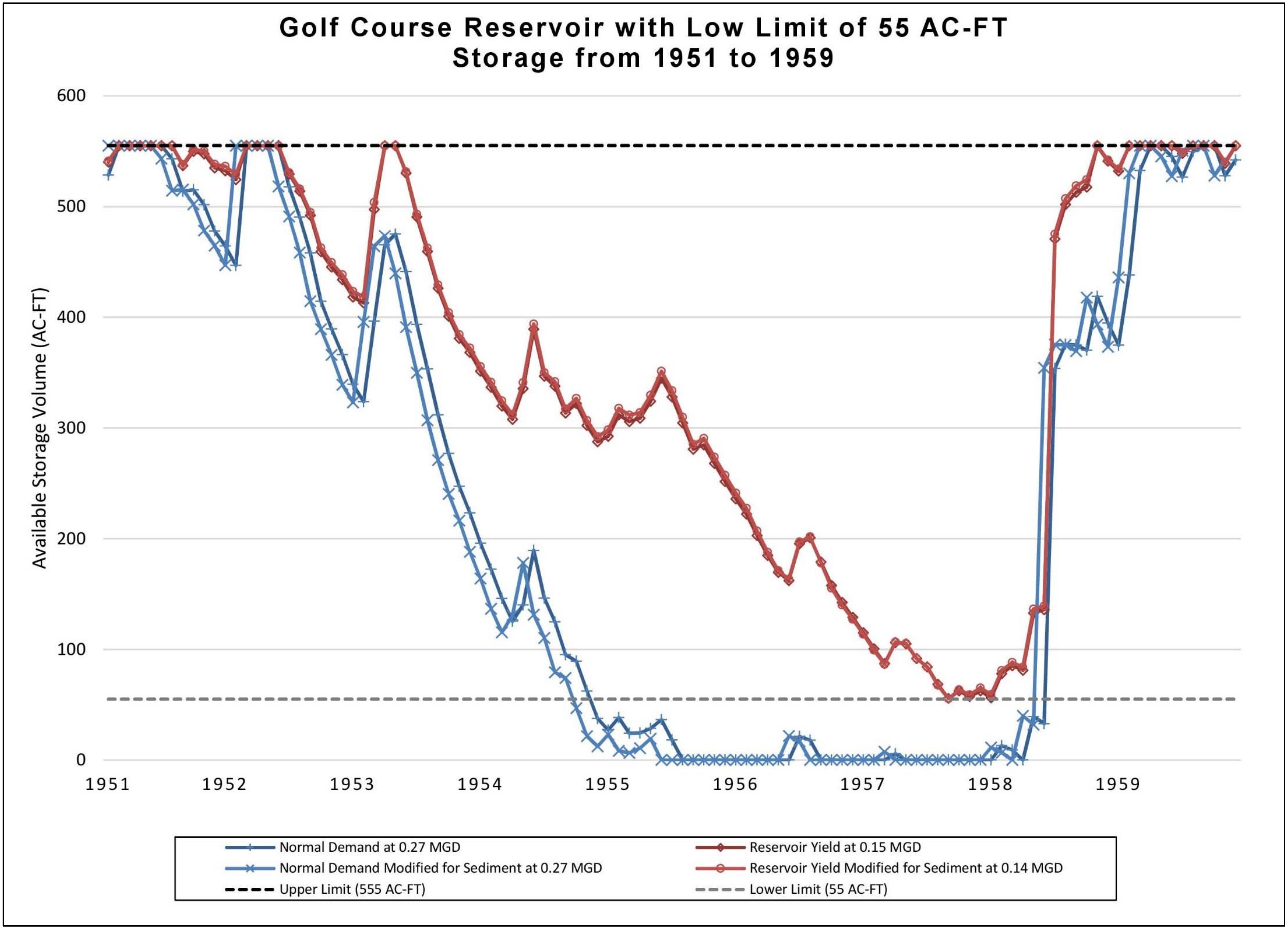
| Inactive Sources Within Cluster | | | | | |
|---|---|---|---|---|---|
| System ID# | System Type | System Name | County | Source | Year of Closure |
| MO2010329 | Surface Water | Green City | Sullivan | Inadequate lakes to demand; single stage treatment facility became inadequate; closed plant; now purchase water from NCMRWC | 2005 |
| MO2010574 | Groundwater | Newtown | Sullivan | Failed wells (declining yield, likely due to iron/silt); closed plant; now purchase water from Sullivan PWSD #1 | 1995 |
| MO2010389 | Groundwater | Humphreys | Sullivan | Failed wells (declining yield, likely due to iron/silt); closed plant; now purchase water from Sullivan PWSD #1 | 1990 |
| MO2010108 | Groundwater | Browning | Sullivan | Failed wells (declining yield, likely due to iron/silt); closed plant; now purchase water from Sullivan PWSD #1 | 1990 |

<table>
<tr><th colspan="12">Surface Water Supply(s) Within Cluster</th></tr>
<tr><th rowspan="2">Cluster</th><th rowspan="2">Lake/ Reservoir</th><th colspan="2">Cluster Current Demand</th><th colspan="2">Raw Water Capacity Without Pumping, With Sediment</th><th rowspan="2">Excess Capacity (Reservoir Yield- Normal Raw Demand) MGD</th><th rowspan="2">Lake Purpose (S=water supply, R=recreation, C=flood control) in order of importance</th><th rowspan="2">Year Dam Built</th><th rowspan="2">Surface Area (acre)</th><th rowspan="2">Total Volume (ac.-ft.)</th><th rowspan="2">Water Supply Volume (ac.-ft.)</th></tr>
<tr><th>Normal Treated (MGD)</th><th>Normal Raw (MGD)</th><th>Source Yield Capacity (MGD)</th><th>Cluster Yield Capacity (MGD)</th></tr>
<tr><td>SW-1</td><td>Elmwood Reservoir</td><td rowspan="2">1.572</td><td rowspan="2">1.629</td><td>0.800</td><td rowspan="2">0.940</td><td rowspan="2">-0.689</td><td>S, R</td><td>1972</td><td>194.77</td><td>2503.2</td><td>2416.5</td></tr>
<tr><td>SW-1</td><td>Milan Lake (Golf Course)</td><td>0.140</td><td>S, R</td><td>1940</td><td>41.01</td><td>555.2</td><td>500.3</td></tr>
</table>

<table>
<tr><th colspan="10">Results from USGS Low Flow Equations* for Stream Intakes in 10-county region</th></tr>
<tr><th colspan="4"></th><th colspan="3">Inputs</th><th colspan="3">Outputs</th></tr>
<tr><th>Cluster</th><th>Supplier</th><th>PWS System ID</th><th>Intake</th><th>Drainage Area ($Mi^2$)</th><th>Length (mi)</th><th>Stream Variable</th><th>7Q10 (MGD)</th><th>30Q10 (MGD)</th><th>60Q10 (MGD)</th></tr>
<tr><td>SW-1</td><td>NCMRWC</td><td>2021537</td><td>Locust Creek at Intake</td><td>217.63</td><td>44.08</td><td>0.745</td><td>0.264</td><td>0.568</td><td>0.921</td></tr>
<tr><td colspan="10">* Computed Statistics at Streamgages, and Methods for Estimated Low-Flow Frequency Statistics and Development of Regional Regression Equations for Estimating Low Flow Frequency Statistics at Ungaged Locations in Missouri, USGS 2013</td></tr>
</table>



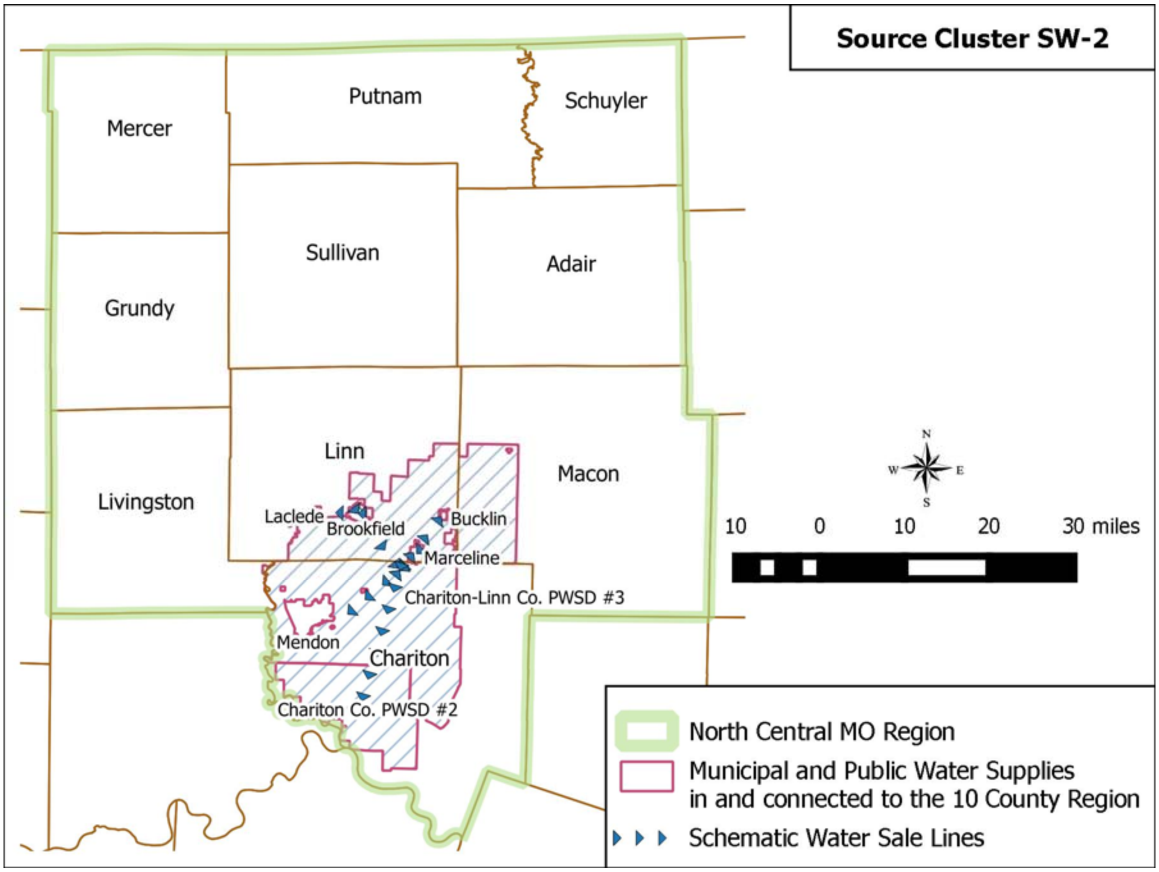

*RESOP Graph 1 Elmwood Lake*




*RESOP Graph 2 Golf Course Reservoir*

# Cluster SW-2

**Sources Inadequate**




The two sources for Cluster SW-2 are the City of Brookfield (SW-2B) and the City of Marceline (SW-2M), both of which operate separate surface water reservoirs and separate water treatment facilities. These two communities and sources are included in Cluster SW-2 because of a common secondary system in Chariton-Linn PWSD #3. Marceline does not provide water to Brookfield, nor does Brookfield provide water to Marceline, but Chariton-Linn PWSD #3 is responsible for a large part of both sources demand. Of the 8 systems in this cluster that have abandoned treatment activities, 7 have been purchased by or purchase water from Chariton-Linn PWSD #3. These systems are noted on the Inactive Sources table in this section. The closure of these eight systems have caused demand to increase from both Brookfield and Marceline, causing a larger water deficit for these two larger communities during drought conditions.

The City of Brookfield maintains four ground storage basins, known as the Brookfield Reservoir. These basins are filled from a pump station in the adjacent Yellow Creek. This complex of basins has no significant recharge from runoff given the basin's bermed perimeters, and the capacity, when full, total approximately 115 million gallons or 353 acre-feet. RESOP analysis is not available for this source but the 200 acre-feet needed for public confidence to comply with MDNR standards, will be excluded from the RESOP analysis of Brookfield City Lake instead. During a DOR these basins would provide approximately 200 days of raw water supply before being unusable. USGS low flow equations calculate the 7Q10 at .258 MGD which is well short of the daily raw supply needed to meet normal demand. Due to the extreme and prolonged nature of the DOR, Yellow Creek is not a dependable source of water. There for given the no pumping condition, the Brookfield Reservoir is not a viable source of water during extreme conditions.

The other Brookfield source is the Brookfield City Lake, which is also augmented with pumping from Yellow Creek. Due to mechanical issues with the pump station supplying the Lake in the early 2000's the lake was reported to be over 12' below normal pool, drastically reducing supply capacity. RESOP analysis on this lake determined during DOR conditions the reservoir yield capacity is 0.180 MGD without augmenting from Yellow Creek. The current treated water normal demand on Brookfield's sources is 0.494 MGD, which corresponds to a raw water normal demand of 0.543 MGD. Comparing the reservoir yield capacity to the raw water normal demand equals a net negative source capacity of 0.363 MGD during DOR conditions.

The City of Marceline maintains two reservoirs and a creek pump station on Mussel Fork Creek to augment the reservoirs as needed. USGS low flow data shows that Mussel Fork Creek flow is not sufficient to pump during prolonged dry periods. The larger, New Marceline Lake serves as the primary source and is modeled to have a RESOP reservoir yield capacity of 0.448 MGD, without pumping, during the DOR. While the Old Marceline Reservoir, with the same conditions has a RESOP reservoir yield capacity of .060 MGD. The calculation of the Old Marceline Reservoir was provided from in the Missouri Water Supply System Study of 2013 (MDNR 2013). The system does have the capability to pump water from the Old Reservoir to the New Marceline Lake and the water treatment facility. The Marceline water treatment facility was built in 2000 and maintains an average flow of approximately 1,250 gpm.

Marceline's two sources can combine for a daily reservoir yield of 0.454 MGD, which is less than the current treated demand of 0.508 MGD. The Marceline raw water normal demand is approximately 0.572 MGD, which results in a net negative reservoir yield capacity of 0.118 MGD. Combined with the net negative yield capacity of Brookfield, Cluster SW-2 has a total net negative yield capacity of 0.515 MGD. This analysis concludes that Cluster SW-2 sources are inadequate.

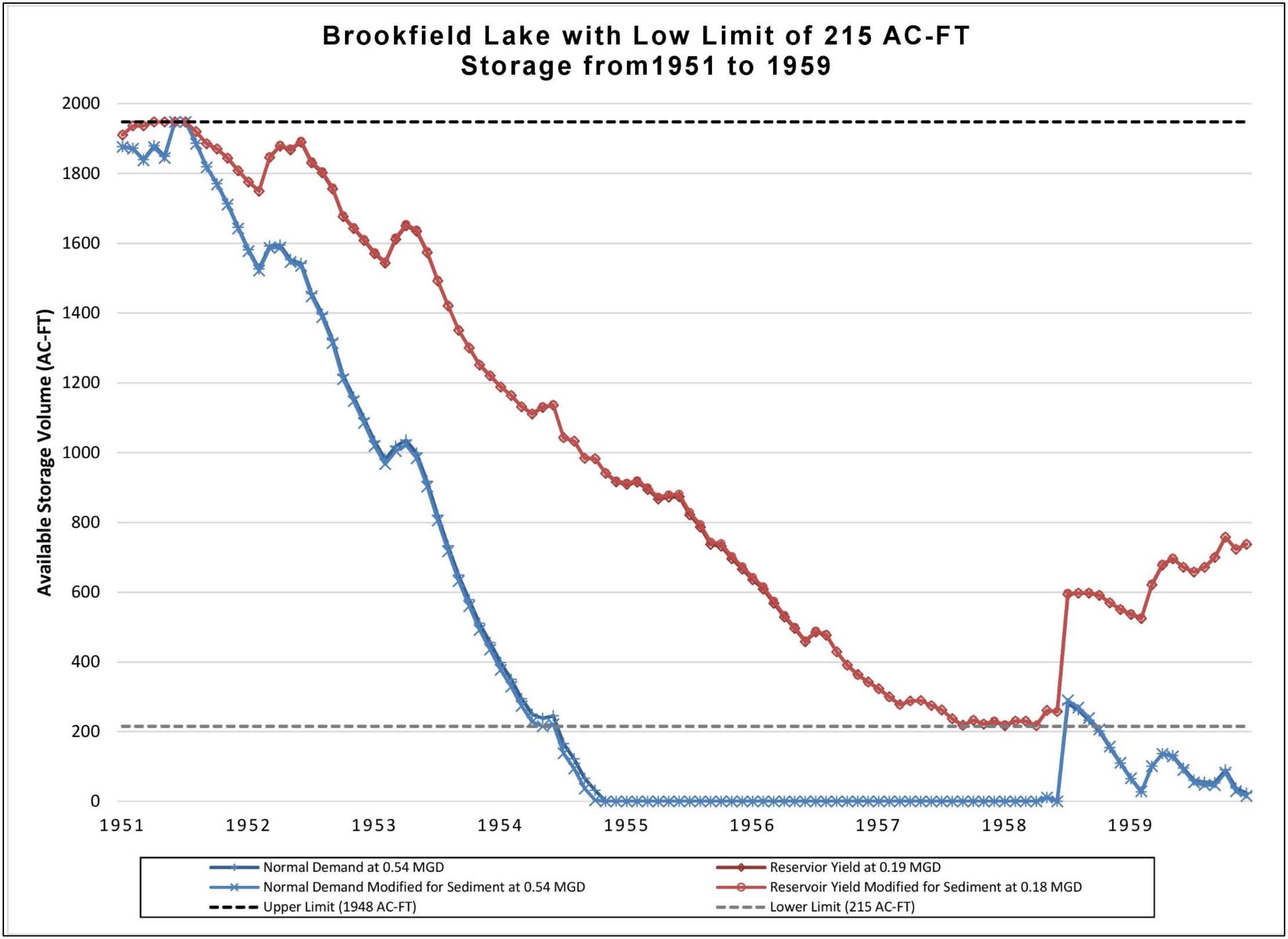
| 2015-2016 Cluster Average Daily Production and Demand (Treated Water Quantities) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Source Cluster | Tier System | | | | | MGD Produced | % purchase from supplier | Total MGD Consumed |
| | 1st | 2nd | 3rd | 4th | 5th | | | |
| SW-2 | Brookfield | | | | | 0.494 | | 0.376 |
| | | Laclede | | | | | 100% | 0.031 |
| | | Chariton-Linn PWSD #3 | | | | | 25% | 0.351 |
| | | | Bucklin | | | | 100% | 0.017 |
| | | | Mendon | | | | 100% | 0.018 |
| | | | Chariton PWSD #2 | | | | 35% | 0.049 |
| | Marceline | | | | | 0.520 | | 0.257 |
| | | Chariton-Linn PWSD #3 | | | | | 75% | 0.351 |
| | | | Bucklin | | | | 100% | 0.017 |
| | | | Mendon | | | | 100% | 0.018 |
| | | | Chariton PWSD #2 | | | | 35% | 0.049 |

| Results from USGS Low Flow Equations* for Stream Intakes in 10-county region | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Inputs | | | Outputs | | |
| Cluster | Supplier | PWS System ID | Intake | Drainage Area (Mi$^2$) | Length (mi) | Stream Variable | 7Q10 (MGD) | 30Q10 (MGD) | 60Q10 (MGD) |
| SW-2 | Marceline | 2010497 | Mussel Fork at Intake | 146.7 | 55.6 | 0.695 | 0.100 | 0.229 | 0.284 |
| SW-2 | Brookfield | 2010105 | West Yellow Creek at intake | 195.27 | 54.7 | 0.659 | 0.258 | 0.546 | 0.723 |

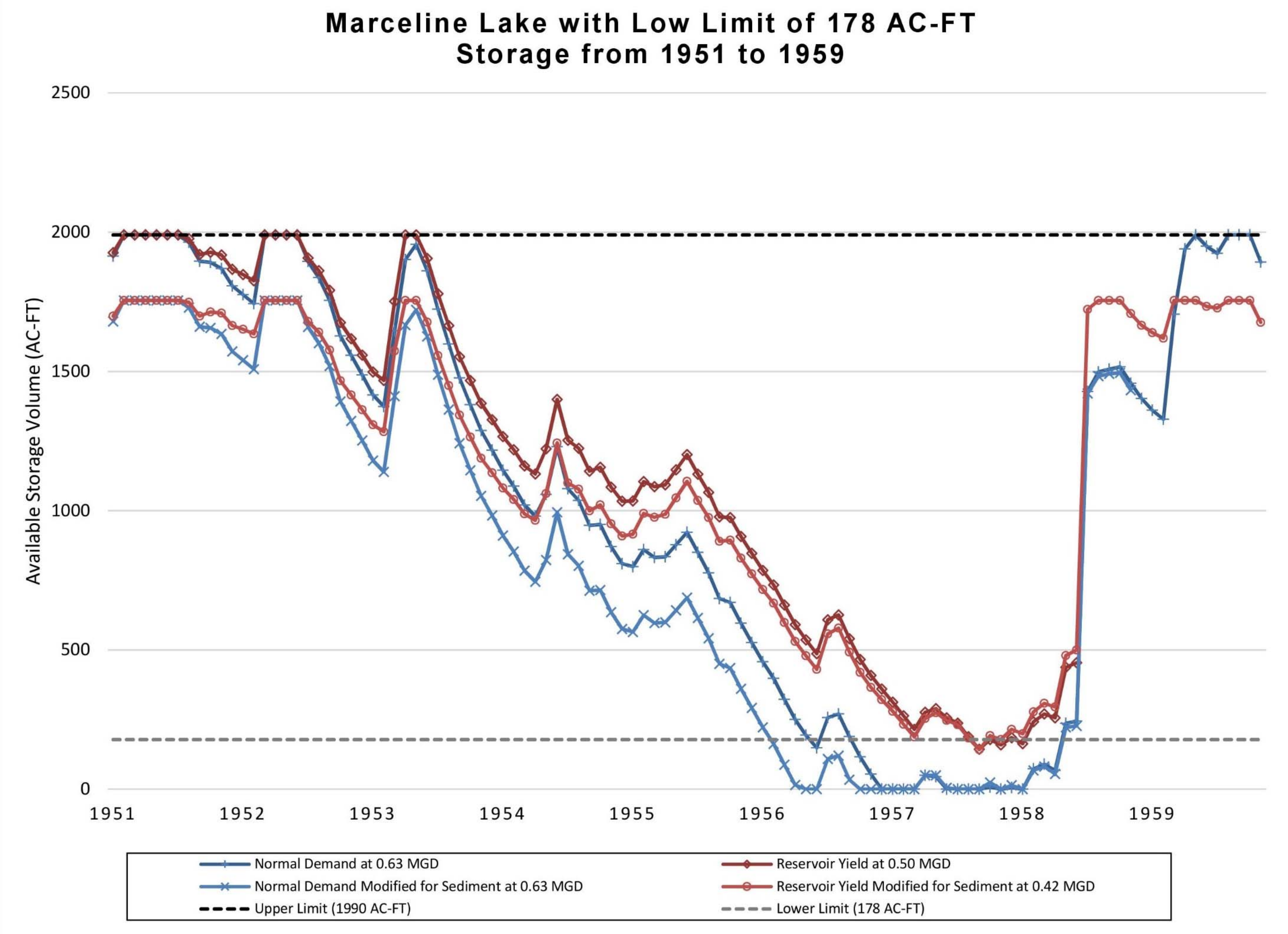
* Computed Statistics at Streamgages, and Methods for Estimated Low-Flow Frequency Statistics and Development of Regional Regression Equations for Estimating Low Flow Frequency Statistics at Ungaged Locations in Missouri, (USGS 2013)

| Inactive Sources Within Cluster | | | | | |
|---|---|---|---|---|---|
| System ID# | type | System Name | County | Source | Year of Closure |
| MO2010112 | Surface Water | Bucklin | Linn | Inadequate lake (shallow and heavily silted); struggled with disinfection-by-products; closed plant; now purchase water from Chariton-Linn #3. | 2010 |
| MO2010185 | Groundwater | Laclede | Linn | Failed shallow wells (declining yield, likely due to iron/silt); closed plant; now purchase water from Brookfield | 1980 |
| N/A | Surface Water | Ethel | Macon | Inadequate lake (shallow and heavily silted); closed inadequate treatment plant; adsorbed by Chariton-Linn #3 | 1990 |
| N/A | Surface Water | New Cambria | Macon | Inadequate lake (shallow and heavily silted); closed inadequate treatment plant; adsorbed by Chariton-Linn #3 | 1990 |
| N/A | Groundwater | Sumner | Chariton | Failed shallow wells with declining yield; closed plant; adsorbed by Chariton-Linn #3 | 2008 |
| MO2010514 | Groundwater | Mendon | Chariton | Failed shallow wells (declining yield, high in iron); closed plant; now purchase water from Chariton-Linn #3 | 2004 |
| N/A | Groundwater | Rothville | Chariton | Failed shallow wells (declining yield, high in iron); closed plant; adsorbed by Chariton-Linn #3 | 1990 |
| N/A | Surface Water | Lake Nehai Tonkayea | Chariton | Inadequate treatment plant; difficulty maintaining qualified operator; closed plant; adsorbed by Chariton-Linn #3 | 1990 |

| | | **Cluster Current Demand** | | **Raw Water Yield: Without Pumping, With Sediment Loading** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cluster** | **Lake/ Reservoir** | **Normal Treated (MGD)** | **Normal Raw (MGD)** | **Source Yield Capacity (MGD)** | **Cluster Yield Capacity (MGD)** | **Excess Capacity (Cluster Yield-Cluster Normal Raw Demand) MGD** | **Lake Purpose (S=water supply, R=recreation, C=flood control) in order of importance** | **Year Dam Built** | **Surface Area (acre)** | **Total Volume (ac.-ft.)** | **Water Supply Volume (ac.-ft.)** |
| SW-2 | Brookfield Lake | 1.014 | 1.115 | 0.180 | 0.600 | -0.515 | S, R | 1959 | 107.9 | 2070.3 | 1948.18 |
| SW-2 | Brookfield Reservoir | | | n/a | | | S | 1952 | 63.4 | n/a | n/a |
| SW-2 | Marceline Lake | | | n/a | | | S | 1928 | 61.2 | n/a | n/a |
| SW-2 | Marceline Lake (New) | | | 0.420 | | | S, R | 1980 | 172.8 | 1990 | 1812 |



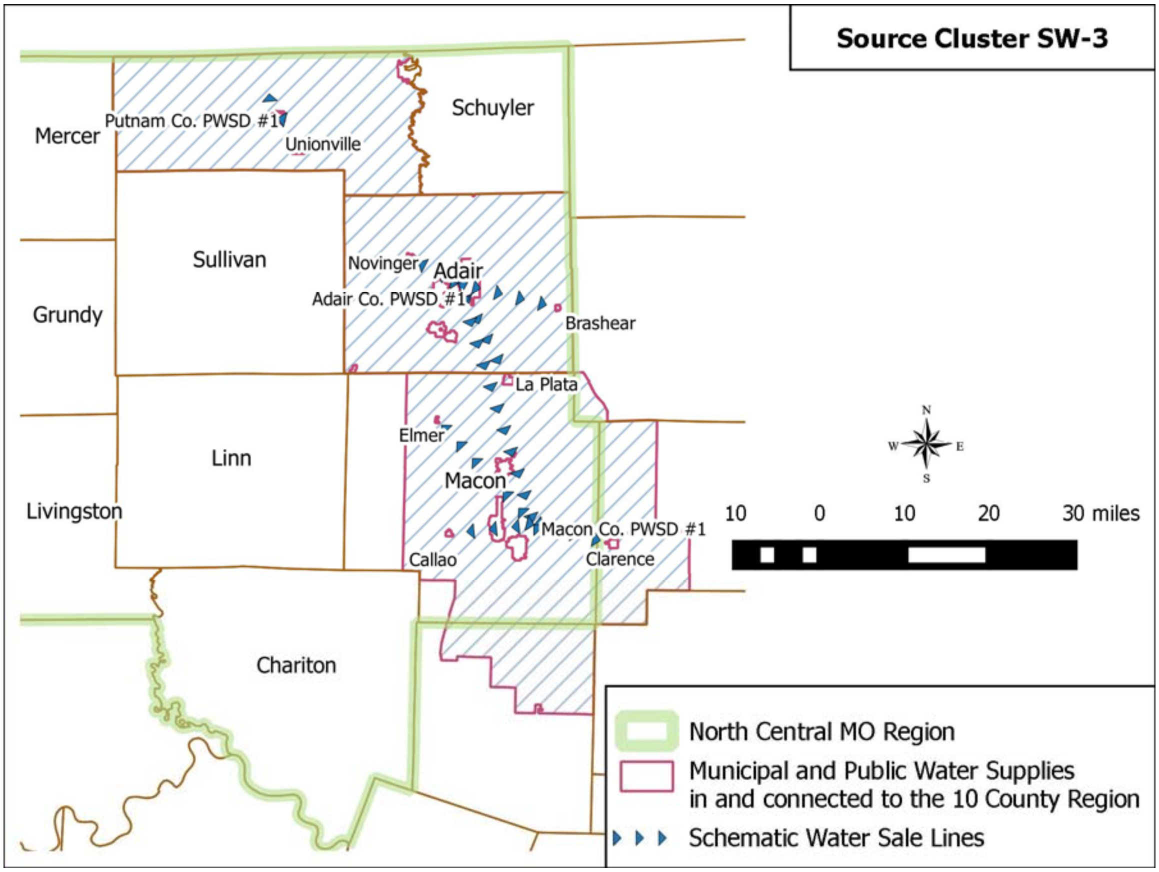

*RESOP Graph 1Brookfield Lake*




*RESOP Graph 2 Marceline Lake*

# Cluster SW-3

**Source Inadequate**



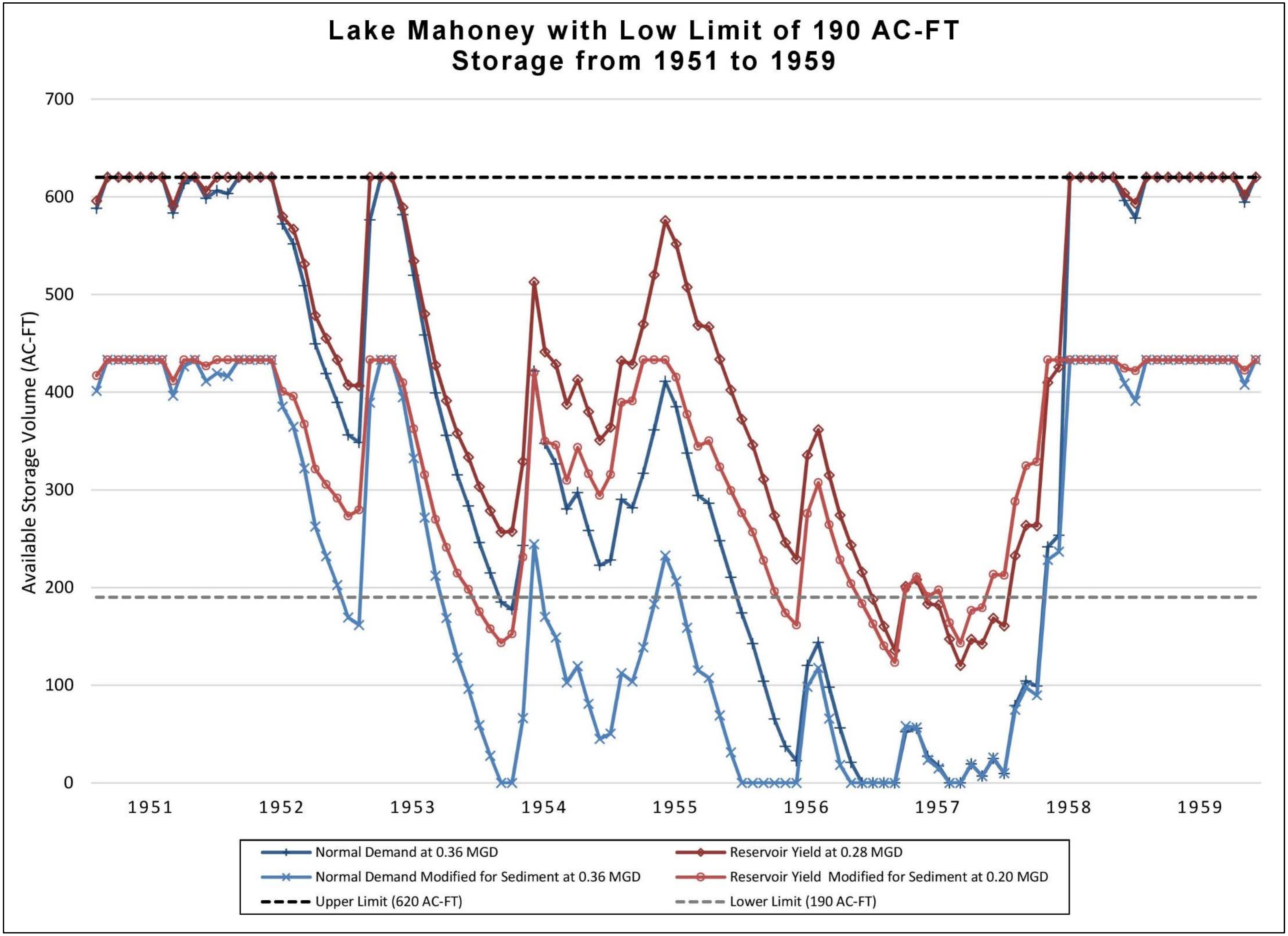

There is currently one source for Cluster SW-3, operated by the City of Unionville, Missouri. Lake Mahoney, which is a 187-acre water supply reservoir, sits at the headwaters to Lake Thunderhead. Lake Thunderhead is a private recreation lake that covers 1,140 acres. The City owned, Lake Mahoney, was originally used for water supply but due to its inadequate size, silting, and high organic content, the City draws water from Thunderhead. It is understood that the agreement between the Lake Thunderhead Homeowners Association and the City of Unionville is not recorded in writing. For this reason Lake Thunderhead is not considered a viable long-term source of water and will not be included in the evaluation.

The service area for water from Unionville is predominately Putnam County. The Source Cluster SW-3 map above depicts a large region that is supplied by the City of Unionville. Examination of the Average Daily Production and Demand table on the next page revels, less than 1 percent of the water to Adair County PWSD #1 is provided by Unionville through Putnam County PWSD #1. None of the water from Unionville enters the Macon County PWSD #1 system. Because of the limited distribution piping detail these relationships are best evaluated in conjunction with the Production and Demand table data. Adair County PWSD #1 purchases less than 5,000 gallons a day to provide for a few customers near Putnam County PWSD #1 service area. Since 1985, records indicate no closed sources within this cluster. Portions of the water treatment facility were upgraded in 2015 to reduce disinfection-by-products and to improve operability of the facility. The decay and siltation of Lake Mahoney will continue to degrade water quality and will remain the limiting factor in the sustainability of dependable water for the communities it serves.

RESOP analysis shows that Lake Mahoney reservoir yield capacity during the DOR is 0.200 MGD. The treated water normal demand for the cluster is 0.330 MGD (or .363 MGD raw water), which results in a net negative raw water daily capacity of 0.163 MGD. Due to this net negative capacity, Cluster SW-3 by analysis has an inadequate source.

| 2015-2016 Cluster Average Daily Production and Demand (Treated Water Quantities) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Source Cluster | Tier System | | | | | MGD Produced | % purchase from supplier | Total MGD Consumed |
| | 1st | 2nd | 3rd | 4th | 5th | | | |
| SW-3 | Unionville | | | | | 0.33 | | 0.165 |
| | | Putnam County PWSD #1 | | | | | 68% | 0.207 |
| | | | Lake Thunderhead HOA | | | | 100% | 0.021 |
| | | | Adair PWSD #1 | | | | 0.75% | 0.463 |
| | | | | Brashear | | | 100% | 0.014 |
| | | | | LaPlata | | | 100% | 0.079 |
| | | | | Novinger | | | 100% | 0.026 |
| | | | | Macon County PWSD #1 | | | 1% | 0.014 |
| | | | | | Callao | | 100% | 0.024 |
| | | | | | Clarence | | 100% | 0.065 |
| | | | | | Elmer | | 100% | 0.005 |

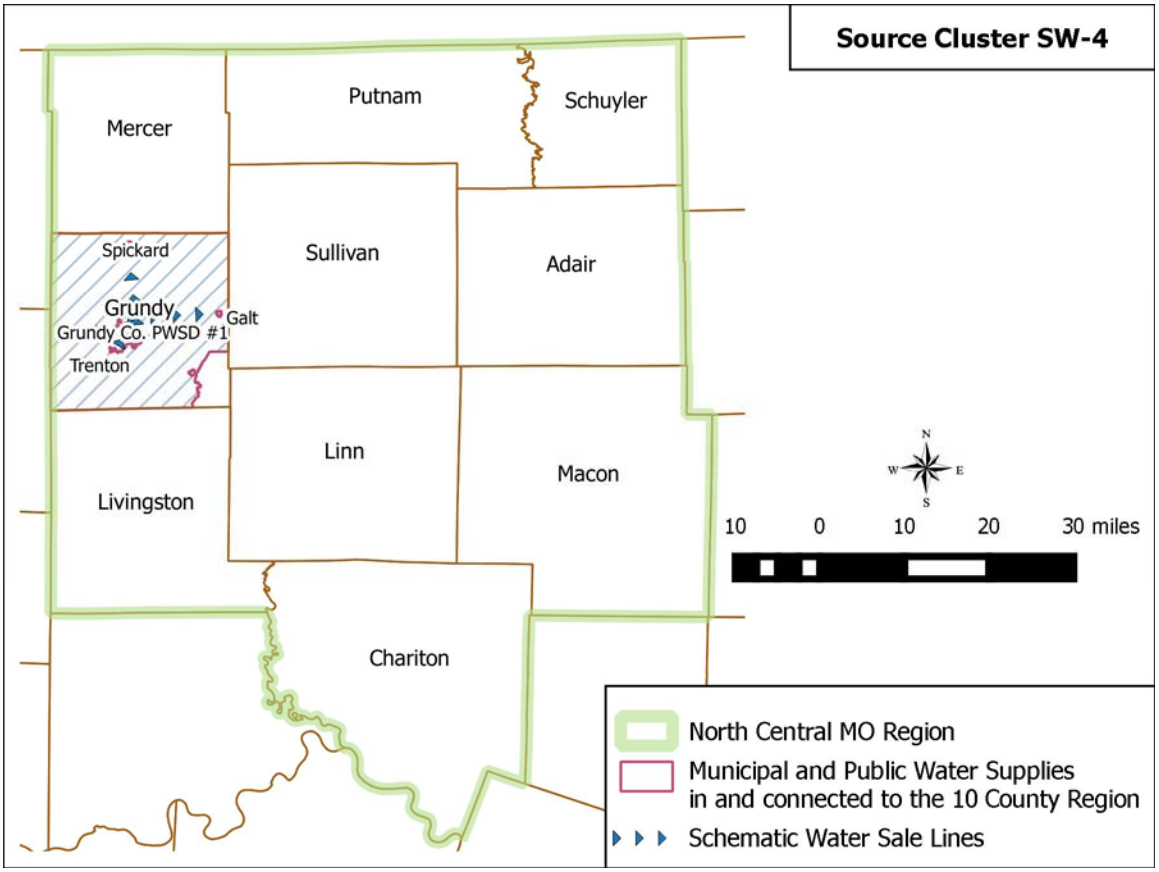
| | | **Cluster Current Demand** | | **Raw Water Yield: Without Pumping, With Sediment Loading** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cluster** | **Lake/ Reservoir** | **Normal Treated (MGD)** | **Normal Raw (MGD)** | **Source Yield Capacity (MGD)** | **Cluster Yield Capacity (MGD)** | **Excess Capacity (Cluster Yield- Cluster Normal Raw Demand) MGD** | **Lake Purpose (S=water supply, R=recreation, C=flood control) in order of importance** | **Year Dam Built** | **Surface Area (acre)** | **Total Volume (ac.-ft.)** | **Water Supply Volume (ac.-ft.)** |
| SW-3 | Unionville Reservoir | 0.33 | 0.363 | 0.200 | 0.200 | -0.163 | S, R | 1941 | 73.5 | 620 | 430 |




*RESOP Graph 1 Lake Mahoney*

# Cluster SW-4

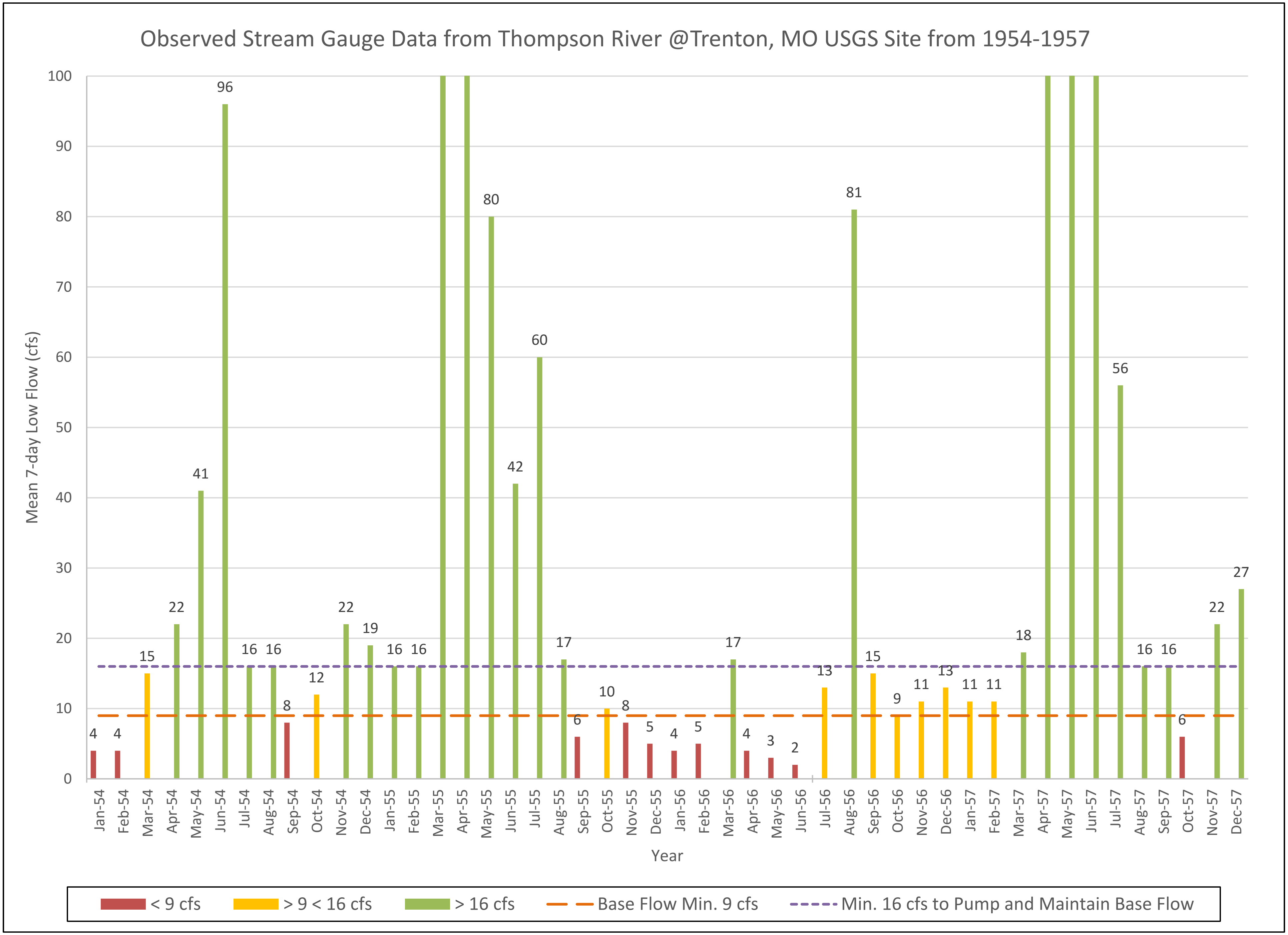
**Source Inadequate**




There is currently one source for Cluster SW-4, which is operated by Trenton Municipal Utilities of Trenton, Missouri. Water is pulled from the Thompson River via intake, and pumped to two raw water storage reservoirs. When these reservoirs are full, and have minimum sediment they have a total capacity of 164.5 million gallons. The North Reservoir has a maximum capacity of 140 million gallons and the South Reservoir has a maximum capacity of 24.5 million gallons. From these reservoirs Trenton Municipal Utilities produces approximately 1.72 MGD of treated water which serve the city of Trenton and customers of Grundy County PWSD #1. The water treatment plant is designed to produce 3,000 gpm and is understood to be in serviceable condition.

Since 1985 two communities in this cluster have abandoned water treatment activities and now purchase water from Grundy PWSD #1. The Inactive Systems table on the next page identifies those communities and briefly describes the reasoning for closure.

To produce 1.720 MGD of treated water approximately 1.892 MGD of raw water is need, due to treatment losses. Summing the entire volume of the reservoirs and dividing it by 1.892 MGD approximates 86.9 days of supply. The Minimum Design Standards for Missouri Community Water Systems recommends a 120 day surplus reserve storage after predicted depletion levels during a prolonged severe drought should be considered (MDNR 2013). Trenton does not have 120 days of surplus reserve storage under normal conditions. The reservoirs are bermed (meaning limited rain recharge) and depend on flow from the Thompson River and therefore also look at 3.1.1.f, which suggests a 7 Q 10 evaluation of the source. The Observed Stream Gauge Data from the Thompson River at Trenton, Missouri USGS Site from 1954-1957 shows prolonged periods of low flow. It is important to note that the minimum flow must be above 9 cfs for pumping to occur from the river as noted in the Missouri Water Supply Study (MDNR 2013). The intake pumps rated at 3,125 gpm (6.96 cfs), but the flow must be above 16 cfs to pump at full capacity. At 3,125 gpm the current demand of 1.892 gallons can be pumped in approximately 10 hours. Given that Trenton has less than 120 days of storage and documents periods of insufficient flow in the Thompson River to pump water, Cluster SW-4 by analysis to have an inadequate source.




*Graph 1 Observed Stream Data from Thompson River at Trenton, MO*

| 2015-2016 Cluster Average Daily Production and Demand (Treated Water Quantities) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Source Cluster | Tier System | | | | | MGD Produced | % purchase from supplier | Total MGD Consumed |
| | 1st | 2nd | 3rd | 4th | 5th | | | |
| SW-4 | Trenton Municipal Utilities | | | | | 1.718 | | 1.477 |
| | | Grundy County PWSD #1 | | | | | 100% | 0.241 |
| | | | Galt | | | | 100% | 0.021 |
| | | | Spickard | | | | 100% | 0.028 |

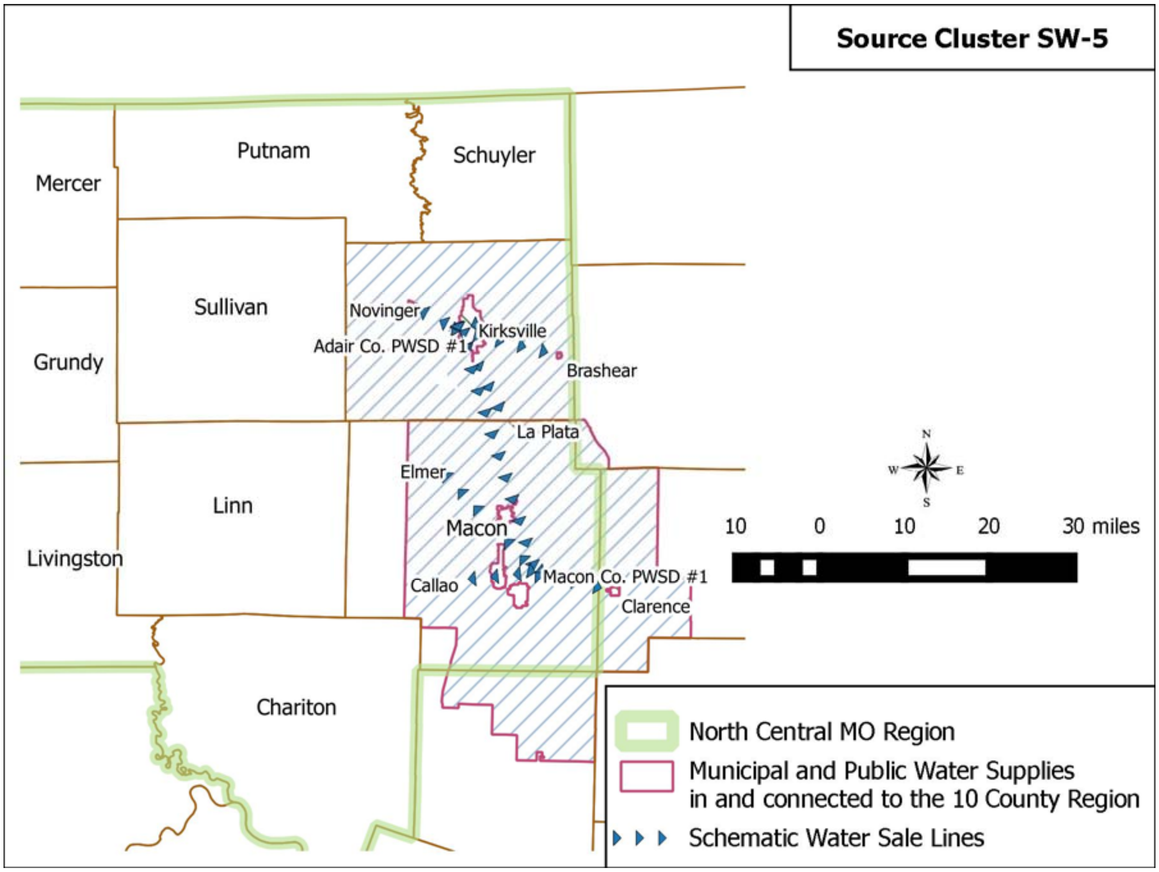
| Inactive Sources Within Cluster | | | | | |
|---|---|---|---|---|---|
| System ID# | type | System Name | County | Source | Year of Closure |
| MO2010300 | Groundwater | Galt | Grundy | Failed shallow wells (declining yield, high in iron); closed plant; now purchase water from Grundy PWSD #1 | 1990 |
| MO2010753 | Groundwater | Spickard | Grundy | Failed shallow wells (declining yield); closed plant; now purchase water from Linn-Livingston #3 | 1985 |

| Results from USGS Low Flow Equations* for Stream Intakes in 10-county region | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Inputs | | | Outputs | | |
| Cluster | Supplier | PWS System ID | Intake | Drainage Area ($Mi^2$) | Length (mi) | Stream Variable | 7Q10 (MGD) | 30Q10 (MGD) | 60Q10 (MGD) |
| SW-4 | Trenton | 2010796 | Thompson River at Intake | 1722.3 | 155.46 | 0.714 | 6.268 | 8.673 | 12.949 |

* Computed Statistics at Streamgages, and Methods for Estimated Low-Flow Frequency Statistics and Development of Regional Regression Equations for Estimating Low Flow Frequency Statistics at Ungaged Locations in Missouri, USGS 2013

# Cluster SW-5

**Source Inadequate**




There is currently two sources for Cluster SW-5, Forest Lake and Hazel Creek Lake, which are operated by the City of Kirksville, Missouri. Water is pulled, from the Forest Lake or Hazel Creek Lake, via intakes and pumped to the treatment facility to a 7-million gallon, earthen, pretreatment settling basin. The 585-acre Forest Lake is owned by the State of Missouri and is operated as a Thousand Hills State Park. The 501.7 acre Hazel Creek Lake is owned and operated by the City of Kirksville. Both lakes' primary purposes are recreation with a secondary purpose of water supply. Dependent upon routine water quality tests, operators pump water from either lake to the pretreatment basin. This basin is located at the water treatment plant is sized to provide approximately two days of raw water storage.

Since 1985, two communities in this cluster have abandoned water treatment activities and purchase water from secondary system of Kirksville, Adair County PWSD #1 and Macon County PWSD #1. The Inactive Systems table on the next page identifies those communities and briefly describes the reasoning for closure.

To calculate the lower limits for RESOP modeling the first step was to evaluate the bathymetry provided by USGS. Based upon this data which provided reservoir elevations and corresponding volumes in acre-feet, the known elevation of inlets was noted and a minimum depth over the inlet was selected. In this case the inlet elevations site higher than the bottom one-third elevation change from the total elevation given by the bottom of reservoir to spillway elevation. The unusable volume according to this calculation was set at 2,120 acre-feet for Forest Lake and 1,450 acre-feet for Hazel Creek Lake

For RESOP modeling and evaluation purposes only one source can be evaluated at a time so a proportional demand approach was used in this evaluation similar to the approach in the Missouri Water Supply Study (MDNR 2013). The proportions were calculated by dividing each sources daily reservoir yield capacity by the daily cluster yield capacity. Running RESOP analysis using the lower limits described previous, the individual reservoir yields for Forest and Hazel Creek lakes were 2.69 MGD and 1.48 MGD respectively. To calculate the proportional demand the individual reservoir yields were divided by the total combined yield, 4.43 MGD, resulting in Forest

Lake yields 66.7% (2.95 MGD of the total 4.43 MGD) and Hazel Creek Lake yields the remaining 33.3 percent (1.265 MGD of the total 4.43 MGD) of the total combined yield. In addition, the Design Standards of Missouri Community Water Systems a suggested minimum of 120 days of surplus storage beyond predicted depletion levels during a prolonged and severe drought for public confidence. The 2015 treated water demand, found in the Average Daily Production and Demand table, was 3.432 MGD. This correlates to an approximate total average daily raw water demand of 3.775 MGD or proportionally, 2.510 MGD (3.775 multiplied by 66.6 percent) from Forest Lake and 1.265 MGD (3.775 multiplied by 33.3 percent) from Hazel Creek Lake.

To comply with Missouri minimum design standards these proportional demands must be multiplied by 120 days, corresponding to 301.2 MG for Forest Lake and 151.2 MG for Hazel Creek. Converting the public confidence volumes to acre-feet will allow the RESOP analysis to be reevaluated for a new lower limit that includes public confidence. To convert gallons to acre feet the following calculation was used:

$$gallons \times \frac{1}{7.48}\left(\frac{ft^3}{gallon}\right) \times \frac{1}{43{,}560}\left(\frac{acre}{ft^2}\right) = acre\ ft.$$

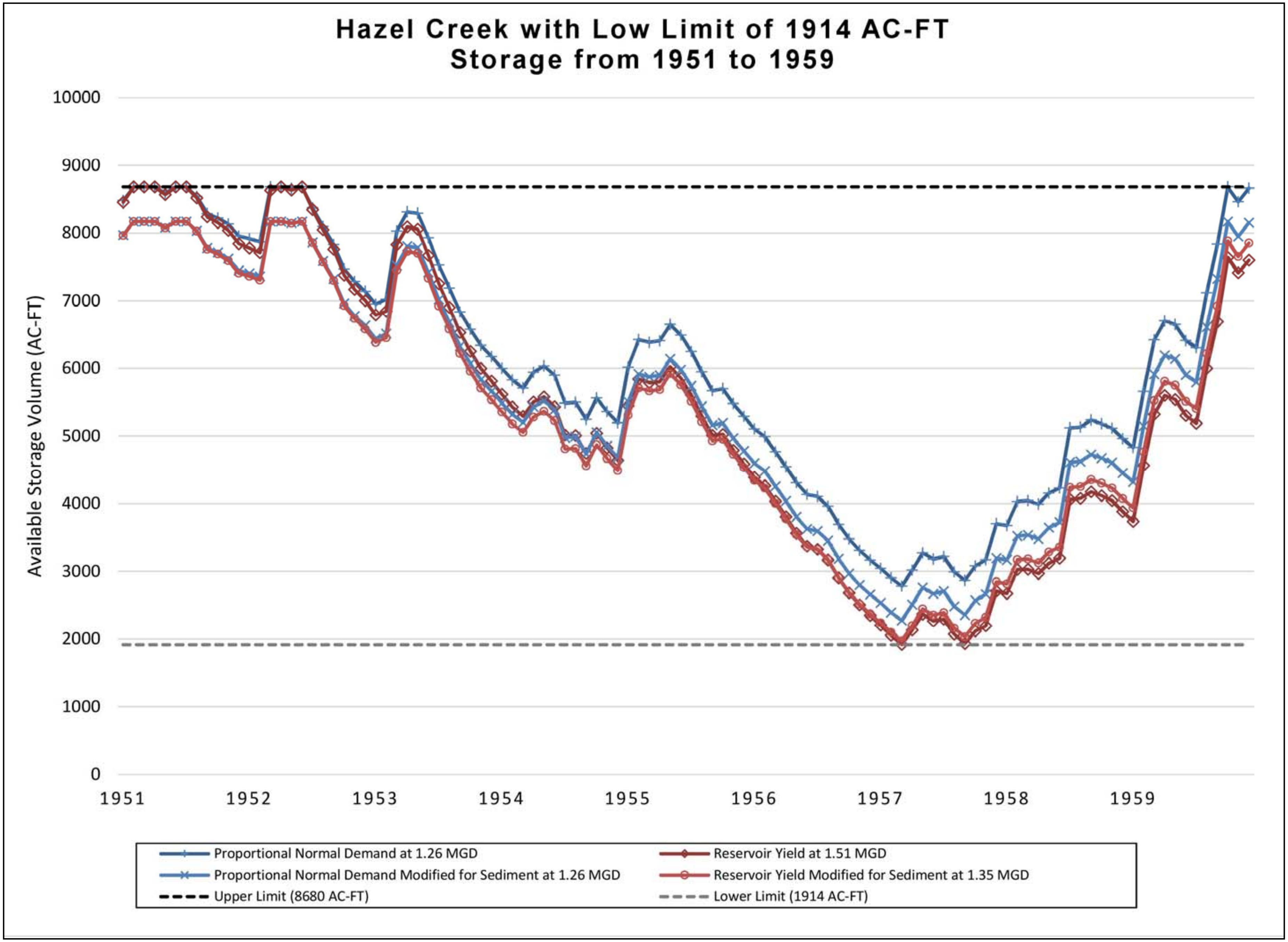
The consumer confidence for Forest Lake equals 924 acre-ft. and 464 acre-ft. for Hazel Creek Lake, which corresponding to new lower limits of 3044 acre-ft. and 1914 acre-ft., respectively. Given the new lower limit the reservoir yields were recalculated in RESOP to be 3,044 acre-ft. (Forest Lake) and 1,914 acre-ft. (Hazel Creek Lake). The new reservoir yield for the two supplies, inclusive of public confidence, are 2.69 MGD (Forest Lake) and 1.35 MGD (Hazel Creek Lake), for a total cluster yield capacity of 4.04 MGD. To compare the current normal demand treatment losses must be accounted for, this is done by adding a 10 percent factor of the treated demand from 2015. The average daily treated water quantity is shown in the Production and Demand table below, and totals 3.432 MGD. Adding 10% the raw water used on an average day in 2015 was 3.775 MGD. Subtracting this demand from the combined reservoir yield equals 0.265 MGD of excess capacity.

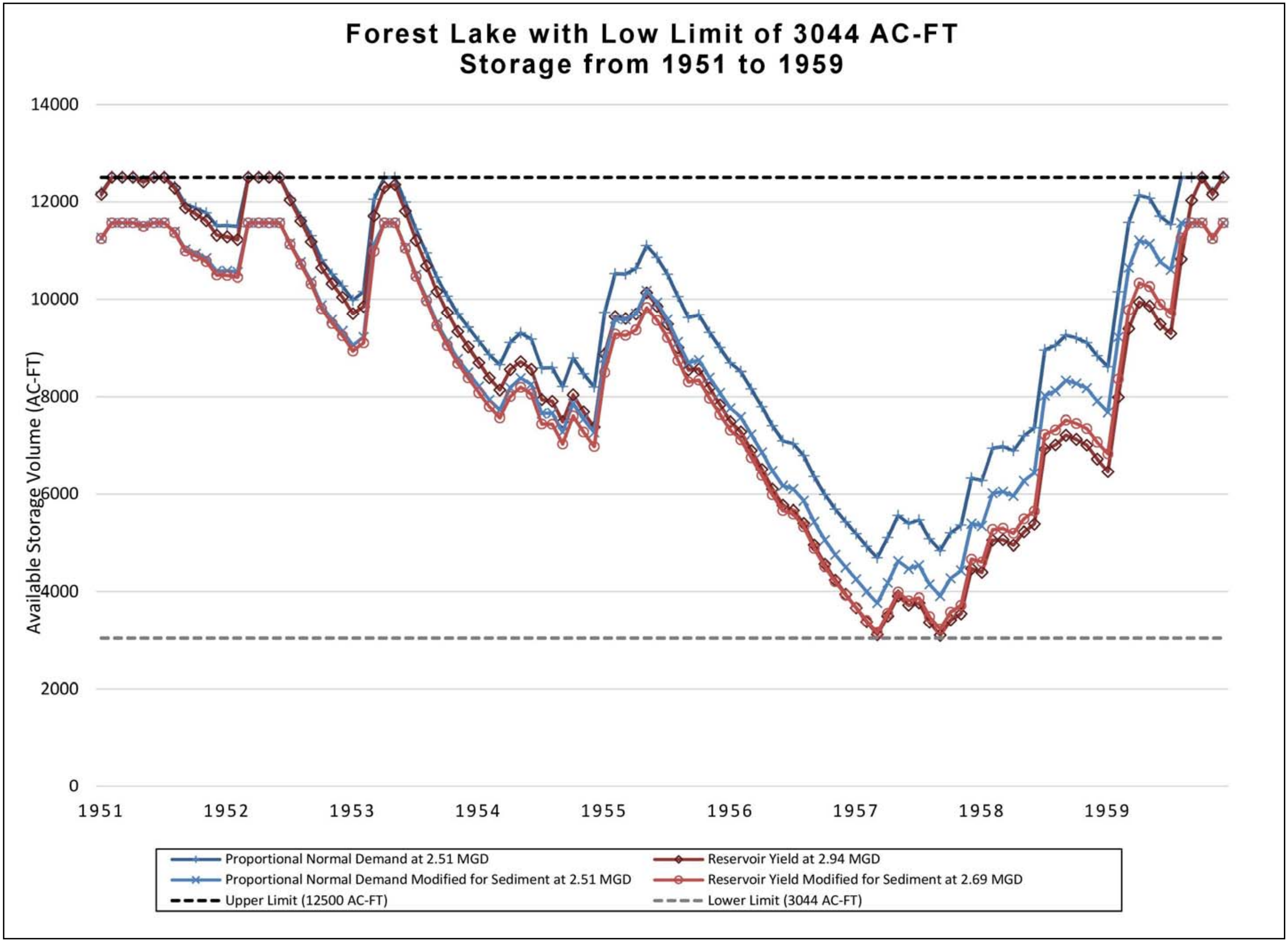
In December 2015, Kraft-Heinz Company announced a $250 million expansion of the Kraft Foods/ Oscar Mayer plant located in Kirksville, Missouri (Hunsicker 2016). City staff it was indicated in correspondence with Allstate that the expansion would increase the daily demand by approximately 0.350 MGD of treated water to the facility. This increase in demand is not reflected in the 2015 demand data but is important in this evaluation. Adding the impending raw water demand of 0.385 MGD or (0.350 MGD x 1.1=raw demand) to the 3.775 MGD of current demand totals 4.16 MGD, which is 0.125 MGD beyond the RESOP reservoir yield. Therefore, the sources of Cluster SW-5 are inadequate for the current and impending demand under DOR conditions.

| 2015-2016 Cluster Average Daily Production and Demand (Treated Water Quantities) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Source Cluster | Tier System | | | | | MGD Produced | % purchase from supplier | Total MGD Consumed |
| | 1st | 2nd | 3rd | 4th | 5th | | | |
| SW-5 | Kirksville | | | | | 3.432 | | 2.970 |
| | | Adair PWSD #1 | | | | | 99% | 0.462 |
| | | | Brashear | | | | 100% | 0.014 |
| | | | LaPlata | | | | 100% | 0.079 |
| | | | Novinger | | | | 100% | 0.026 |
| | | | Macon County PWSD #1 | | | | 1% | 0.139 |
| | | | | Callao | | | 100% | 0.024 |
| | | | | Clarence | | | 100% | 0.065 |
| | | | | Elmer | | | 100% | 0.005 |

| Inactive Sources Within Cluster | | | | | |
|---|---|---|---|---|---|
| System ID# | type | System Name | County | Source | Year of Closure |
| MO2010587 | Groundwater | Novinger | Adair | Failed shallow wells (declining yield); closed plant; now purchase water from Adair PWSD #1 | 2005 |
| MO2010451 | Surface Water | La Plata | Macon | Inadequate lakes; closed inadequate treatment plant; now purchase water from Adair PWSD #1 | 2000 |

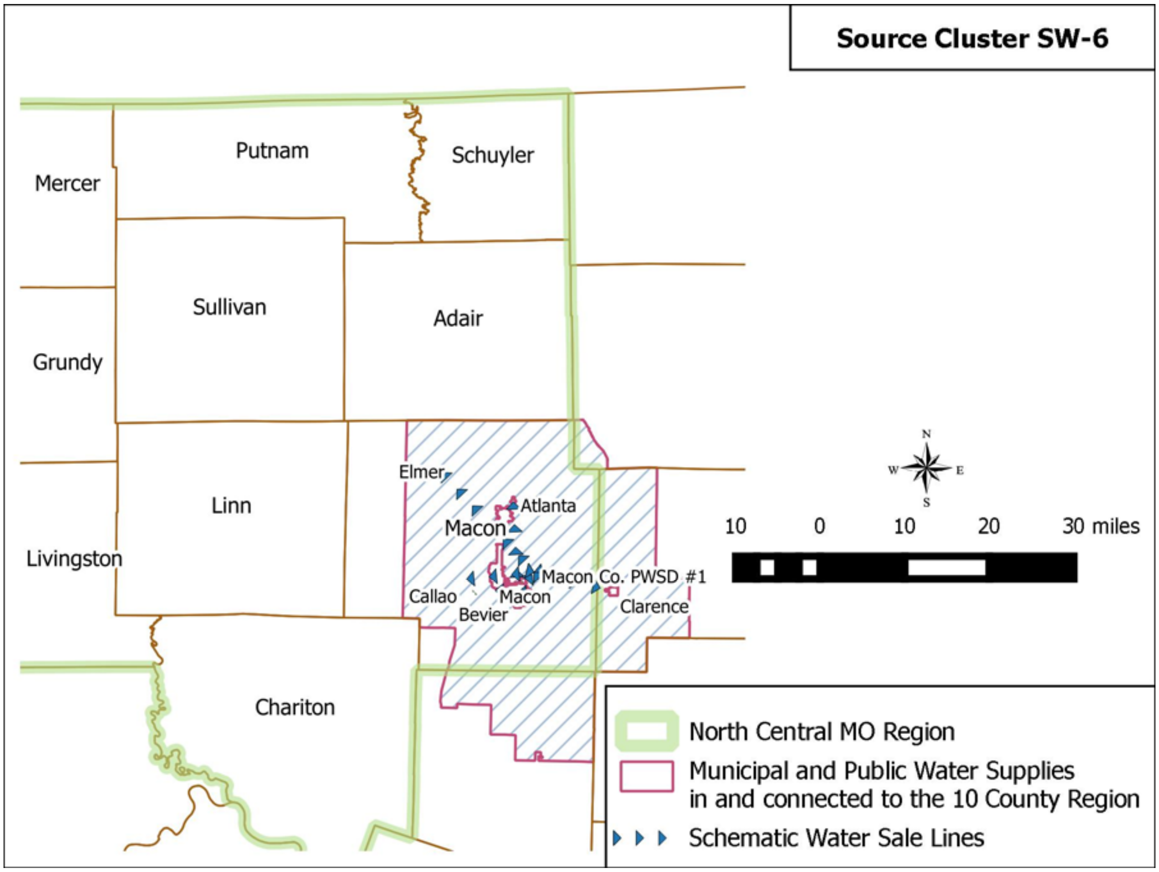
| Surface Water Supply(s) Within Cluster | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Cluster Current Demand | | Raw Water Yield: Without Pumping, With Sediment Loading | | | | | | | | |
| Cluster | Lake/ Reservoir | Normal Treated (MGD) | Normal Raw (MGD) | Source Yield Capacity (MGD) | Cluster Yield Capacity (MGD) | Excess Capacity (Cluster Yield-Cluster Normal Raw Demand) MGD | Lake Purpose (S=water supply, R=recreation, C=flood control) in order of importance | Year Dam Built | Surface Area (acre) | Total Volume (ac.-ft.) | Water Supply Volume (ac.-ft.) |
| SW-5 | Forest Lake* | 2.51 | 2.76 | 2.691 | 4.040 | -0.120 | R, S | 1951 | 585.2 | 12500 | 10,380 |
| SW-5 | Hazel Creek Lake* | 1.27 | 1.40 | 1.349 | | | R, S | 1982 | 501.7 | 8680 | 7,230 |


Hazel Creek with Low Limit of 1914 AC-FT
Storage from 1951 to 1959
Available Storage Volume (AC-FT)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Proportional Normal Demand at 1.26 MGD
Proportional Normal Demand Modified for Sediment at 1.26 MGD
Upper Limit (8680 AC-FT)
Reservoir Yield at 1.51 MGD
Reservoir Yield Modified for Sediment at 1.35 MGD
Lower Limit (1914 AC-FT)


Forest Lake with Low Limit of 3044 AC-FT
Storage from 1951 to 1959
Available Storage Volume (AC-FT)
14000
12000
10000
8000
6000
4000
2000
0
1951
1952
1953
1954
1955
1956
1957
1958
1959
Proportional Normal Demand at 2.51 MGD
Proportional Normal Demand Modified for Sediment at 2.51 MGD
Upper Limit (12500 AC-FT)
Reservoir Yield at 2.94 MGD
Reservoir Yield Modified for Sediment at 2.69 MGD
Lower Limit (3044 AC-FT)

# Cluster SW-6

**Source Adequate**




There is currently one sources for Cluster SW-6, Long Branch Lake, which is operated by the U.S. Army Corps of Engineers. The primary purpose of Long Branch Lake is flood control, with secondary purposes of water supply and recreation. Macon Municipal Utilities (MMU) has purchased rights to 4,400 acre-feet of water supply storage within the reservoir. According to MMU this is approximately 36 percent more capacity then the current demand. The current treated water demand for Cluster SW-6 is 2.50 MGD, as noted in the Production and Demand table on the next page.

Since 1985, three communities in this cluster have abandoned water treatment activities and now purchase water from the secondary system of Macon County PWSD #1. The Inactive Systems table on the next page identifies those communities and briefly describes the reasoning for closure.

A RESOP model was not developed for this source given known characteristics of the lake. Long Branch Lake has a total of 36,800 acre-feet at normal pool. Of that 24,400 acre feet are allocate for water supply storage. The rights to the remaining 20,000 acre-feet are held by the U.S. Army Corps of Engineers. For purposes of this evaluation only the 4,400 acre-feet will be considered as usable capacity.

The Missouri Water Supply Study did not evaluate Long Branch specifically, but it did mention it as a potential source of water for Sugar Creek Lake in Moberly, Missouri, as seen in the following (MDNR 2013)

> "When flow in East Fork Chariton River is not sufficient for diversion, the city would be able to purchase water from Long Branch Reservoir at Macon. Water can be released from Long Branch Reservoir and allowed to flow downstream to the pump intake near Moberly. Moberly has been reporting East Fork Chariton River as a supply source beginning in 1992.

The volume of water that would be required by pumping from East Fork Chariton River:

1954…………………………………….. 317.3 million gallons
1955…………………………………….. 421.3 million gallons
1956…………………………………….. 421.3 million gallons
1957…………………………………….. 421.3 million gallons
1958…………………………………….. 208.5 million gallons"

If this emergency release were needed, it is assumed it would come from the 20,000 acre-feet of water supply at a volume of nearly three times what is needed for pumping due to losses and capture rate. More information is needed to access this potential. This uncertainty is a reason for not including the currently unused water supply reserve in the cluster evaluation.

Cluster SW-6 has a total excess yield capacity of 0.650 MGD and, therefore, the source is adequate for the current demand under DOR conditions.

| 2015-2016 Cluster Average Daily Production and Demand (Treated Water Quantities) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Source Cluster | Tier System | | | | | MGD Produced | % purchase from supplier | Total MGD Consumed |
| | 1st | 2nd | 3rd | 4th | 5th | | | |
| SW-6 | Macon | | | | | 2.5 | | |
| | | Atlanta | | | | | 100% | 0.020 |
| | | Bevier | | | | | 100% | 0.056 |
| | | Macon County PWSD #1 | | | | | 89% | 1.232 |
| | | | Callao | | | | 100% | 0.024 |
| | | | Clarence | | | | 100% | 0.065 |
| | | | Elmer | | | | 100% | 0.005 |

| Inactive Sources Within Cluster | | | | | |
|---|---|---|---|---|---|
| System ID# | type | System Name | County | Source | Year of Closure |
| MO2010247 | Groundwater | Elmer | Macon | Failed shallow wells (declining yield, likely due to iron/silt); closed plant; now purchase water from Macon PWSD #1 | 1985 |
| MO2010035 | Surface Water | Atlanta | Macon | Inadequate lake; struggled with disinfection-by-products; closed plant; now purchase water from Macon | 1985 |
| MO2010125 | Groundwater | Callao | Macon | Failed shallow wells (declining yield); closed plant; now purchase water from Macon PWSD #1 | 1990 |

| | Cluster Current Demand | | Raw Water Yield: Without Pumping, With Sediment Loading | | Excess Capacity (Cluster Yield-Cluster Normal Raw Demand) MGD | Lake Purpose (S=water supply, R=recreation, C=flood control) in order of importance | Year Dam Built | Surface Area (acre) | Total Volume (ac.-ft.) | Water Supply Volume (ac.-ft.) |
|---|---|---|---|---|---|---|---|---|---|---|
| Lake/ Reservoir | Normal Treated (MGD) | Normal Raw (MGD) | Source Yield Capacity (MGD) | Cluster Yield Capacity (MGD) | | | | | | |
| Long Branch Lake | 2.5 | 2.75 | 3.400 | 3.400 | 0.650 | C, S, R | 1979 | 2682.8 | 8,680 | 7,230 |

## Summary of Surface Water Cluster Evaluations

The six surface water clusters were evaluated under the assumptions of 50 years of sediment loading into reservoirs, DOR recharge rates, full reservoir capacity at beginning of time sequence, and that volume associated with the lower one-thrid reservoir elevation is unusable. Additionally, quantity standards in Chapter 3 of the Minimum Design Standards for Missouri Community Water Systems (MDNR 2013) were used to evaluate clusters reliability. The analysis ignores the predicted increases in drought length and severity caused by climate change and focuses on the ability of a source to meet current normal demand.

Totaling the 2015 normal demand of surface water clusters with inadequate sources during a drought, equal in magnitude to the DOR, equals 8.416 MGD. Note this total includes the impending demand (0.35 MGD) for Kirksville as noted in the Cluster SW-5 report. A complete listing of the Surface Water Cluster Production & Demand Table from 2015 is located in Appendix J. The impact of inadequate cluster water sources could result in the complete depletion of water in 5 of 6 the existing clusters. Figure 7, below, shows clusters with inadequate sources in red and Cluster SW-6, the only adequate source, in green. Each segment of the pie corresponds to a surface water producer within the 10 county region. The size of each segment is proportionate to the average daily demand produced by each system, shown as the value at the end of the labels in MGD.

A total of 11.401 MGD of treated surface water was produced in 2015 according to data provided by systems. The current regional trend, as shown by Baker 2015, is that systems have been abandoning treatment facilities and sources as they degrade beyond the point of serviceability or if they become too expensive to maintain.

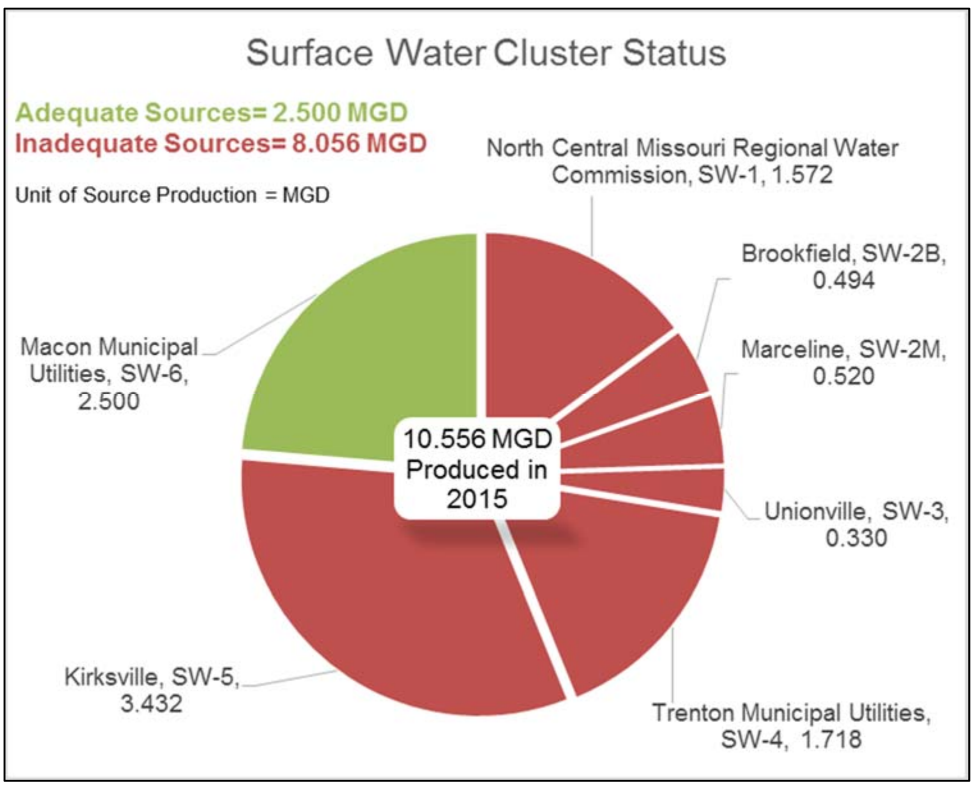


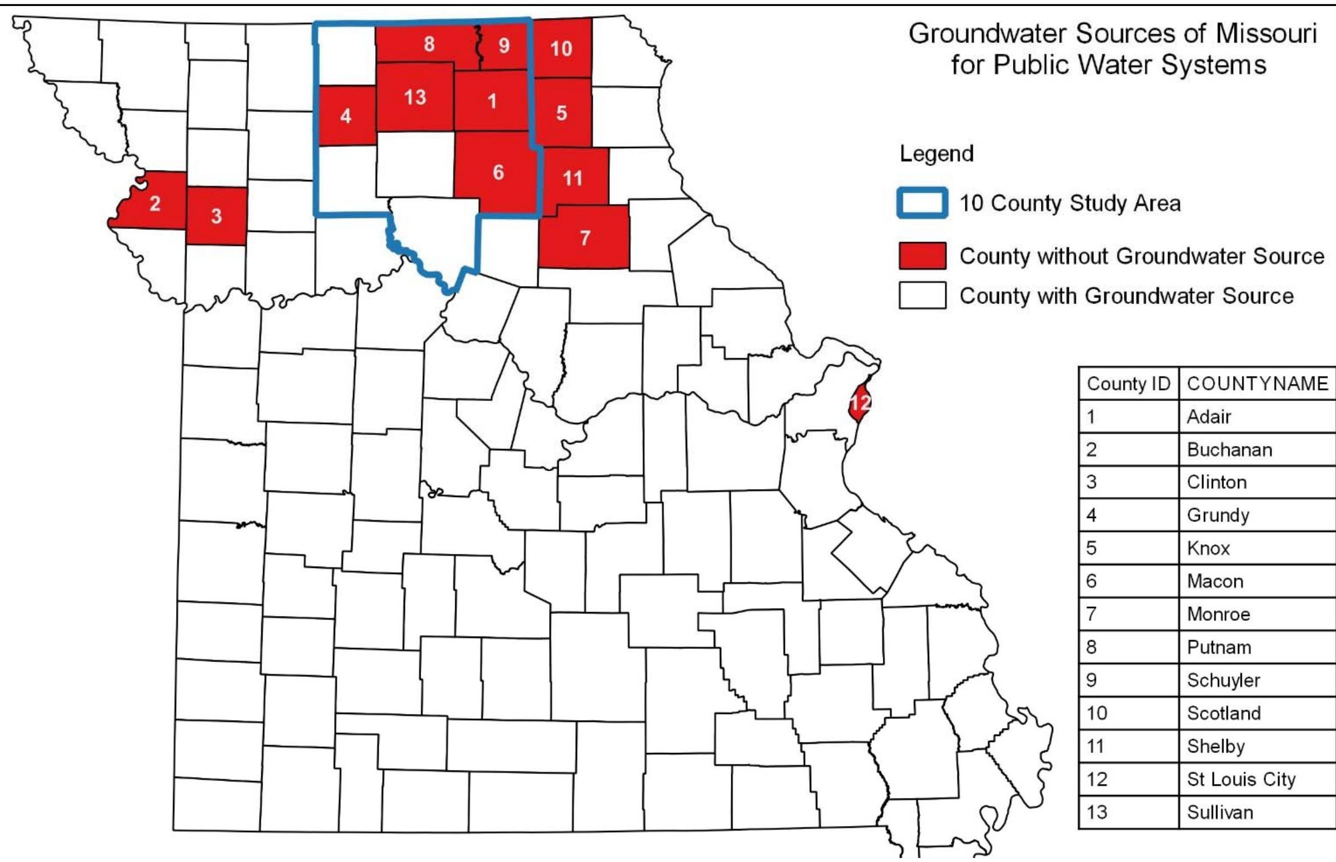

*Figure 7: Regional Surface Water Cluster Summary.*

## Overview of Groundwater Cluster Evaluations

The analysis of groundwater sources, is based on regional and local geology, historical data, and engineering design criteria. Specific well analysis cannot definitively predict how long or at what rate a well will yield water or what water quality. Therefore, this evaluation will summarize historic geologic findings from both the Missouri Geologic Survey and individual systems; review the history of wells (abandoned, active, inactive, plugged and boring results) within the region; and explain assumptions based on local engineering experience. A determination of a clusters adequacy to provide long-term, reliable water will be based on the evaluation criteria and will be included in the Groundwater Summary. Data used in this evaluation is based on individual system interviews, reports by USGS, MDNR, and individual well drillers. The Missouri Spatial Data Information Service (MSDIS) and Missouri Geologic Survey provided the GIS metadata.

The evaluation of groundwater sources for individual clusters is complicated by a host of variables that range from water quantity to quality. These factors are illuminated in the excerpt from Miller later in this section. This unpredictability goes beyond daily variation in water quality and/or hydraulic head, but can change without notice and render a well permanently useless for supply.  This uncertainty and known required maintenance of wells serves as the basis for MDNR recommendation to have redundant sources for groundwater supplies for communities as outlined in Chapter 3 Section 2.1.2 of the Minimum Design Standards for Missouri Community Water Systems.

As of 2016, MDNR data confirms that four of the 10 counties in the study region of north-central Missouri have public drinking water facilities that use a groundwater source for raw water (MDNR 2016). These include: Chariton, Linn, Livingston, and Mercer counties. State wide, 13 counties in Missouri which do not have a single groundwater source system, see Figure 8 below. Six of those 13 are within the 10-county study area, and all 13 are located north of the Missouri River. Additionally, four of the 13 counties outside of the study area are directly adjacent to the study area. Buchanan County, which is outside of the study area, does not have a public water




| County ID | COUNTYNAME |
|---|---|
| 1 | Adair |
| 2 | Buchanan |
| 3 | Clinton |
| 4 | Grundy |
| 5 | Knox |
| 6 | Macon |
| 7 | Monroe |
| 8 | Putnam |
| 9 | Schuyler |
| 10 | Scotland |
| 11 | Shelby |
| 12 | St Louis City |
| 13 | Sullivan |

*Figure 8: Groundwater Sources of Missouri for Public Water Systems*

treatment system, and is served by Missouri River alluvium groundwater wells from a supplier in adjacent Andrew County.

The distinct lack of groundwater-type public water systems in the northern part of Missouri, as depicted in Figure 8, is based on the hydrogeology of the region. The following excerpt is from the Groundwater Resources of Missouri, which is Volume III of the Missouri State Water Plan Series. The excerpt summarizes hydrogeology the Northwestern Provence of Missouri, which overlays seven of the western counties in the region of study.

> *"Groundwater resources in much of northwest Missouri are poor. The thick carbonate aquifers that supply large quantities of high-quality water in the Ozarks and east central Missouri are also present at great depth in the northwestern part of the state. In northwest Missouri they yield water so highly mineralized that, for practical purposes, it is unusable. Bedrock formations in the Northwestern Missouri groundwater province older than Pennsylvanian-age yield highly-mineralized water. Usable quantities of groundwater are locally available from Pennsylvanian strata, but yields are typically low and the water quality is marginal. Glacial deposits, depending on thickness and texture, can yield from zero to more than 500 gpm. Except for the Missouri River alluvium, alluvial deposits in northwestern Missouri generally yield small quantities of water. This is because the alluvial sediments of the smaller rivers are finer grained and more poorly-sorted than those of the Missouri River. However, there are significant exceptions to this, especially near the mouths of major northwest Missouri rivers where the alluvium may yield quantities of water suitable for irrigation or public water supply. Many years ago, geologists recognized that the stratigraphy and geomorphology of this area are so complex and site specific that it is difficult to predict either the lithologic character or the thickness of material likely to be encountered at any drill site. So, in 1956, using funds provided by the Missouri Legislature, the Missouri Geological Survey (now the Division of Geology and Land Survey) began an ambitious test drilling program to determine the thickness and character of the glacial drift in the Northwestern Missouri groundwater province. The project, which ended in1960, included 19 of the 23 counties in the province. These drilling studies did much to help northwest Missouri towns and rural residents develop safer, more reliable water supplies. The four northwestern Missouri counties excluded from detailed drilling studies were found not to contain appreciable thicknesses of permeable glacial drift materials. Limited funds prevented their study, as well as a similar study to cover the northeastern part of the state. Table 14 is a listing of county studies available for the area. The studies are a valuable aid to finding and developing water supplies. Groundwater storage estimates for northwest Missouri included with this report rely heavily on the data collected during the 1950s" (MDNR 1997).*

The available groundwater data set is the Public Water Wells data set, which provides information about wells in the state of Missouri. The parent data set is the Wellhead Information Management System (WIMS) database that is maintained by the MDNR, Missouri Geological Survey, Geological Survey Program, and Wellhead Protection Section. The WIMS database resulted from implementation of the Water Well Drillers Law of 1985. The information about well location, well ownership, well completion date, well construction, well yield, static water level, and borehole stratigraphy was provided by well drillers as required by state statute RSMo 256.600-256.640. Wells drilled prior to July of 1987 are not included in this data set. A WIMS well search is also available online at http://dnr.mo.gov/mowells/publicLanding.do.

A database of public drinking wells, including closure information, was not required until after the 1996 amendment to the Safe Drinking Water Act. The Safe Drinking Water Information System (SDWIS) database is historically incomplete for many small rural systems that have drilled dozens of wells over the last 100 years and plugged those that became inadequate or untreatable. Planners and engineers are left to evaluate groundwater availability and reliability based on regional geologic reports and community-specific records as available.

Figure 9, below, was developed with the metadata provided by Missouri Geologic Survey in the Well Log data set. The data was originally from the 1950's exploration Miller referenced filtered to provide a graphical representation of the over 500 wells drilled to evaluate the geology of the area. The drillers' logs, which included yield information, are grouped by color and size, and the borings, which did not include yield data are marked with "x." The drillers' notes of potential yield were given in ranges; for example, the highest yielding test hole, located in Putnam County, had a noted range of 500-1,000 gpm. The other potentially high yielding test hole was in Mercer County and was noted to have a potential yield of 300-600 gpm. For purposes of the graphic, the high-range value was used on the entire data set. Schuyler, Adair, and Macon counties were not included in the 1950s study.

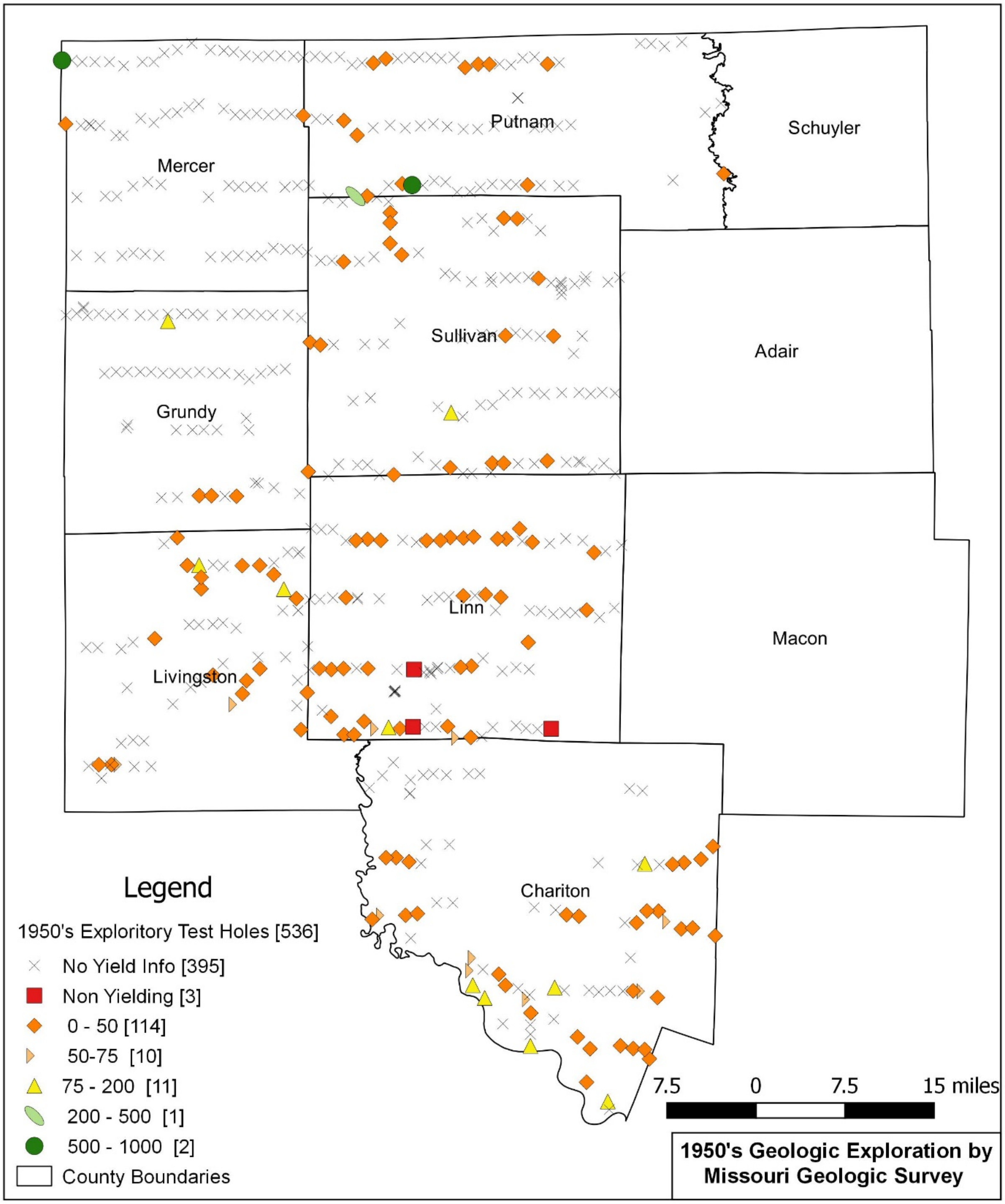
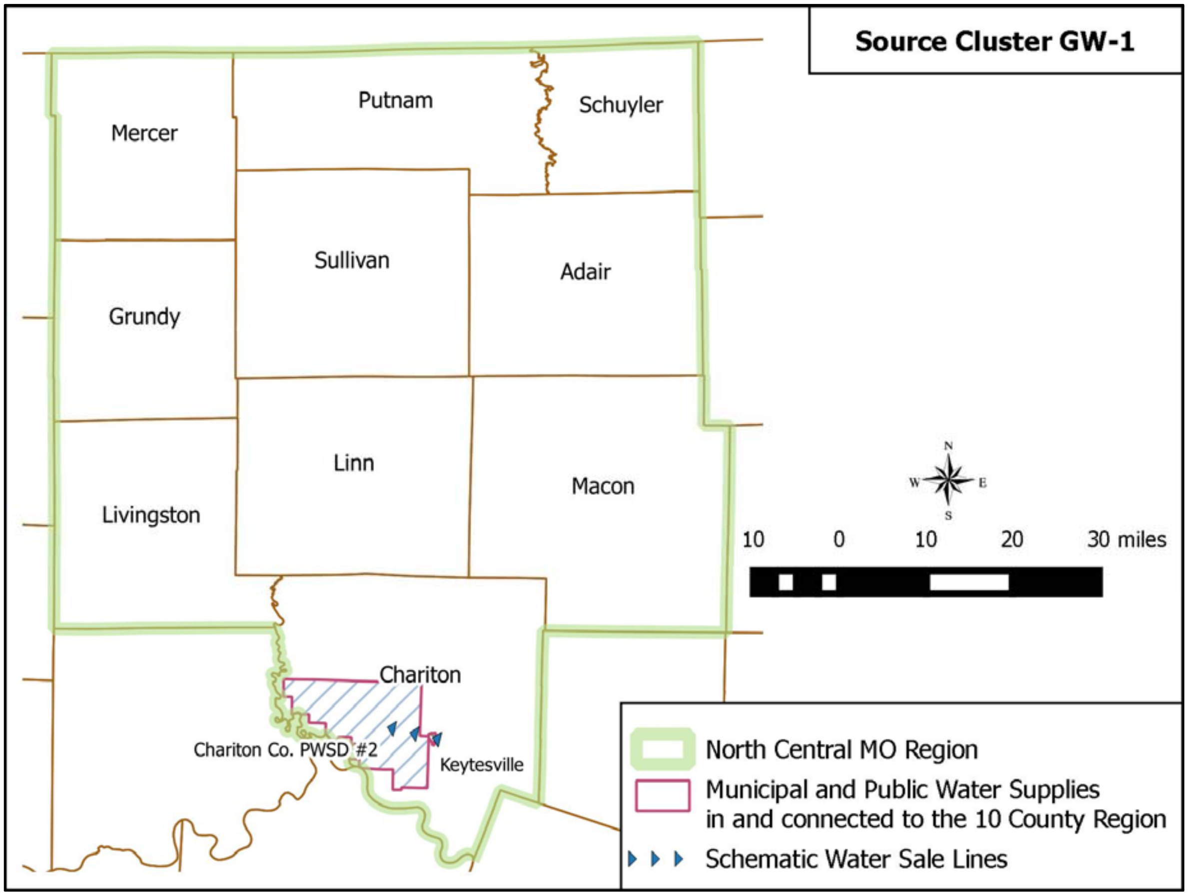



*Figure 9: 1950s Exploratory Test Holes in Northwest Missouri*

# Groundwater Cluster Reports GW-1 to GW-9

# Cluster GW-1

**Sources Inadequate**




Cluster GW-1 is supplied by three groundwater wells and is owned and operated by the City of Keytesville, Missouri. MDNR records indicate that wells #1 through #3 are inactive, and last recorded yields were 11, 10 and 7 gpm respectively. Collectively, the old wells yielded a total 28 gpm for a full 24 hours which would produce approximately 0.032 MGD. This constant draw was still short of needs, causing the City to drill three replacement wells. The current wells, Well #4, #5, and #6, are documented as producing 0.053 MGD (or 36 gpm) each. The treatment facility is designed for a maximum flow of 115 gpm (or .138 MGD @ 20 hours of run time) and is listed as an iron removal type, which was likely a contributing factor to the decline in yield from wells #1-3.

It is important to note that the wells in this cluster are within 8 miles of the Missouri River channel and 2 miles of the Chariton River channel. The wells are located in modern alluvium, near major streamflows, which is uncharacteristic for the majority of the sources in the evaluated 10 county region. This proximity can be misleading to the long-term dependability of wells. Given the history of declining wells, this evaluation has identified Cluster GW-1's sources as inadequate.

The Daily Production and Demand table below details Chariton PWSD #2 purchases approximately 0.022 MGD from Keytesville.

| 2015-2016 Cluster Average Daily Production and Demand (Treated Water Quantities) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Source Cluster | Tier System | | | | | MGD Produced | % purchase from supplier | Total MGD Consumed |
| | 1st | 2nd | 3rd | 4th | 5th | | | |
| GW-1 | Keytesville | | | | | 0.0530 | | 0.031 |
| | | Chariton PWSD #2 | | | | | 45% | 0.049 |

# Keytesville

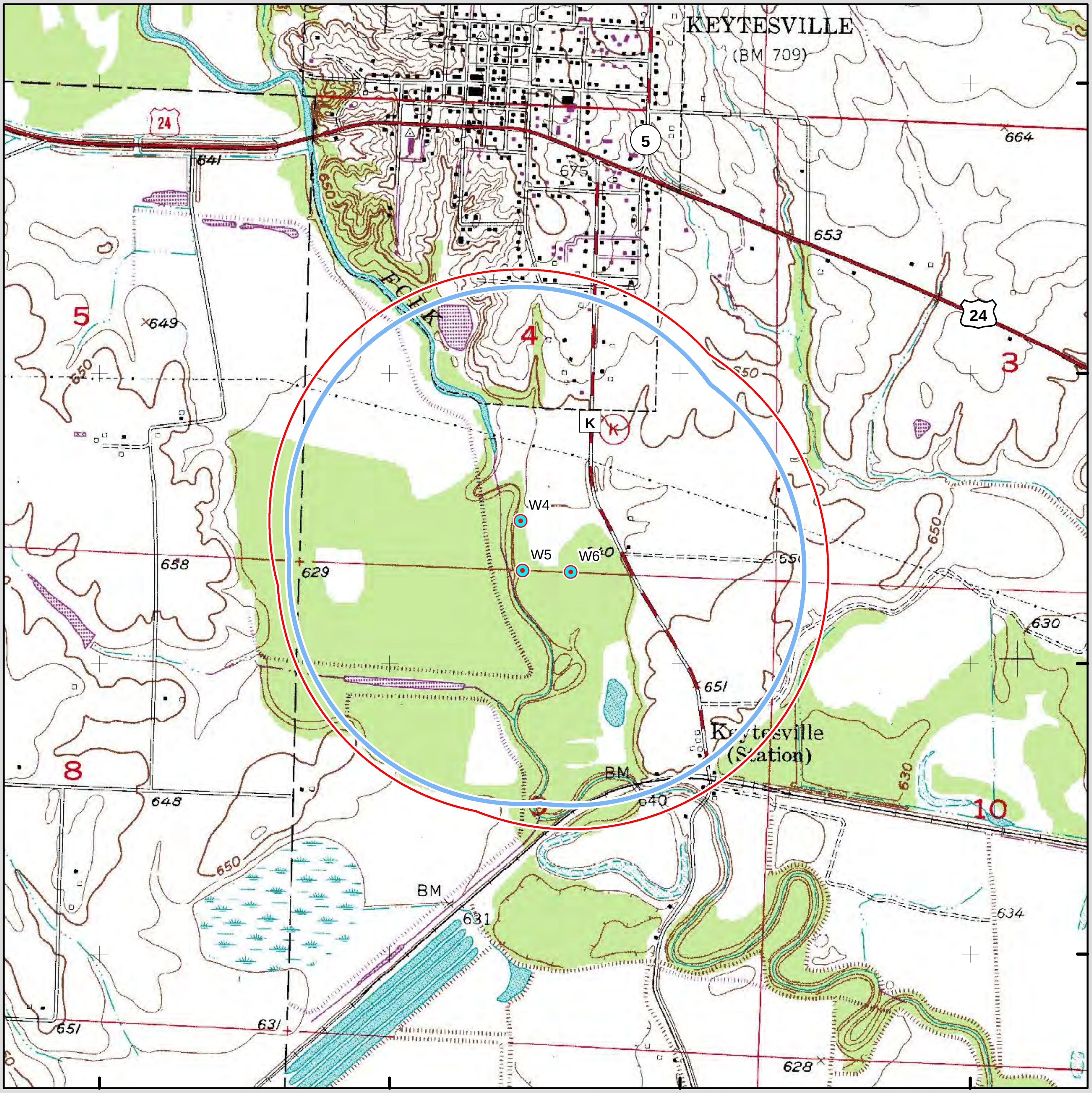
## PWSS No. 2010420

3 Wells, Chariton County

Prepared by: CENTER FOR APPLIED RESEARCH AND ENVIRONMENTAL SYSTEMS UNIVERSITY OF MISSOURI

Map Update: Jan 22, 2016

Missouri Department of Natural Resources




**Well System**

System Well

**SWAP Delineation Boundary**

20-year time of travel

Half-mile buffer


Feet

0 1,600 3,200

SWAP - Source Water Assessment Plan --
http://drinkingwater.missouri.edu/swap/
For basemap symbols, see the U.S. Geological Survey (USGS) publication: Topographic Map Symbols.

# Keytesville

PWSS No. 2010420

Chariton County

3 wells

Prepared by: CENTER FOR APPLIED RESEARCH AND ENVIRONMENTAL SYSTEMS UNIVERSITY OF MISSOURI

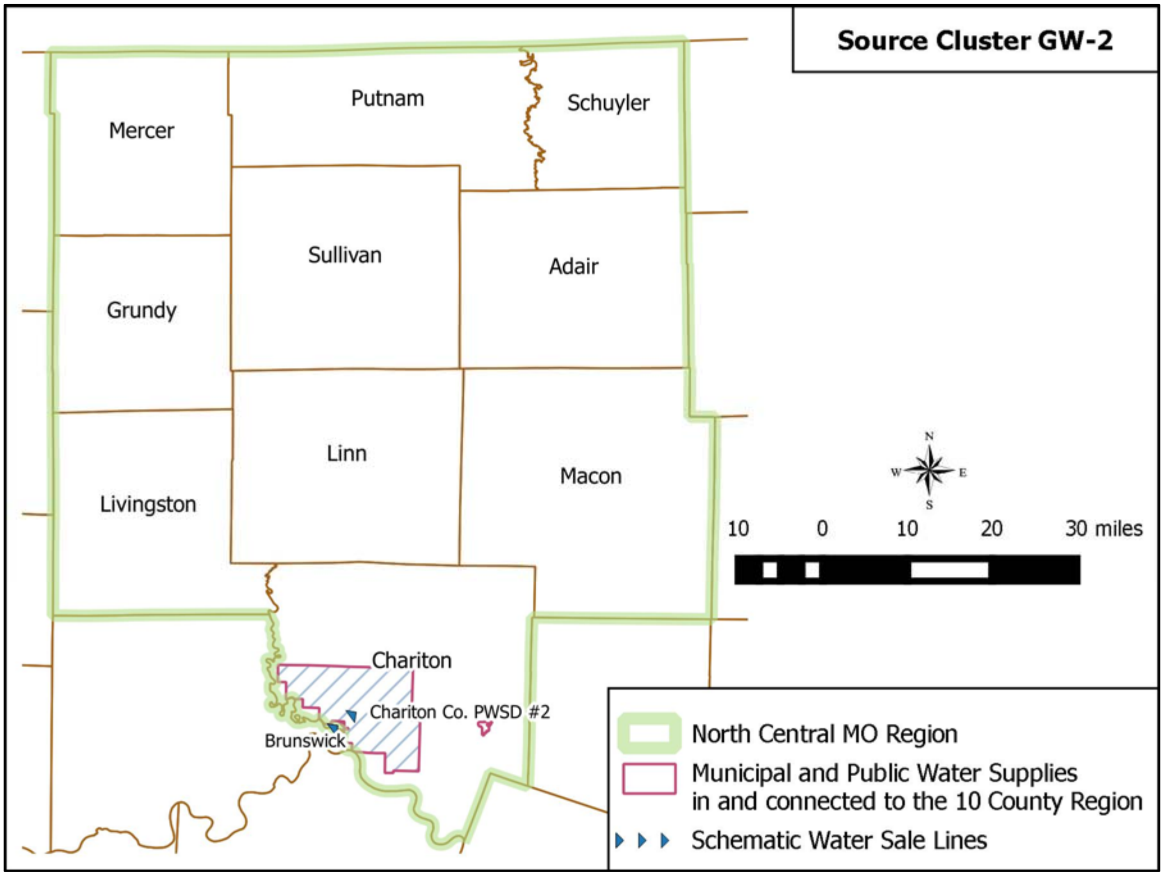
Sheet Update: Jan 25, 2016

Missouri Department of Natural Resources

| | | | |
|---|---|---|---|
| Well Number | W4 | W5 | W6 |
| Extended PWS # | 2010420104 | 2010420105 | 2010420106 |
| Local Well Name | replaces Well #1 | replaces Well #2 | replaces Well #3 |
| Well ID # | 18053 | 18054 | 18055 |
| DGLS ID # | | | |
| Facility Type | City | City | City |
| Status | Active | Active | Active |
| Latitude | 39.42094 | 39.4194 | 39.41936 |
| Longitude | -92.93667 | -92.9366 | -92.93467 |
| Location Method | GPS | GPS | GPS |
| Method Accuracy (ft) | 98 | 98 | 98 |
| USGS 7.5 Quadrangle | Keytesville | Keytesville | Keytesville |
| County | Chariton | Chariton | Chariton |
| MoDNR Region | Northeast | Northeast | Northeast |
| Date Drilled (year) | 2004 | 2004 | 2004 |
| Material (C/U) | Unconsolidated | Unconsolidated | Unconsolidated |
| Base of Casing Formation | Alluvium | Alluvium | Alluvium |
| Total Depth Formation | Pennsylvanian | Pennsylvanian | Pennsylvanian |
| Total Depth | 52 | 50 | 49 |
| Ground Elevation (ft) | | | |
| Top Seal | Tremie Grout | Tremie Grout | Tremie Grout |
| Bottom Seal | | | |
| Casing Depth (ft) | 48 | 50 | 35 |
| Casing Size (in) | 24 | 24 | 24 |
| Casing Type | Steel | Steel | Steel |
| Elev. of Casing Top (ft) | | | |
| Outer Casing Depth (ft) | | | |
| Outer Casing Size (in) | | | |
| Screen Length (ft) | | 15 | 15 |
| Screen Size (in) | | | |
| Static Water Level (ft) | 12 | 8 | 11 |
| Well Yield (gpm) | | | |
| Head (ft) | | | |
| Draw Down (ft) | | | |
| Pump Test Date (year) | | | |
| Pump Type | | | Submersible |
| Pump Manufacturer | | | Grundfos |
| Pump Depth (ft) | 20 | 18 | 18 |
| Pump Capacity (gpm) | 150 | 150 | 150 |
| Pump Meter (Y/N) | | | |
| VOC Detection (Y/N) | | | |
| Nitrate Detection (Y/N) | | | |
| Chlorination (Y/N) | | | |
| Filtration (Y/N) | | | |
| GWUDISW (Y/N) | | | |
| Surface Drainage | | | |
| State Approved(Y/N) | | | |
| Date Abandoned (year) | | | |
| Date Plugged (year) | | | |

# Cluster GW-2

**Sources Adequate**




Cluster GW-2 is supplied by groundwater wells and is owned and operated by the Missouri American Water Company - Brunswick. The data for the following table was based on MDNR Sanitary Survey's and was accessed via the Drinking Water Watch website (MDNR 2016). Note that the Well #3 yield (MGD) was calculated from the Yield (gpm) x 1,440 (60 minutes/ hour x 24 hours/ day). The limiting factor is the treatment facility which is designed for a maximum flow of 300 gpm or 0.360 MGD (based on 20 hours of run time). It is important to note that Well #3 in this cluster is within 800 feet of the Grand River channel and 4,300 feet of the Missouri River channel. Given the immediate proximity to a major stream flow, location in modern alluvium, and no known history of declining yield, Cluster GW-2's source is identified as adequate.

| Missouri American - Brunswick | Yield (gpm) | Yield (MGD) | Pump Capacity (gpm) | Design Rate (gpm) |
|---|---|---|---|---|
| Well #1 | 19 | 0.028 | 150 | |
| Well #2 | 52 | 0.075 | 150 | |
| Well #3 | 715 | 1.030 | 400 | |
| Treatment Plant | | | | 300 |

The treated water demands of 2015 are shown in the following table.

| 2015-2016 Cluster Average Daily Production and Demand (Treated Water Quantities) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Source Cluster | Tier System | | | | | MGD Produced | % purchase from supplier | Total MGD Consumed |
| | 1st | 2nd | 3rd | 4th | 5th | | | |
| GW-2 | Mo American Brunswick | | | | | 0.0841 | | 0.057 |
| | | Chariton PWSD #2 | | | | | 55% | 0.049 |

# Mo American - Brunswick

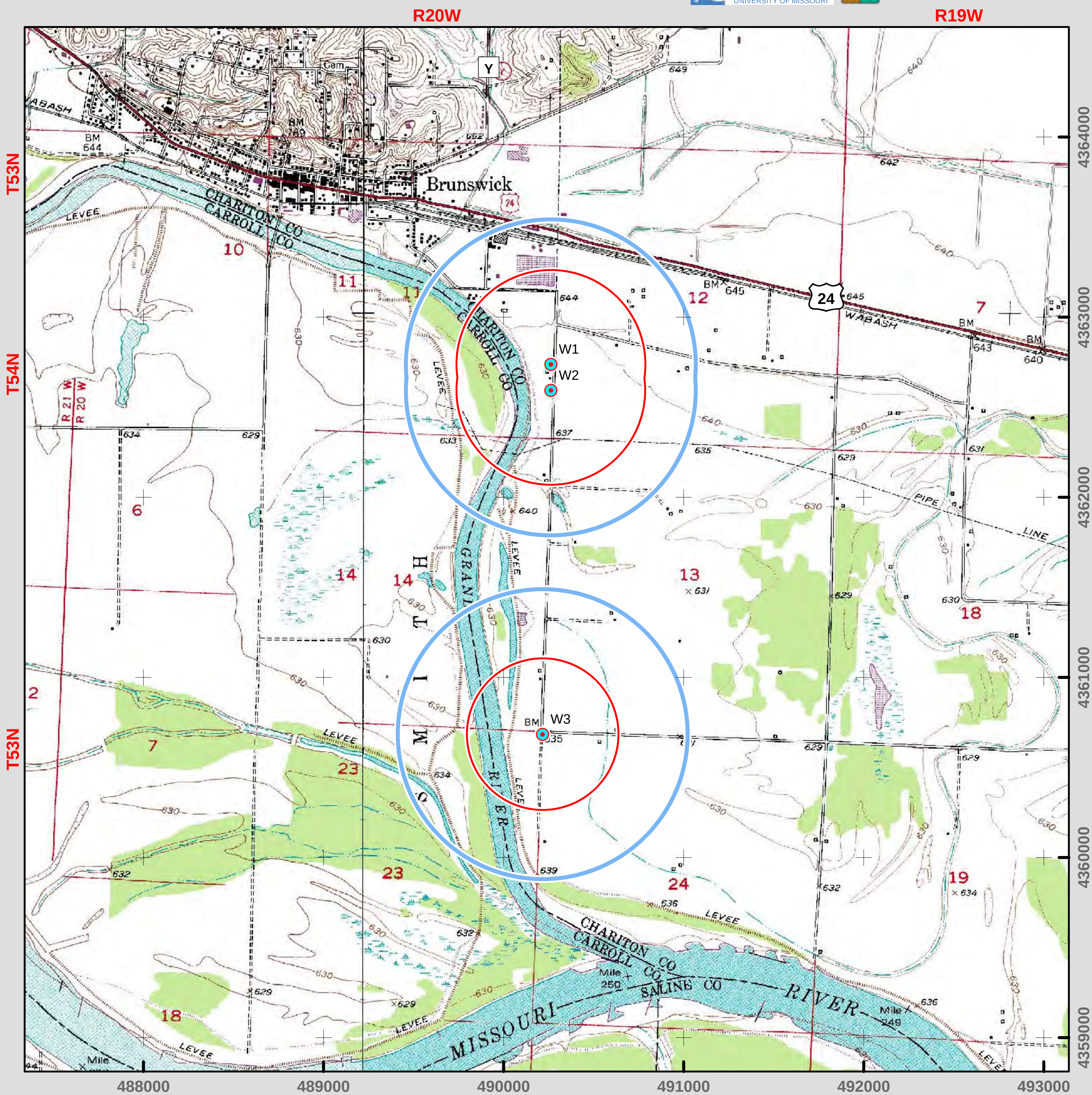
## PWSS No. 2010109

3 Wells, Chariton County

Prepared by: CENTER FOR APPLIED RESEARCH AND ENVIRONMENTAL SYSTEMS UNIVERSITY OF MISSOURI

Map Update: Jan 22, 2016

Missouri Department of Natural Resources



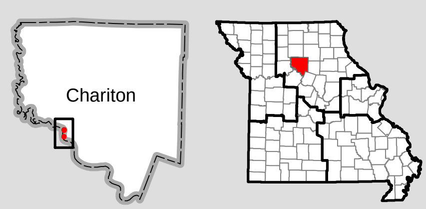

**Well System**

System Well

**SWAP Delineation Boundary**

20-year time of travel

Half-mile buffer




Miles

0 0.5 1

SWAP - Source Water Assessment Plan --
http://drinkingwater.missouri.edu/swap/
For basemap symbols, see the U.S. Geological Survey (USGS) publication: Topographic Map Symbols.

# Mo American - Brunswick

PWSS No. 2010109

Chariton County

3 wells

Prepared by: CENTER FOR APPLIED RESEARCH AND ENVIRONMENTAL SYSTEMS UNIVERSITY OF MISSOURI

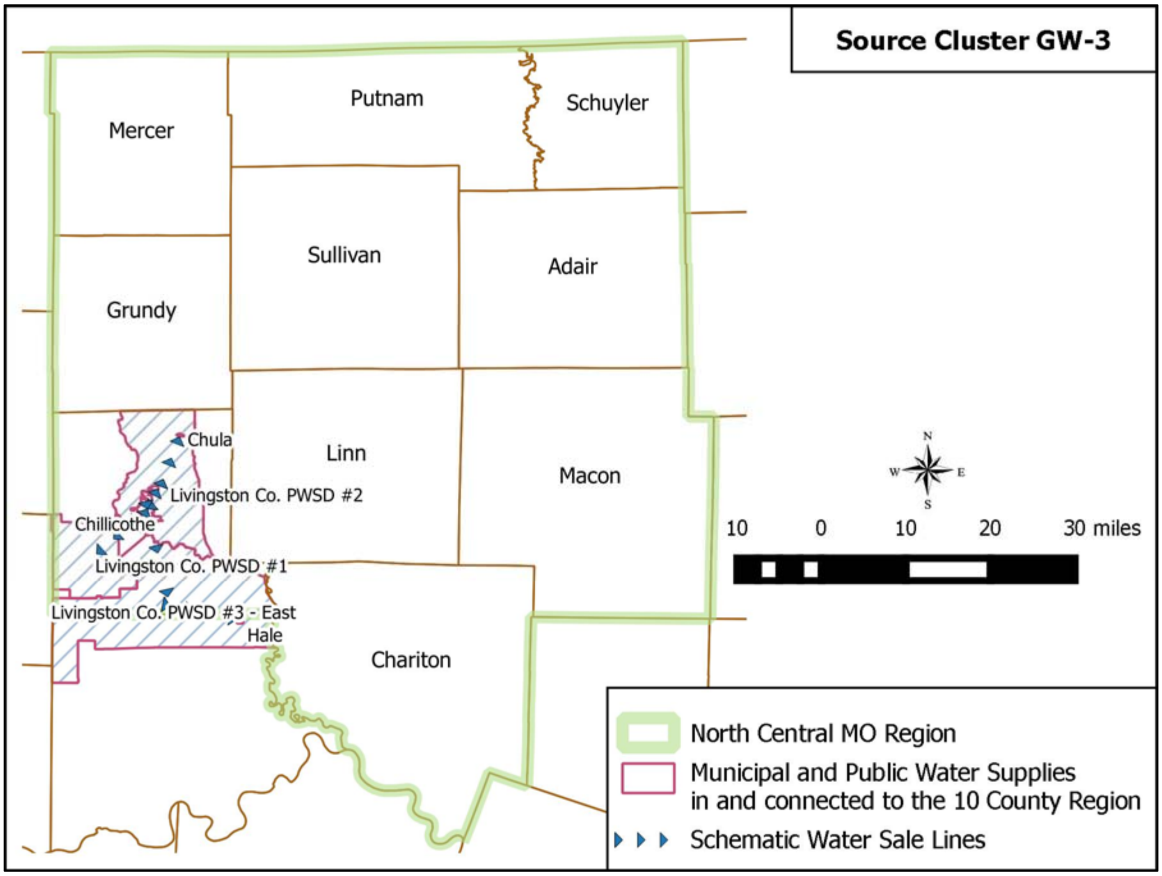
Sheet Update: Jan 25, 2016

Missouri Department of Natural Resources

| Well Number | W1 | W2 | W3 |
| --- | --- | --- | --- |
| Extended PWS # | 2010109101 | 2010109102 | 2010109103 |
| Local Well Name | Well #1 | Well #2 | Well #3 |
| Well ID # | 14612 | 14613 | 14614 |
| DGLS ID # | | | |
| Facility Type | City | City | City |
| Status | Active | Active | Active |
| Latitude | 39.41411 | 39.41281 | 39.39561 |
| Longitude | -93.11311 | -93.11311 | -93.11361 |
| Location Method | DRG/MAP | DRG/MAP | DRG/MAP |
| Method Accuracy (ft) | 33 | 33 | 33 |
| USGS 7.5 Quadrangle | Brunswick East | Brunswick East | Brunswick East |
| County | Chariton | Chariton | Chariton |
| MoDNR Region | Northeast | Northeast | Northeast |
| Date Drilled (year) | 1951 | 1952 | 1982 |
| Material (C/U) | Unconsolidated | Unconsolidated | Unconsolidated |
| Base of Casing Formation | Alluvium | Alluvium | Alluvium |
| Total Depth Formation | Alluvium | Alluvium | Alluvium |
| Total Depth | 65 | 65 | 82 |
| Ground Elevation (ft) | | | |
| Top Seal | Pump Base | Pump Base | Mechanical Seal |
| Bottom Seal | Steel Plate | Steel Plate | Steel Plate |
| Casing Depth (ft) | 26 | 26 | 31 |
| Casing Size (in) | 24 | 24 | 24 |
| Casing Type | Steel | Steel | Steel |
| Elev. of Casing Top (ft) | 644 | 644 | 640 |
| Outer Casing Depth (ft) | | | |
| Outer Casing Size (in) | | | |
| Screen Length (ft) | 20 | 20 | 25 |
| Screen Size (in) | 12 | 12 | 16 |
| Static Water Level (ft) | 15 | 15 | 4 |
| Well Yield (gpm) | 200 | 150 | 750 |
| Head (ft) | | | |
| Draw Down (ft) | 5 | 11 | 5 |
| Pump Test Date (year) | 1993 | 1993 | 1993 |
| Pump Type | Submersible | Submersible | Submersible |
| Pump Manufacturer | Crown | Crown | Crown |
| Pump Depth (ft) | 52 | 52 | |
| Pump Capacity (gpm) | 160 | 160 | 160 |
| Pump Meter (Y/N) | Y | Y | Y |
| VOC Detection (Y/N) | N | N | N |
| Nitrate Detection (Y/N) | N | N | N |
| Chlorination (Y/N) | Y | Y | Y |
| Filtration (Y/N) | Y | Y | Y |
| GWUDISW (Y/N) | N | N | N |
| Surface Drainage | Satisfactory | Satisfactory | Satisfactory |
| State Approved(Y/N) | Y | Y | Y |
| Date Abandoned (year) | | | |
| Date Plugged (year) | | | |

# Cluster GW-3

**Sources Adequate**




Cluster GW-3 is supplied by groundwater wells and is owned and operated by Chillicothe Municipal Utilities. MDNR records indicate six active alluvial wells ranging in yield from 650-1,000 gpm each and are located in the alluvium for the Grand River. The iron removal type water treatment plant has a design capacity of 2,200 gpm or 2.64 MGD (running for 20 of 24 hours a day).

The Production and Demand table details the three wholesale customers and their customers. Livingston County PWSD #2 utilizes treated water form Chillicothe for approximately 49 percent of their total demand. In 2015, Chillicothe Municipal Utilities produced approximately 60 percent of the total groundwater in the 10-county study region. Livingston PWSD #1, closed its groundwater treatment plant in 2005 after well yield declined below demand and approximately 28 test wells failed to produce a viable solution. This information is included in Appendix C.

Given the immediate proximity to major modern alluvium and stream flow, Cluster GW-3 is identified as having adequate sources.

| 2015-2016 Cluster Average Daily Production and Demand (Treated Water Quantities) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Source Cluster | Tier System | | | | | MGD Produced | % purchase from supplier | Total MGD Consumed |
| | 1st | 2nd | 3rd | 4th | 5th | | | |
| GW-3 | Chillicothe Municipal Utilities | | | | | 1.3 | | 0.893 |
| | | Livingston Co. PWSD #1 | | | | | 100% | 0.077 |
| | | Livingston Co. PWSD #2 | | | | | 49% | 0.151 |
| | | | Chula | | | | 100% | 0.016 |
| | | Livingston Co. PWSD #3 East | | | | | 100% | 0.197 |
| | | | Hale | | | | 100% | 0.043 |

# Chillicothe Municipal Utilities

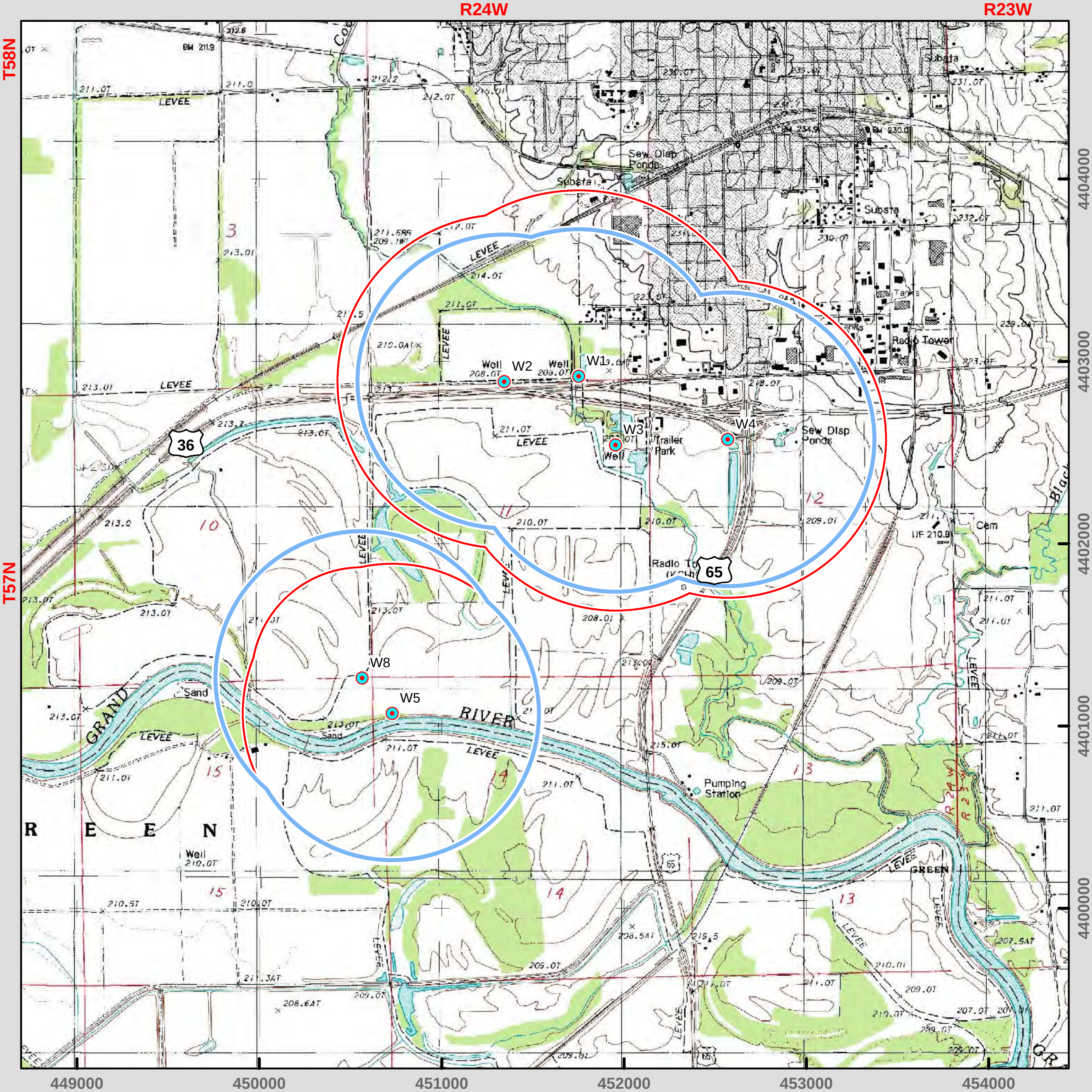
## PWSS No. 2010162

6 Wells, Livingston County

Prepared by: CENTER FOR APPLIED RESEARCH AND ENVIRONMENTAL SYSTEMS UNIVERSITY OF MISSOURI

Map Update: Jan 22, 2016

Missouri Department of Natural Resources



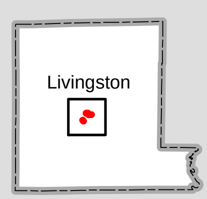

### Well System

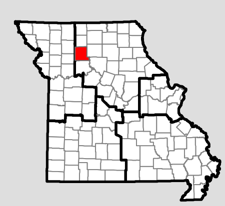
System Well

### SWAP Delineation Boundary

20-year time of travel

Half-mile buffer



Miles

0 0.5 1

SWAP - Source Water Assessment Plan --
http://drinkingwater.missouri.edu/swap/
For basemap symbols, see the U.S. Geological Survey (USGS) publication: Topographic Map Symbols.

# Chillicothe Municipal Utilities

PWSS No. 2010162

Livingston County, sheet 1 of 2

6 wells

Sheet Update: Jan 25, 2016

Prepared by: CENTER FOR APPLIED RESEARCH AND ENVIRONMENTAL SYSTEMS UNIVERSITY OF MISSOURI

Missouri Department of Natural Resources

| Well Number | W1 | W2 | W3 | W4 | W5 |
|---|---|---|---|---|---|
| Extended PWS # | 2010162101 | 2010162102 | 2010162103 | 2010162104 | 2010162105 |
| Local Well Name | Well #1 | Well #2 | Well #3 | Well #4 | Well #5 |
| Well ID # | 13827 | 13828 | 13829 | 13830 | 16992 |
| DGLS ID # | | | | 029061 | |
| Facility Type | City | City | City | City | City |
| Status | Active | Active | Active | Active | Active |
| Latitude | 39.77485 | 39.77456 | 39.77146 | 39.77177 | 39.758125 |
| Longitude | -93.5634 | -93.56816 | -93.56101 | -93.55383 | -93.575196 |
| Location Method | DRG/MAP | DRG/MAP | DRG/MAP | DRG/MAP | PLSS |
| Method Accuracy (ft) | 33 | 33 | 33 | 33 | 800 |
| USGS 7.5 Quadrangle | Chillicothe | Chillicothe | Chillicothe | Chillicothe | Chillicothe |
| County | Livingston | Livingston | Livingston | Livingston | Livingston |
| MoDNR Region | Northeast | Northeast | Northeast | Northeast | Northeast |
| Date Drilled (year) | 1968 | 1971 | 1971 | 1993 | |
| Material (C/U) | Unconsolidated | Unconsolidated | Unconsolidated | Unconsolidated | Unconsolidated |
| Base of Casing Formation | Glacial Deposits | Glacial Deposits | Glacial Deposits | Glacial Deposits | Glacial Deposits |
| Total Depth Formation | Glacial Deposits | Glacial Deposits | Glacial Deposits | Glacial Deposits | Glacial Deposits |
| Total Depth | 105 | 120 | 126 | 110 | 135 |
| Ground Elevation (ft) | 676 | 676 | 682 | 659 | 682 |
| Top Seal | Mechanical Seal | Mechanical Seal | | Cement Grout | Cement Grout |
| Bottom Seal | Steel Plate | Steel Plate | | Cement Grout | Gravel Pack |
| Casing Depth (ft) | | | | 75 | 115 |
| Casing Size (in) | | | | 18 | 18 |
| Casing Type | Steel | Steel | Steel | Steel | Steel |
| Elev. of Casing Top (ft) | | | | | |
| Outer Casing Depth (ft) | | | | 30 | 20 |
| Outer Casing Size (in) | | | | 42 | 48 |
| Screen Length (ft) | 25 | 30 | 28 | 35 | 20 |
| Screen Size (in) | 18 | 18 | 18 | 18 | 18 |
| Static Water Level (ft) | 38 | 37 | 42 | 18 | |
| Well Yield (gpm) | 700 | 700 | 650 | 950 | |
| Head (ft) | 154 | 186 | 150 | | 158 |
| Draw Down (ft) | 30 | 31 | 24 | 32 | |
| Pump Test Date (year) | 1991 | 1991 | 1991 | 1992 | |
| Pump Type | Vertical Turbine | Vertical Turbine | Vertical Turbine | Submersible | Vertical Turbine |
| Pump Manufacturer | Layne & Bowler | Layne & Bowler | | | |
| Pump Depth (ft) | 80 | 80 | 60 | 86 | |
| Pump Capacity (gpm) | 1000 | 1000 | 1000 | 950 | 1000 |
| Pump Meter (Y/N) | Y | Y | Y | Y | |
| VOC Detection (Y/N) | Y | N | N | N | |
| Nitrate Detection (Y/N) | N | N | N | N | |
| Chlorination (Y/N) | Y | Y | Y | Y | |
| Filtration (Y/N) | Y | Y | Y | Y | |
| GWUDISW (Y/N) | N | N | N | N | |
| Surface Drainage | Satisfactory | Satisfactory | | | |
| State Approved(Y/N) | Y | Y | Y | Y | |
| Date Abandoned (year) | | | | | |
| Date Plugged (year) | | | | | |

# Chillicothe Municipal Utilities

PWSS No. 2010162

Livingston County, sheet 2 of 2

6 wells

Prepared by:

CENTER FOR APPLIED RESEARCH AND ENVIRONMENTAL SYSTEMS UNIVERSITY OF MISSOURI

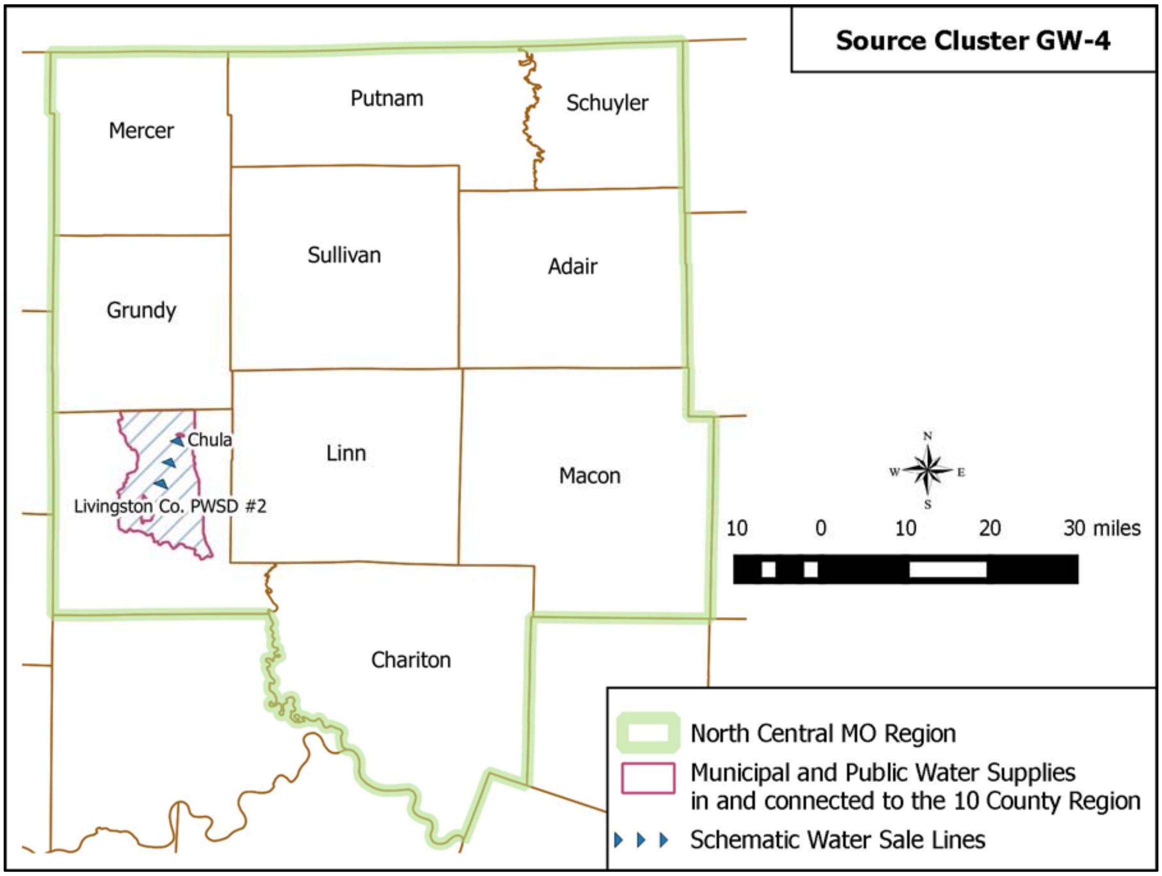
Sheet Update: Jan 25, 2016

Missouri Department of Natural Resources

| | |
|---|---|
| Well Number | W8 |
| Extended PWS # | 2010162108 |
| Local Well Name | Well #6 |
| Well ID # | 18865 |
| DGLS ID # | |
| Facility Type | City |
| Status | Active |
| Latitude | 39.75982 |
| Longitude | -93.57716 |
| Location Method | GPS |
| Method Accuracy (ft) | 33 |
| USGS 7.5 Quadrangle | Chillicothe |
| County | Livingston |
| MoDNR Region | Northeast |
| Date Drilled (year) | |
| Material (C/U) | Unconsolidated |
| Base of Casing Formation | Glacial Deposits |
| Total Depth Formation | Glacial Deposits |
| Total Depth | |
| Ground Elevation (ft) | 682 |
| Top Seal | Cement Grout |
| Bottom Seal | Cement Grout |
| Casing Depth (ft) | |
| Casing Size (in) | |
| Casing Type | Steel |
| Elev. of Casing Top (ft) | |
| Outer Casing Depth (ft) | |
| Outer Casing Size (in) | |
| Screen Length (ft) | |
| Screen Size (in) | |
| Static Water Level (ft) | |
| Well Yield (gpm) | |
| Head (ft) | |
| Draw Down (ft) | |
| Pump Test Date (year) | |
| Pump Type | |
| Pump Manufacturer | |
| Pump Depth (ft) | |
| Pump Capacity (gpm) | |
| Pump Meter (Y/N) | |
| VOC Detection (Y/N) | |
| Nitrate Detection (Y/N) | |
| Chlorination (Y/N) | |
| Filtration (Y/N) | |
| GWUDISW (Y/N) | |
| Surface Drainage | |
| State Approved(Y/N) | |
| Date Abandoned (year) | |
| Date Plugged (year) | |

# Cluster GW-4

**Sources Inadequate**




Cluster GW-4 is supplied, in part, by a groundwater well owned and operated by Livingston County PWSD #2. Missouri DNR records indicate the well was drilled in 2013 and yields approximately 276 gpm. The iron removal water treatment plant was designed for a maximum flow of 230 gpm. Based on 2015 annual average water production and demand data from the district, the well produces approximately 51 percent (0.087 MGD) of the total system demand (0.167 MGD). The remaining 49 percent (0.080 MGD) is purchased from Chillicothe Municipal Utilities. Note demand and production numbers do not equate, this error is attributed to water loss within the system by conversation with system staff.

The City of Chula began purchasing water from Livingston County PWSD #2 in 1985 after closing its water treatment plant after declining yield limited its capacity.

Well log data shows that Livingston County PWSD #2 has two inactive wells, Well #1 drilled in 1964 and Well #2 drilled in 1988. The data does not indicate a date of closure for the wells. The glacial deposit formation, which the wells are documented as located in, is known to contain high iron and varying quantities of water. Well #2 was drilled to a total depth of 139 feet below the surface and had a static water level of 53 feet below the surface. Drawdown information lists the depth at 110 feet below the surface when the 250 gpm pump was running. This slow recharge is an important factor in the reliability of a groundwater well. Additional information on Well #1 and Well #2 is located in Appendix F. Given the history of declining wells, this evaluation has identified Cluster GW-4's sources as inadequate.

| 2015-2016 Cluster Average Daily Production and Demand (Treated Water Quantities) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Source Cluster | Tier System | | | | | MGD Produced | % purchase from supplier | Total MGD Consumed |
| | 1st | 2nd | 3rd | 4th | 5th | | | |
| GW-4 | Livingston Co. PWSD #2 | | | | | 0.087 | 52% | 0.151 |
| | | Chula | | | | | 100% | 0.016 |

# Livingston Co. PWSD #2

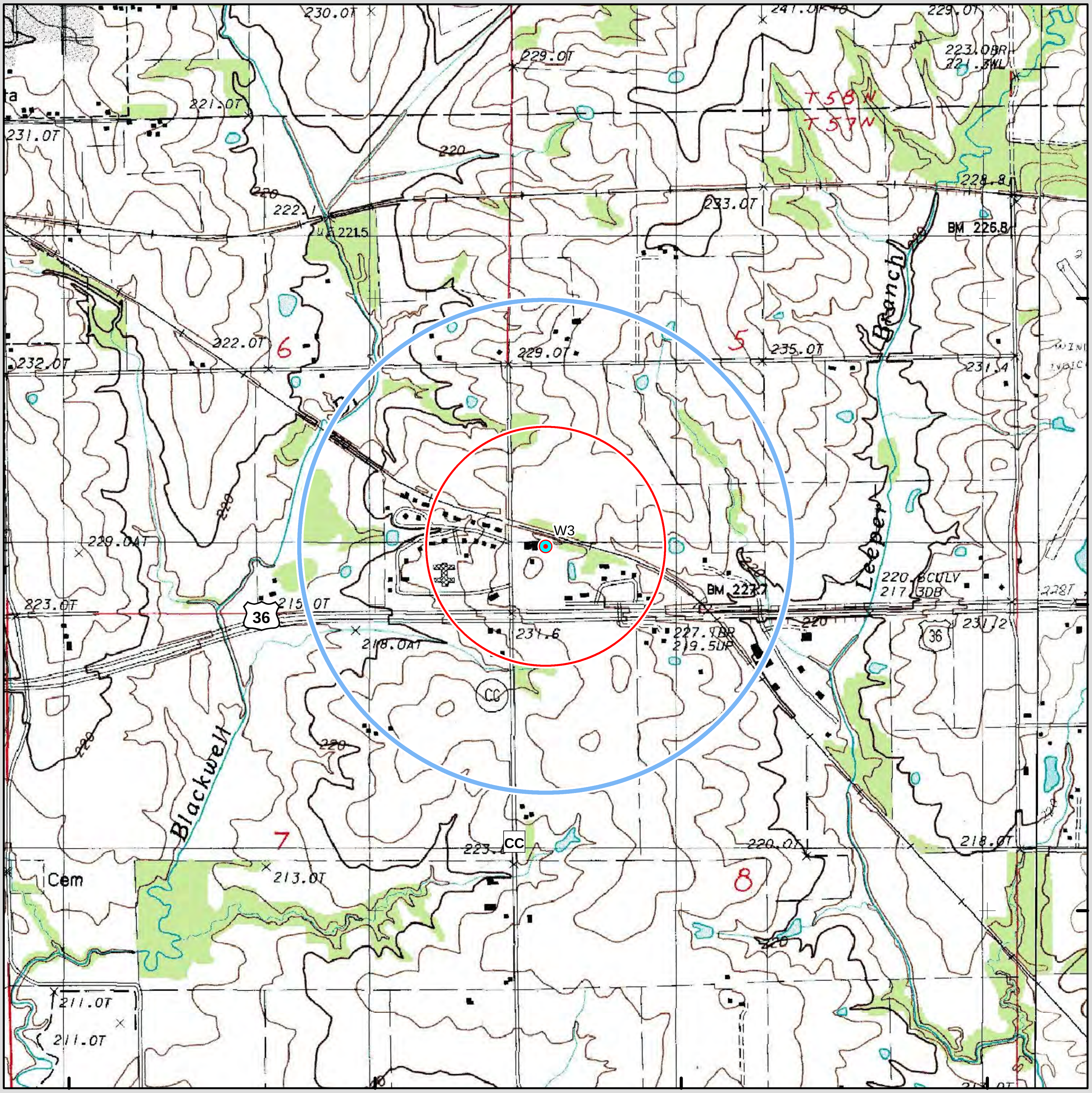
## PWSS No. 2024353

1 Well, Livingston County

Prepared by: CENTER FOR APPLIED RESEARCH AND ENVIRONMENTAL SYSTEMS UNIVERSITY OF MISSOURI

Map Update: Jan 22, 2016

Missouri Department of Natural Resources



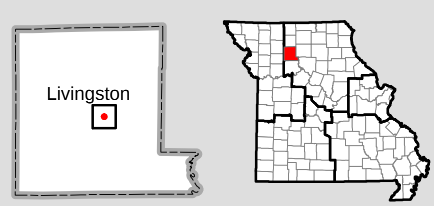

**Well System**

System Well

**SWAP Delineation Boundary**

20-year time of travel

Half-mile buffer




Feet

0 1,500 3,000

SWAP - Source Water Assessment Plan -- http://drinkingwater.missouri.edu/swap/
For basemap symbols, see the U.S. Geological Survey (USGS) publication: Topographic Map Symbols.

# Livingston Co. PWSD #2

PWSS No. 2024353

Livingston County

1 well

Prepared by: CENTER FOR APPLIED RESEARCH AND ENVIRONMENTAL SYSTEMS UNIVERSITY OF MISSOURI

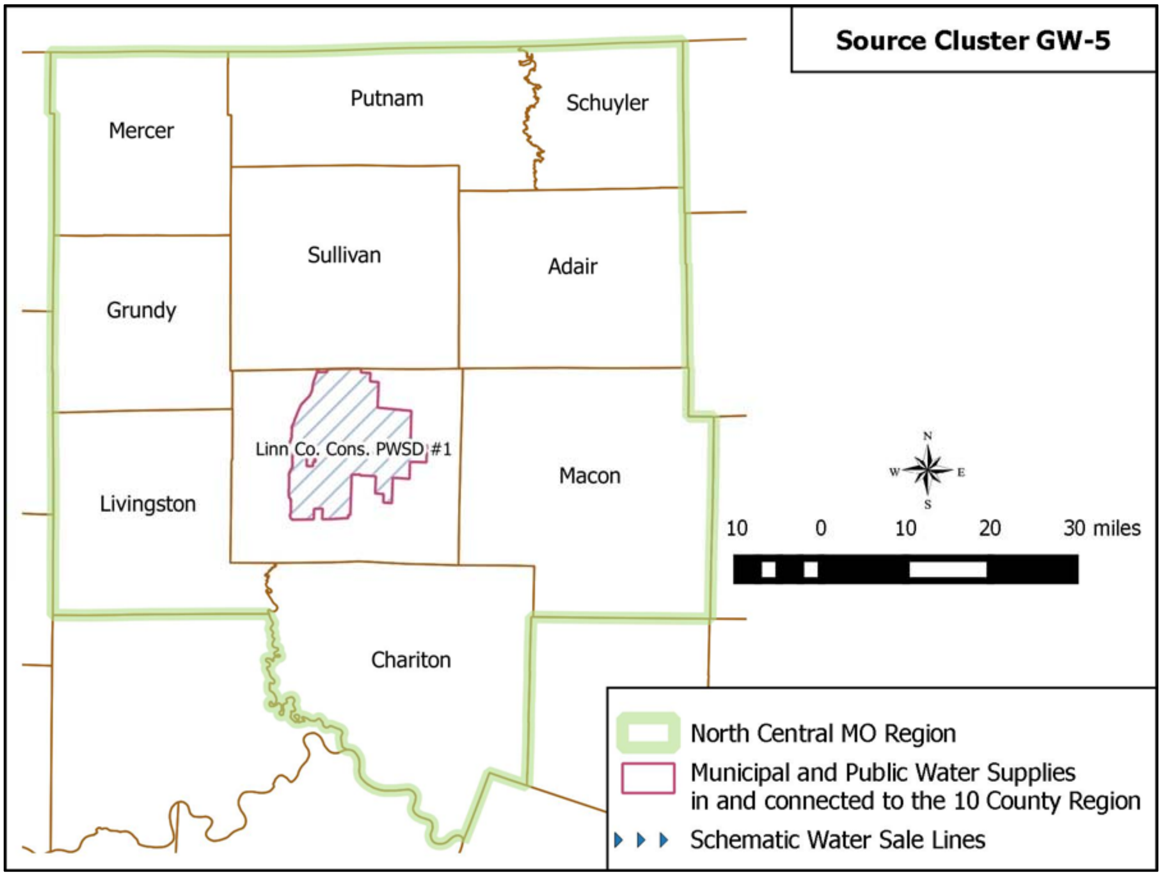
Sheet Update: Jan 25, 2016

Missouri Department of Natural Resources

| | |
|---|---|
| Well Number | W3 |
| Extended PWS # | 2024353103 |
| Local Well Name | Well #3 |
| Well ID # | 18764 |
| DGLS ID # | |
| Facility Type | Water District |
| Status | Active |
| Latitude | 39.77758 |
| Longitude | -93.51897 |
| Location Method | GPS |
| Method Accuracy (ft) | 10 |
| USGS 7.5 Quadrangle | Chillicothe |
| County | Livingston |
| MoDNR Region | Northeast |
| Date Drilled (year) | 2013 |
| Material (C/U) | Unconsolidated |
| Base of Casing Formation | Alluvium |
| Total Depth Formation | Alluvium |
| Total Depth | 185 |
| Ground Elevation (ft) | 775 |
| Top Seal | Cement Grout |
| Bottom Seal | Cement Grout |
| Casing Depth (ft) | 156 |
| Casing Size (in) | 12 |
| Casing Type | Steel |
| Elev. of Casing Top (ft) | |
| Outer Casing Depth (ft) | |
| Outer Casing Size (in) | |
| Screen Length (ft) | 171 |
| Screen Size (in) | 12 |
| Static Water Level (ft) | 95 |
| Well Yield (gpm) | 276 |
| Head (ft) | |
| Draw Down (ft) | |
| Pump Test Date (year) | |
| Pump Type | Submersible |
| Pump Manufacturer | |
| Pump Depth (ft) | 153 |
| Pump Capacity (gpm) | 250 |
| Pump Meter (Y/N) | |
| VOC Detection (Y/N) | |
| Nitrate Detection (Y/N) | |
| Chlorination (Y/N) | |
| Filtration (Y/N) | |
| GWUDISW (Y/N) | |
| Surface Drainage | |
| State Approved(Y/N) | |
| Date Abandoned (year) | |
| Date Plugged (year) | |

# Cluster GW-5

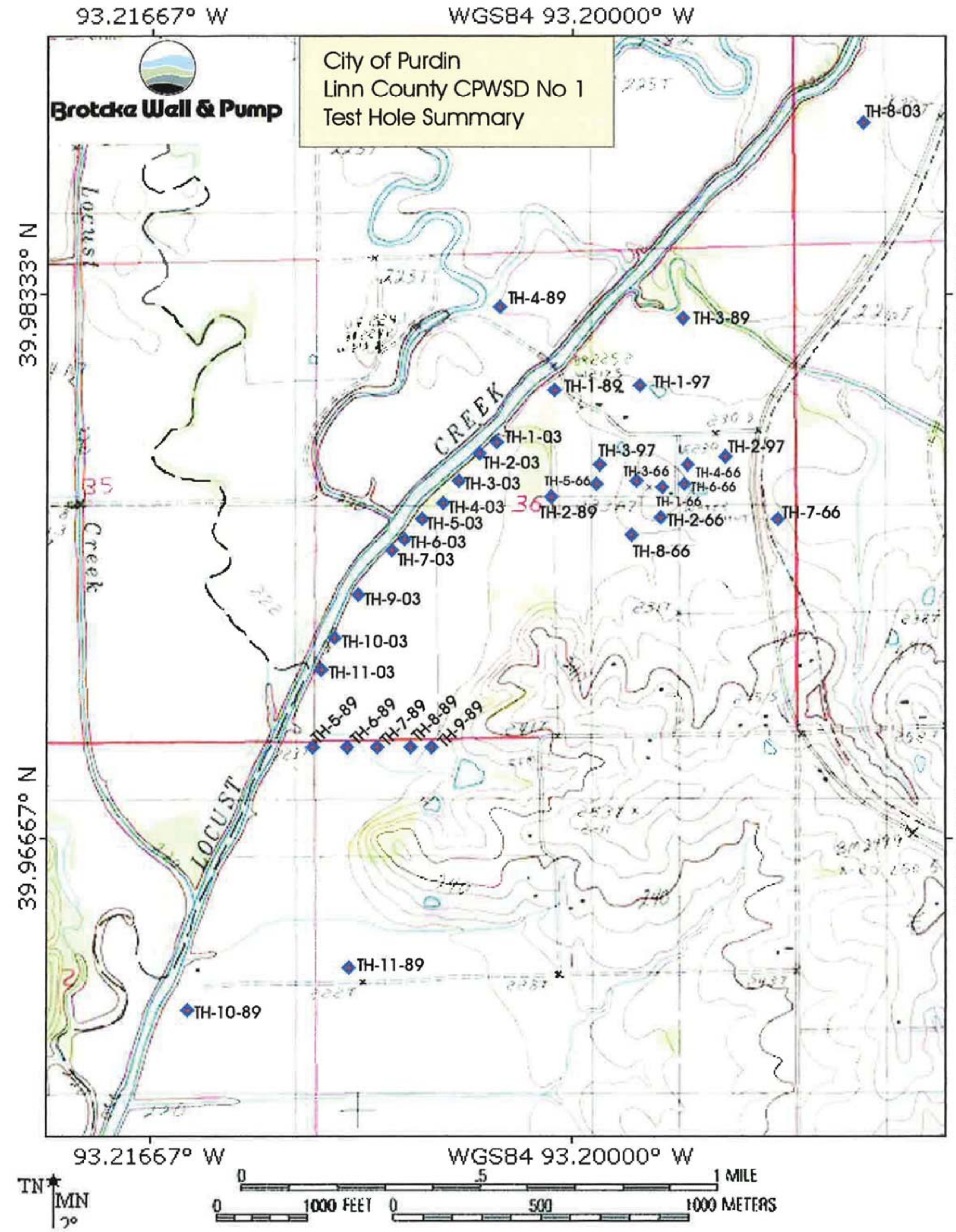
**Sources Inadequate**




Cluster GW-5 is supplied by five groundwater wells and is owned and operated by Linn County Consolidated PWSD #1. The 2015 average daily treated water normal demand for this cluster was 0.085 MGD and serves approximately 1,620 people. Missouri DNR records and information from district staff was used to develop the Water Yield and System Capacities table below. Note that Well #3 is not used due to its high iron content.

| Water Yield and System Capacities | | | | |
|---|---|---|---|---|
| **Linn Co. Cons. PWSD #2** | Yield (gpm) | Yield (MGD) | Pump Capacity (gpm) | Design Rate (gpm) |
| Well #1 | 32 | 0.046 | 41 | |
| Well #2 | 41 | 0.059 | 75 | |
| Well #3 | - | - | 75 | |
| Well #4 | 75 | 0.108 | 75 | |
| Well #5 | 20 | 0.029 | 25 | |
| Treatment Plant | | | | 200 |

The letter in Appendix B describes the 2003 test hole activities, where 11 test holes were unsuccessful in identifying an alluvial well capable of producing 50 gpm. The map included in the letter is duplicated on the next page and shows the 33 test holes drilled by Brotcke Well and Pump from 1966 to 2003. Based on the history of the wells in this cluster to be influenced by high iron content, and because of continued deterioration of existing wells and the difficulty in identifying new wells, long-term water reliability within Cluster GW-5 is uncertain, therefore, its sources are identified as inadequate.


93.21667° W
WGS84 93.20000° W
Brotcke Well & Pump
City of Purdin
Linn County CPWSD No 1
Test Hole Summary
TH-8-03
TH-4-89
TH-3-89
TH-1-89
TH-1-97
CREEK
TH-1-03
TH-2-03
TH-3-03
TH-4-03
TH-5-03
TH-6-03
TH-7-03
TH-3-97
TH-2-97
TH-5-66
TH-3-66
TH-4-66
TH-6-66
TH-1-66
TH-2-89
TH-2-66
TH-7-66
TH-8-66
TH-9-03
TH-10-03
TH-11-03
TH-5-89
TH-6-89
TH-7-89
TH-8-89
TH-9-89
LOCUST
Locust
Creek
35
36
39.98333° N
39.96667° N
TH-11-89
TH-10-89
93.21667° W
WGS84 93.20000° W
TN
MN
2°
0
.5
1 MILE
0
1000 FEET
0
500
1000 METERS

# Linn Co. Cons. PWSD #1

## PWSS No. 2024346

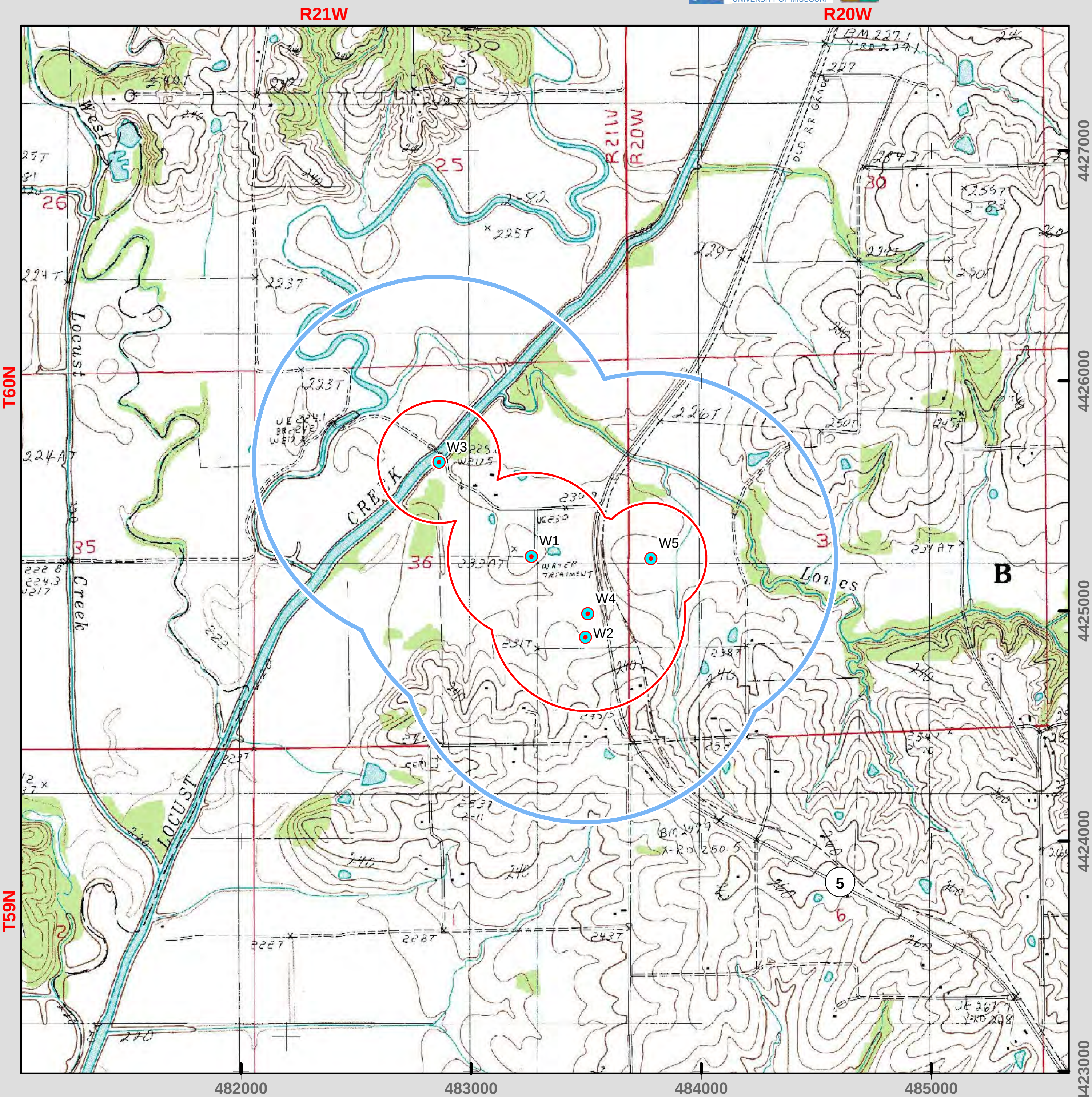
5 Wells, Linn County

Prepared by:

CENTER FOR APPLIED RESEARCH AND ENVIRONMENTAL SYSTEMS UNIVERSITY OF MISSOURI

Map Update: Jan 22, 2016

Missouri Department of Natural Resources



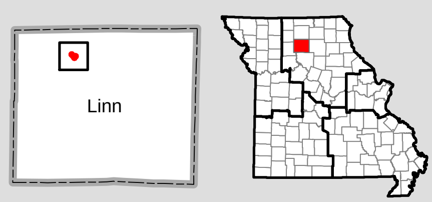

**Well System**

System Well

**SWAP Delineation Boundary**

20-year time of travel

Half-mile buffer




Feet

0 1,900 3,800

SWAP - Source Water Assessment Plan --
http://drinkingwater.missouri.edu/swap/
For basemap symbols, see the U.S. Geological Survey (USGS) publication: Topographic Map Symbols.

Although all data in this dataset have been used by the Missouri Department of Natural Resources (MoDNR), no warranty, expressed or implied, is made by MoDNR as to the accuracy of the data and related materials. The act of distribution shall not constitute any such warranty, and no responsibility is assumed by MoDNR in the use of these data or related materials. This map is subject to change as additional information is acquired. Additional information at: http://drinkingwater.missouri.edu.

# Linn Co. Cons. PWSD #1

PWSS No. 2024346

Linn County

5 wells

Sheet Update: Jan 25, 2016

Prepared by:

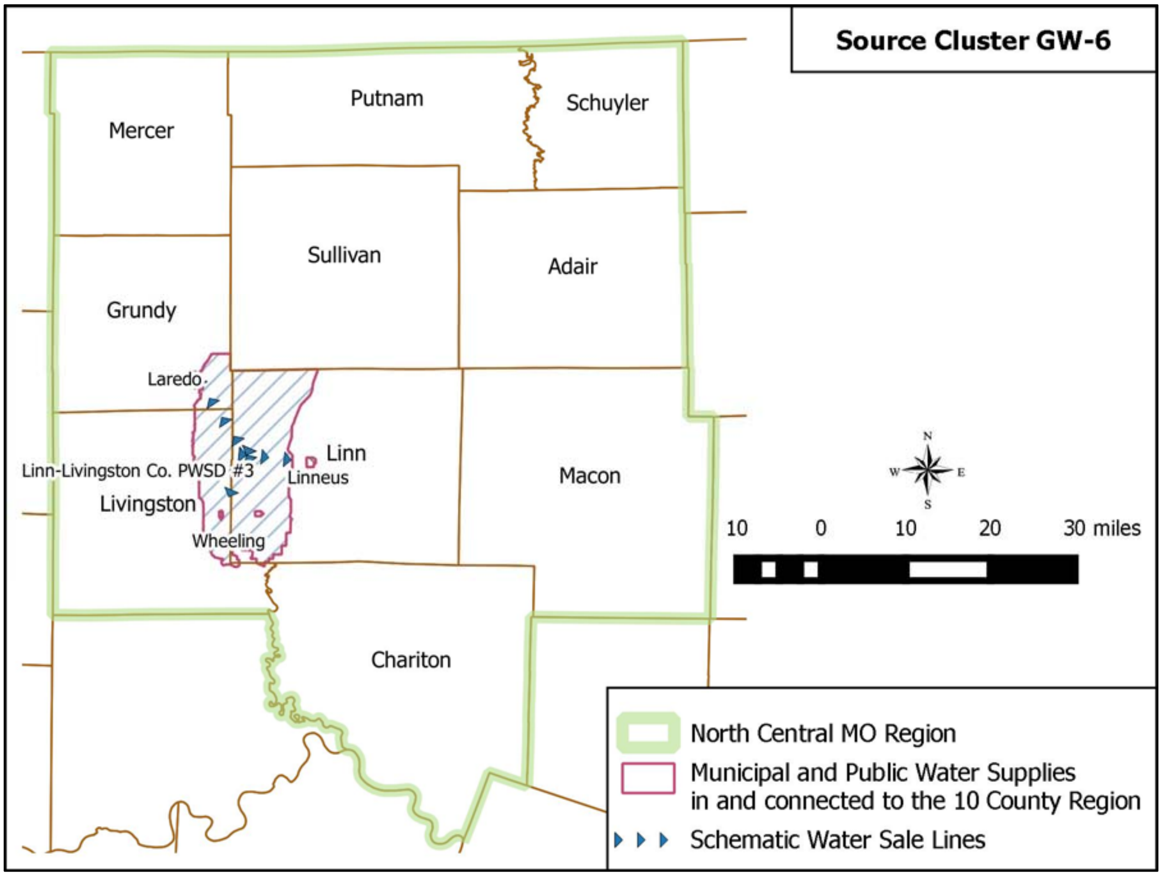
CENTER FOR APPLIED RESEARCH AND ENVIRONMENTAL SYSTEMS UNIVERSITY OF MISSOURI

Missouri Department of Natural Resources

| Well Number | W1 | W2 | W3 | W4 | W5 |
|---|---|---|---|---|---|
| Extended PWS # | 2024346101 | 2024346102 | 2024346103 | 2024346104 | 2024346105 |
| Local Well Name | Well #1 | Well #2 | Well #3 | Well #4 | Well #5 |
| Well ID # | 13867 | 13868 | 13869 | 13870 | 18025 |
| DGLS ID # | | | | | |
| Facility Type | Water District | Water District | Water District | Water District | Water District |
| Status | Active | Active | Active | Active | Active |
| Latitude | 39.97714 | 39.97447 | 39.98082 | 39.97539 | 39.97756 |
| Longitude | -93.19603 | -93.19761 | -93.20074 | -93.1975 | -93.19429 |
| Location Method | DRG/MAP | GPS | DRG/MAP | GPS | DRG/MAP |
| Method Accuracy (ft) | 33 | 75 | 33 | 75 | 90 |
| USGS 7.5 Quadrangle | Linneus | Linneus | Linneus | Linneus | Linneus |
| County | Linn | Linn | Linn | Linn | Linn |
| MoDNR Region | Northeast | Northeast | Northeast | Northeast | Northeast |
| Date Drilled (year) | 1969 | | | 1997 | |
| Material (C/U) | Unconsolidated | Unconsolidated | Unconsolidated | Unconsolidated | |
| Base of Casing Formation | Alluvium | | | Alluvium | |
| Total Depth Formation | Alluvium | | | Alluvium | |
| Total Depth | 78 | | | 72 | |
| Ground Elevation (ft) | 758 | 748 | 722 | 764 | |
| Top Seal | Pitless Adapter | | | Cement Grout | |
| Bottom Seal | Cement Grout | | | | |
| Casing Depth (ft) | | | | 59 | |
| Casing Size (in) | | | | 8 | |
| Casing Type | Steel | | | Steel | |
| Elev. of Casing Top (ft) | | | | | |
| Outer Casing Depth (ft) | | | | 20 | |
| Outer Casing Size (in) | | | | 18 | |
| Screen Length (ft) | | | | 13 | No Screen |
| Screen Size (in) | | | | 8 | No Screen |
| Static Water Level (ft) | 40 | | | | |
| Well Yield (gpm) | | | | | |
| Head (ft) | | | | 125 | |
| Draw Down (ft) | | | | | |
| Pump Test Date (year) | | | | | |
| Pump Type | Submersible | | | Submersible | |
| Pump Manufacturer | Reda | | | | |
| Pump Depth (ft) | 60 | | | | |
| Pump Capacity (gpm) | 50 | | 55 | 105 | |
| Pump Meter (Y/N) | N | | | | |
| VOC Detection (Y/N) | N | N | N | N | |
| Nitrate Detection (Y/N) | N | N | N | N | |
| Chlorination (Y/N) | Y | Y | Y | | |
| Filtration (Y/N) | Y | Y | Y | | |
| GWUDISW (Y/N) | | | | | |
| Surface Drainage | Satisfactory | | | | |
| State Approved(Y/N) | | | | | |
| Date Abandoned (year) | | | | | |
| Date Plugged (year) | | | | | |

# Cluster GW-6

**Sources Inadequate**




Three wells currently provide water for Cluster GW-6, which is owned and operated by Linn-Livingston County PWSD #3. MDNR records indicate wells #1, #3, and #4 are active. Well #2 is inactive due to high sand content and reduced yield. Well #1 is treated for iron bacteria every six to eight weeks during production, which is about four to five months a year. Laredo, a wholesale customer of Linn-Livingston County PWSD #3, closed its groundwater treatment plant due to high iron in 2000. Wheeling, also a wholesale customer, closed its groundwater treatment plant after decades of struggling with declining yield and high iron content as well. A listing of the closed systems within all the clusters can be found in Appendix C.

The current water demands in the cluster are detailed in the following table and total 0.168 MGD of treated water.

Given the history of declining wells and location in glacial deposits, this evaluation has identified Cluster GW-6's sources as inadequate.

| 2015-2016 Cluster Average Daily Production and Demand (Treated Water Quantities) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Source Cluster | Tier System | | | | | MGD Produced | % purchase from supplier | Total MGD Consumed |
| | 1st | 2nd | 3rd | 4th | 5th | | | |
| GW-6 | Linn-Livingston PWSD #3 | | | | | 0.168 | | 0.107 |
| | | Laredo | | | | | 100% | 0.013 |
| | | Linneus | | | | | 100% | 0.028 |
| | | Wheeling | | | | | 100% | 0.020 |

# Linn-Livingston Co. PWSD #3

## PWSS No. 2024350

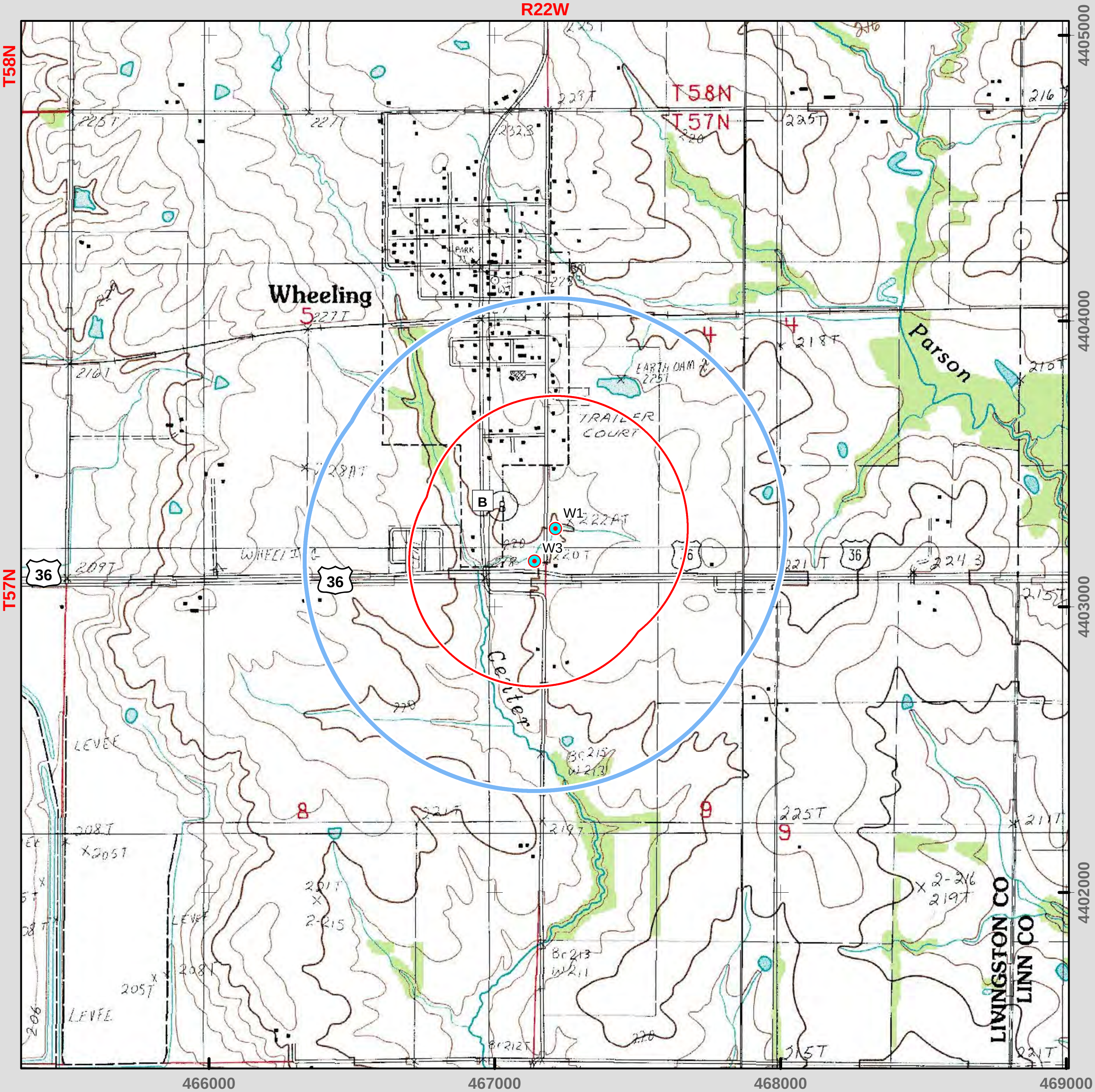
2 Wells, Livingston County

Prepared by:

CENTER FOR APPLIED RESEARCH AND ENVIRONMENTAL SYSTEMS
UNIVERSITY OF MISSOURI

Map Update: Jan 22, 2016

Missouri Department of
Natural Resources



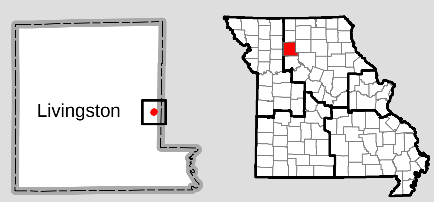

**Well System**

System Well

**SWAP Delineation Boundary**

20-year time of travel

Half-mile buffer




Feet

0 1,600 3,200

SWAP - Source Water Assessment Plan --
http://drinkingwater.missouri.edu/swap/
For basemap symbols, see the U.S. Geological Survey (USGS) publication: Topographic Map Symbols.

# Linn-Livingston Co. PWSD #3

PWSS No. 2024350

Livingston County

2 wells

Prepared by:

CENTER FOR APPLIED RESEARCH AND ENVIRONMENTAL SYSTEMS
UNIVERSITY OF MISSOURI

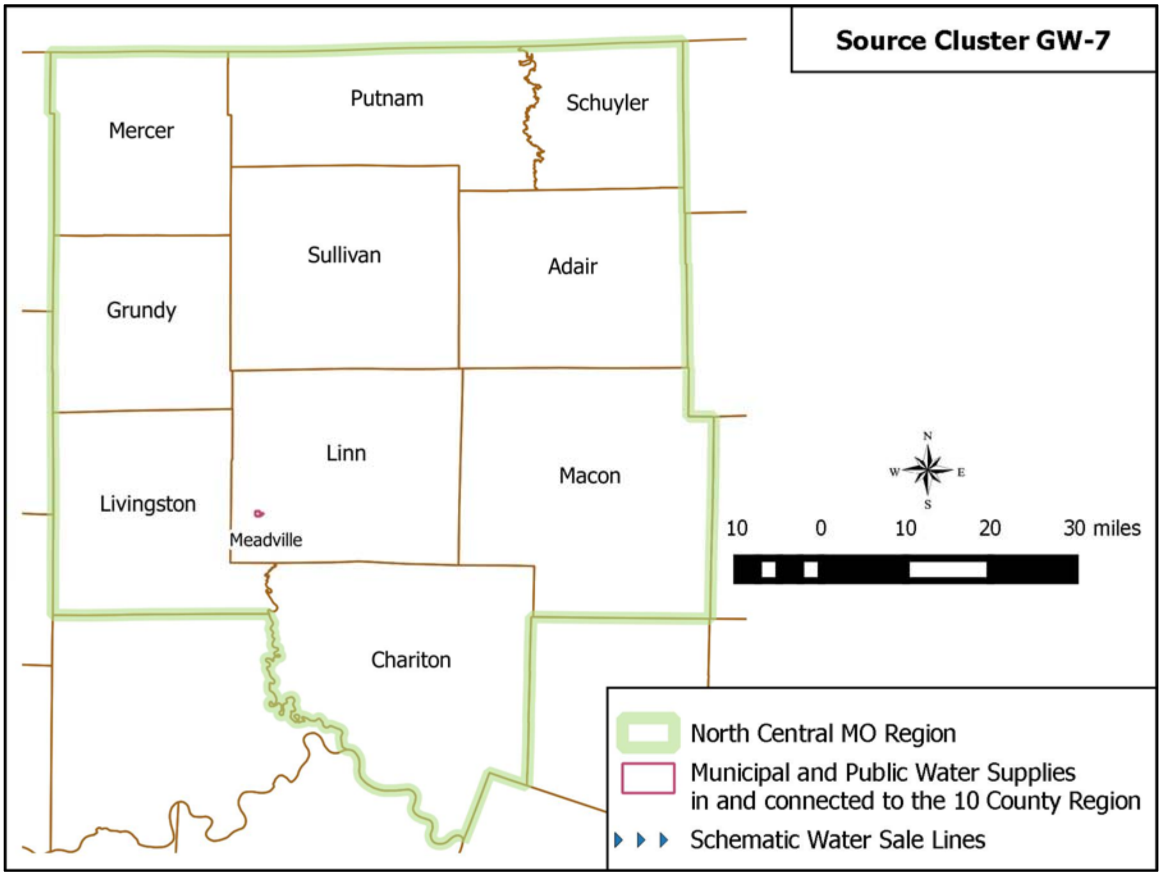
Sheet Update: Jan 25, 2016

Missouri Department of
Natural Resources

| | | |
|---|---|---|
| Well Number | W1 | W3 |
| Extended PWS # | 2024350101 | 2024350103 |
| Local Well Name | Well #1, Old Well | Well #3 |
| Well ID # | 13831 | 18093 |
| DGLS ID # | | |
| Facility Type | Water District | Water District |
| Status | Active | Active |
| Latitude | 39.77878 | 39.77775 |
| Longitude | -93.38288 | -93.383722 |
| Location Method | DRG/MAP | GPS |
| Method Accuracy (ft) | 33 | 98 |
| USGS 7.5 Quadrangle | Wheeling | Wheeling |
| County | Livingston | Livingston |
| MoDNR Region | Northeast | Northeast |
| Date Drilled (year) | 1964 | 2000 |
| Material (C/U) | Unconsolidated | Unconsolidated |
| Base of Casing Formation | Glacial Deposits | Glacial Deposits |
| Total Depth Formation | Glacial Deposits | Glacial Deposits |
| Total Depth | 137 | 131 |
| Ground Elevation (ft) | 754 | |
| Top Seal | | |
| Bottom Seal | | |
| Casing Depth (ft) | 115 | 116 |
| Casing Size (in) | 12 | 18 |
| Casing Type | Steel | Steel |
| Elev. of Casing Top (ft) | | |
| Outer Casing Depth (ft) | | |
| Outer Casing Size (in) | | |
| Screen Length (ft) | 15 | 15 |
| Screen Size (in) | 30 | |
| Static Water Level (ft) | 58 | |
| Well Yield (gpm) | 225 | |
| Head (ft) | | |
| Draw Down (ft) | 20 | 21 |
| Pump Test Date (year) | 1992 | |
| Pump Type | Vertical Turbine | |
| Pump Manufacturer | | |
| Pump Depth (ft) | | |
| Pump Capacity (gpm) | | 250 |
| Pump Meter (Y/N) | Y | |
| VOC Detection (Y/N) | N | |
| Nitrate Detection (Y/N) | N | |
| Chlorination (Y/N) | Y | |
| Filtration (Y/N) | Y | |
| GWUDISW (Y/N) | N | |
| Surface Drainage | | |
| State Approved(Y/N) | Y | |
| Date Abandoned (year) | | |
| Date Plugged (year) | | |

# Cluster GW-7

**Sources Inadequate**




Cluster GW-7 is supplied by two groundwater wells, which are owned and operated by the City of Meadville, Missouri. Well #1 and Well #3 yield approximately 60 gpm each to provide water to the 50 gpm, iron removal, water treatment plant. These two wells are located within 20 feet of each other. The 2015 average daily normal demand was 0.033 MGD serving a population of approximately 450.

Given the location of the wells in glacial deposits, this evaluation has identified Cluster GW-7's sources as inadequate.

# Meadville

## PWSS No. 2010512

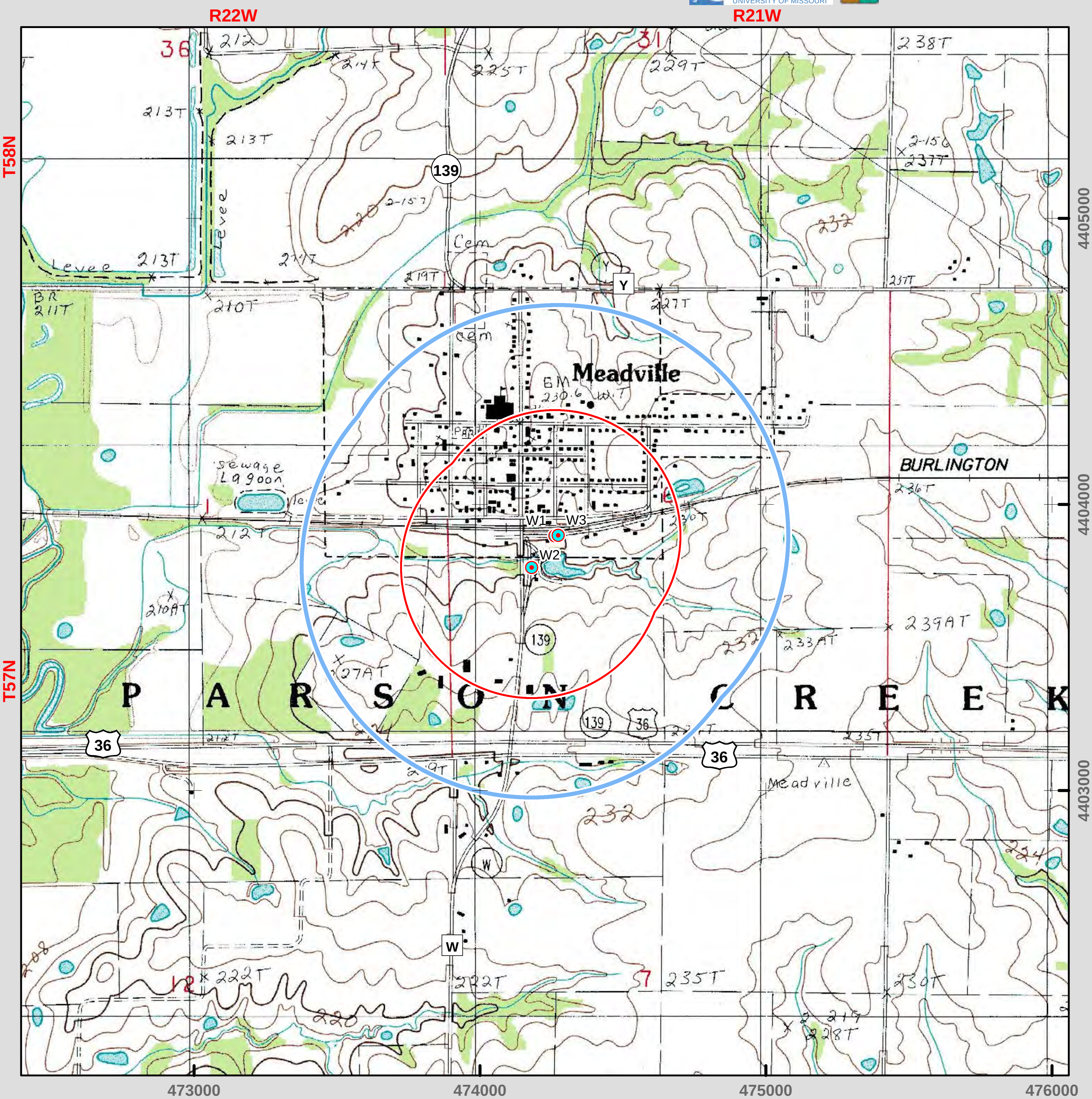
3 Wells, Linn County

Prepared by:

Map Update: Jan 22, 2016

CENTER FOR APPLIED RESEARCH AND ENVIRONMENTAL SYSTEMS UNIVERSITY OF MISSOURI

Missouri Department of Natural Resources



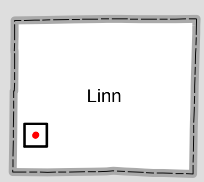

**Well System**

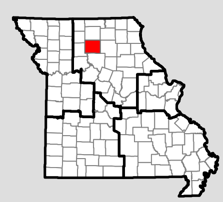
System Well

**SWAP Delineation Boundary**

20-year time of travel

Half-mile buffer



Feet

0 1,600 3,200

SWAP - Source Water Assessment Plan --
http://drinkingwater.missouri.edu/swap/
For basemap symbols, see the U.S. Geological Survey (USGS) publication: Topographic Map Symbols.

# Meadville

PWSS No. 2010512

Linn County

3 wells

Prepared by: CENTER FOR APPLIED RESEARCH AND ENVIRONMENTAL SYSTEMS UNIVERSITY OF MISSOURI

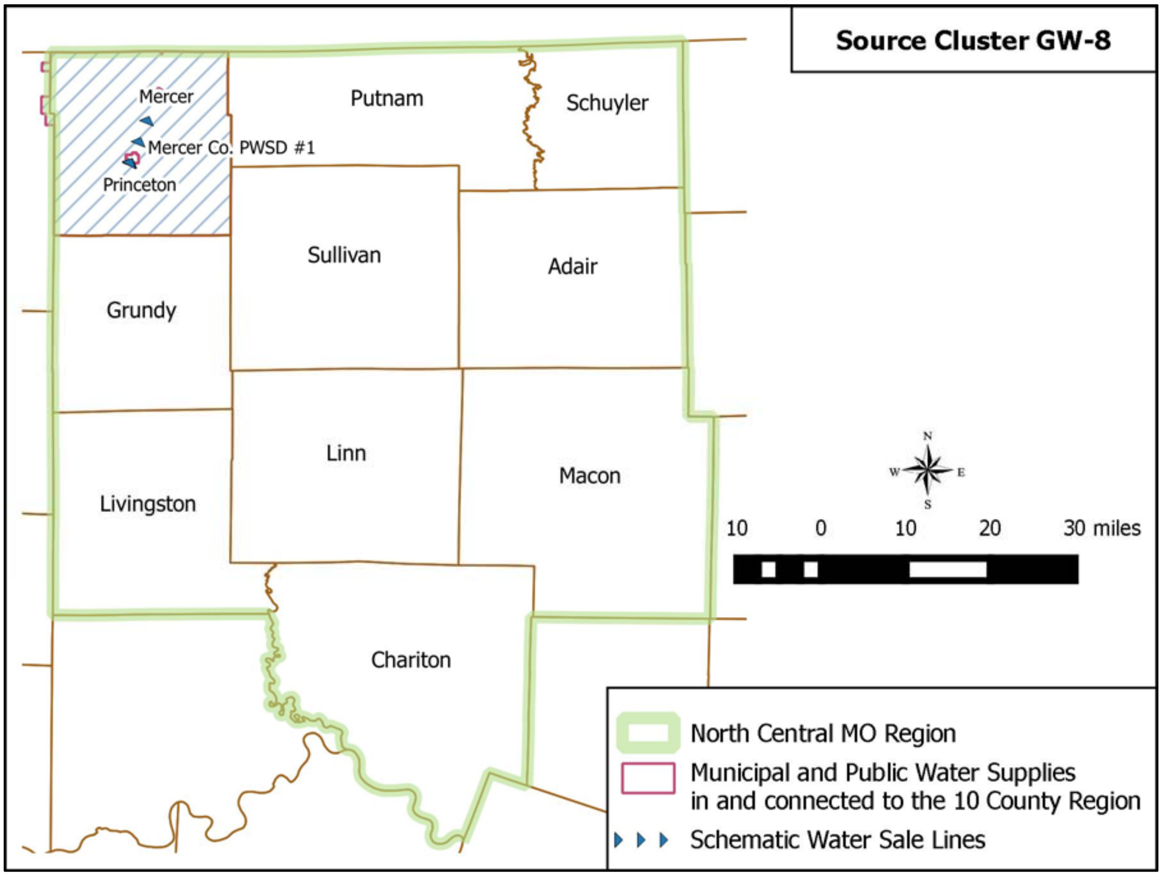
Sheet Update: Jan 25, 2016

Missouri Department of Natural Resources

| | | | |
|---|---|---|---|
| Well Number | W1 | W2 | W3 |
| Extended PWS # | 2010512101 | 2010512102 | 2010512103 |
| Local Well Name | Well #1 | Well #2 | Well #3 |
| Well ID # | 14937 | 14936 | 14938 |
| DGLS ID # | | | |
| Facility Type | City | City | City |
| Status | Active | Emergency | Active |
| Latitude | 39.78458 | 39.78358 | 39.78459 |
| Longitude | -93.30058 | -93.30152 | -93.30045 |
| Location Method | DRG/MAP | DRG/MAP | DRG/MAP |
| Method Accuracy (ft) | 33 | 33 | 33 |
| USGS 7.5 Quadrangle | Meadville | Meadville | Meadville |
| County | Linn | Linn | Linn |
| MoDNR Region | Northeast | Northeast | Northeast |
| Date Drilled (year) | 1954 | 1954 | 1977 |
| Material (C/U) | Unconsolidated | Unconsolidated | Unconsolidated |
| Base of Casing Formation | Glacial Deposits | Glacial Deposits | Glacial Deposits |
| Total Depth Formation | Glacial Deposits | Glacial Deposits | Glacial Deposits |
| Total Depth | 70 | 68 | 82 |
| Ground Elevation (ft) | | | |
| Top Seal | | | |
| Bottom Seal | | | |
| Casing Depth (ft) | | | 74 |
| Casing Size (in) | | | 16 |
| Casing Type | Steel | Steel | Steel |
| Elev. of Casing Top (ft) | | | |
| Outer Casing Depth (ft) | | | |
| Outer Casing Size (in) | | | |
| Screen Length (ft) | | | 10 |
| Screen Size (in) | | | 10 |
| Static Water Level (ft) | | | 43 |
| Well Yield (gpm) | | | 35 |
| Head (ft) | | | |
| Draw Down (ft) | | | 34 |
| Pump Test Date (year) | | | 1977 |
| Pump Type | Vertical Turbine | | Submersible |
| Pump Manufacturer | | | |
| Pump Depth (ft) | | | 77 |
| Pump Capacity (gpm) | 50 | 50 | 40 |
| Pump Meter (Y/N) | Y | | Y |
| VOC Detection (Y/N) | N | N | N |
| Nitrate Detection (Y/N) | N | N | N |
| Chlorination (Y/N) | | | Y |
| Filtration (Y/N) | Y | | Y |
| GWUDISW (Y/N) | N | | N |
| Surface Drainage | | | |
| State Approved(Y/N) | | | Y |
| Date Abandoned (year) | | | |
| Date Plugged (year) | | | |

# Cluster GW-8

Sources Inadequate




Cluster GW-8 is served by six groundwater wells owned and operated by the City of Princeton, Missouri. These wells are documented as being located in the alluvium of the Weldon River. MDNR records indicate eight wells pugged or inactive in the system, detailed in the Well History table below. Given the history of declining wells Cluster GW-8 is identified as having inadequate soures.

| **Well History** | | | | |
|---|---|---|---|---|
| **Well #** | **Status** | **Year Drilled** | **Year Abandoned** | **Year Plugged** |
| Well # 1 | Plugged | 1973 | - | 2009 |
| Well # 1, Old | Plugged | - | 1995 | 1995 |
| Well # 2B | Plugged | 1968 | - | 2002 |
| Well # 3 | Inactive | 1971 | - | - |
| Well # 5 | Plugged | - | - | 2002 |
| Well # 7 | Plugged | 1978 | - | 2002 |
| Well # 12 | Plugged | - | 1995 | 1995 |
| Well # 13 | Plugged | - | 1995 | 1995 |

The Production and Demand table below details the 2015 average consumption of the 0.137 MGD within the cluster.

| 2015-2016 Cluster Average Daily Production and Demand (Treated Water Quantities) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Tier System | | | | | | | |
| Source Cluster | 1st | 2nd | 3rd | 4th | 5th | MGD Produced | % purchase from supplier | Total MGD Consumed |
| GW-8 | Princeton | | | | | 0.137 | | 0.078 |
| | | Mercer | | | | | 100% | 0.024 |
| | | Mercer County PWSD #1 | | | | | 18% | 0.195 |

# Princeton

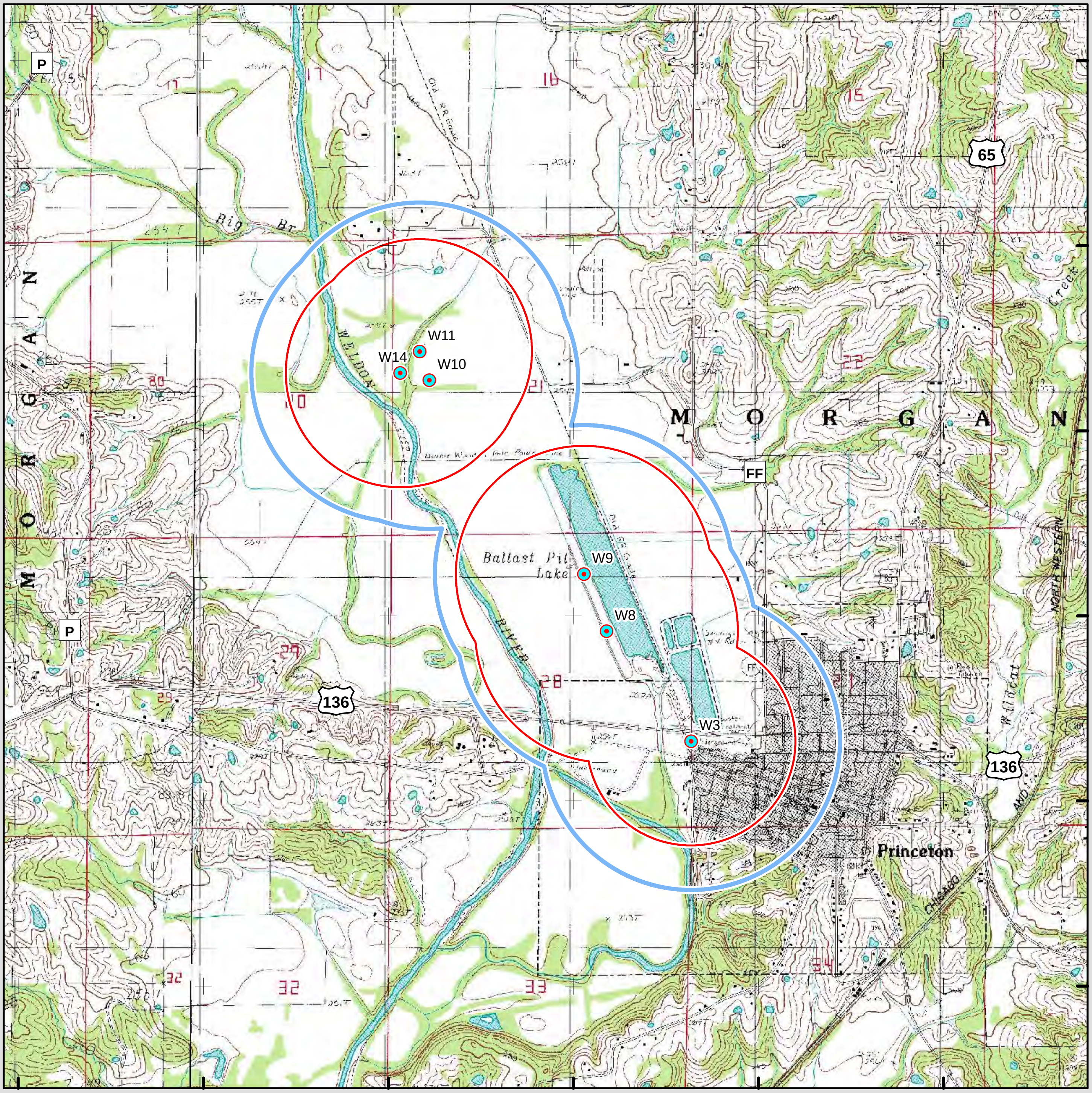
## PWSS No. 2010664

6 Wells, Mercer County

Prepared by: CENTER FOR APPLIED RESEARCH AND ENVIRONMENTAL SYSTEMS UNIVERSITY OF MISSOURI

Map Update: Jan 22, 2016

Missouri Department of Natural Resources



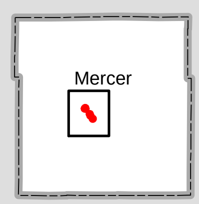

**Well System**

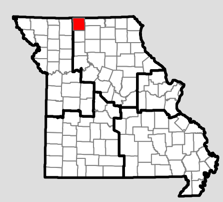
System Well

**SWAP Delineation Boundary**

20-year time of travel

Half-mile buffer



Miles

0 0.5 1

SWAP - Source Water Assessment Plan --
http://drinkingwater.missouri.edu/swap/
For basemap symbols, see the U.S. Geological Survey (USGS) publication: Topographic Map Symbols.

# Princeton

PWSS No. 2010664

Mercer County, sheet 1 of 2

6 wells

Sheet Update: Jan 25, 2016

Prepared by: Center for Applied Research and Environmental Systems, University of Missouri

Missouri Department of Natural Resources

| Well Number | W3 | W8 | W9 | W10 | W11 |
|---|---|---|---|---|---|
| Extended PWS # | 2010664103 | 2010664108 | 2010664109 | 2010664110 | 2010664111 |
| Local Well Name | Well #2A | Well #8 | Well #9 | Well #10 | Well #11 |
| Well ID # | 13680 | 14544 | 14543 | 14546 | 14545 |
| DGLS ID # | | | | | |
| Facility Type | City | City | City | City | City |
| Status | Active | Active | Active | Active | Active |
| Latitude | 40.4 | 40.40533 | 40.4081 | 40.41749 | 40.41884 |
| Longitude | -93.5935 | -93.59893 | -93.6004 | -93.61033 | -93.61114 |
| Location Method | DRG/MAP | DRG/MAP | DRG/MAP | DRG/MAP | DRG/MAP |
| Method Accuracy (ft) | 33 | 33 | 33 | 33 | 33 |
| USGS 7.5 Quadrangle | Princeton | Princeton | Princeton | Princeton | Princeton |
| County | Mercer | Mercer | Mercer | Mercer | Mercer |
| MoDNR Region | Northeast | Northeast | Northeast | Northeast | Northeast |
| Date Drilled (year) | 1957 | 1980 | 1980 | 1995 | |
| Material (C/U) | Unconsolidated | Unconsolidated | Unconsolidated | Unconsolidated | Unconsolidated |
| Base of Casing Formation | Alluvium | Alluvium | Alluvium | Alluvium | Alluvium |
| Total Depth Formation | Alluvium | Alluvium | Alluvium | Alluvium | Alluvium |
| Total Depth | 42 | 37 | 39 | 45 | 44 |
| Ground Elevation (ft) | 830 | 825 | 825 | 825 | 825 |
| Top Seal | | | | | Cement Grout |
| Bottom Seal | | | | | Cement Grout |
| Casing Depth (ft) | | 27 | 29 | | 35 |
| Casing Size (in) | | 16 | 16 | | 24 |
| Casing Type | | Steel | Steel | Steel | Steel |
| Elev. of Casing Top (ft) | | | | | |
| Outer Casing Depth (ft) | | 35 | 34 | 40 | 30 |
| Outer Casing Size (in) | | 36 | 36 | 26 | 48 |
| Screen Length (ft) | 10 | 10 | 10 | 15 | 10 |
| Screen Size (in) | | 16 | 16 | 26 | 24 |
| Static Water Level (ft) | 12 | 18 | 19 | | 18 |
| Well Yield (gpm) | 65 | 90 | 90 | | 225 |
| Head (ft) | | 75 | 75 | 88 | 89 |
| Draw Down (ft) | 10 | 11 | 13 | | 18 |
| Pump Test Date (year) | | | | | |
| Pump Type | Submersible | Submersible | Submersible | Submersible | Submersible |
| Pump Manufacturer | | Sta-Rite | Sta-Rite | | |
| Pump Depth (ft) | 32 | 29 | | | 37 |
| Pump Capacity (gpm) | 80 | 105 | 115 | 150 | 150 |
| Pump Meter (Y/N) | | Y | Y | | |
| VOC Detection (Y/N) | N | N | N | N | N |
| Nitrate Detection (Y/N) | N | N | N | N | N |
| Chlorination (Y/N) | Y | Y | Y | Y | |
| Filtration (Y/N) | Y | Y | Y | | |
| GWUDISW (Y/N) | | | | | |
| Surface Drainage | | | | | |
| State Approved(Y/N) | | | | | Y |
| Date Abandoned (year) | | | | | |
| Date Plugged (year) | | | | | |

# Princeton

PWSS No. 2010664

Mercer County, sheet 2 of 2

6 wells

Prepared by: CENTER FOR APPLIED RESEARCH AND ENVIRONMENTAL SYSTEMS UNIVERSITY OF MISSOURI

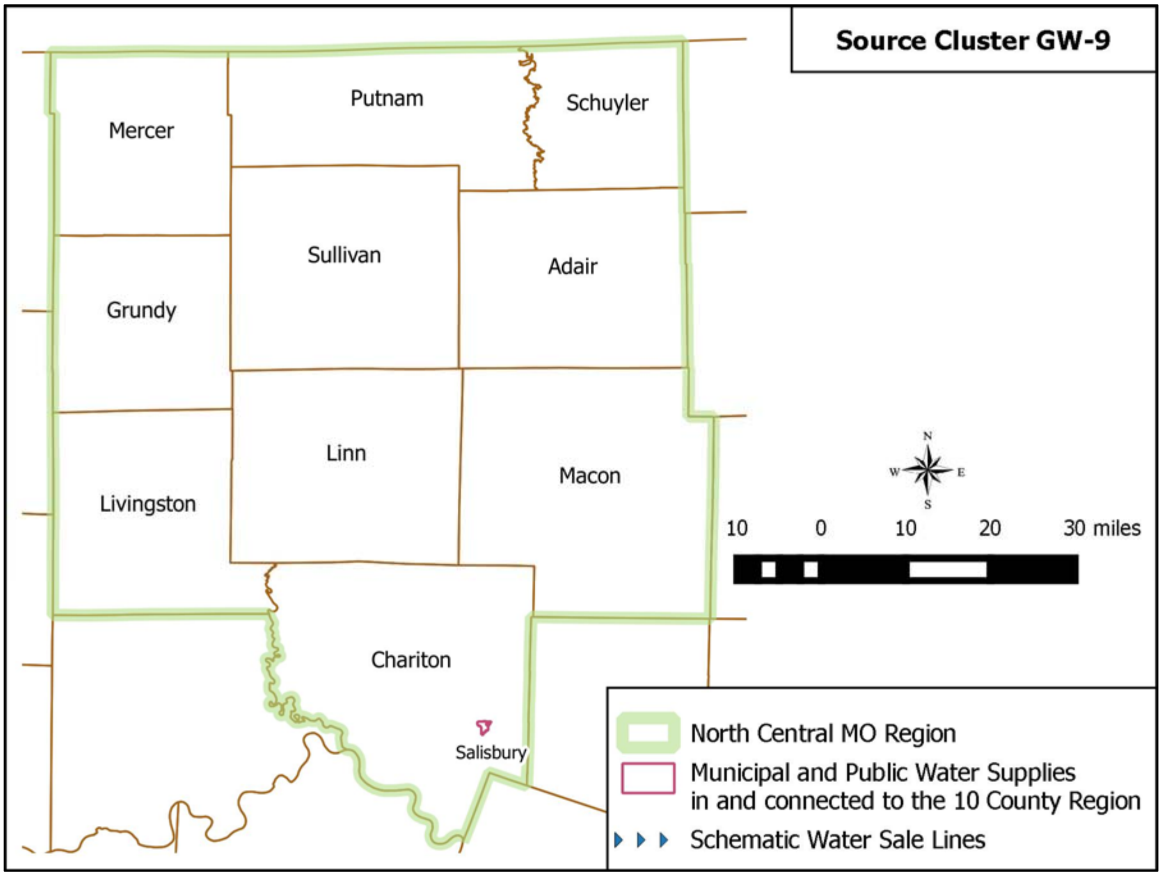
Sheet Update: Jan 25, 2016

Missouri Department of Natural Resources

| | |
|---|---|
| Well Number | W14 |
| Extended PWS # | 2010664114 |
| Local Well Name | Well #12 |
| Well ID # | 17224 |
| DGLS ID # | |
| Facility Type | City |
| Status | Active |
| Latitude | 40.41783 |
| Longitude | -93.61218 |
| Location Method | GPS |
| Method Accuracy (ft) | 75 |
| USGS 7.5 Quadrangle | Princeton |
| County | Mercer |
| MoDNR Region | Northeast |
| Date Drilled (year) | 2004 |
| Material (C/U) | Unconsolidated |
| Base of Casing Formation | Glacial Deposits |
| Total Depth Formation | Glacial Deposits |
| Total Depth | 44 |
| Ground Elevation (ft) | 825 |
| Top Seal | |
| Bottom Seal | |
| Casing Depth (ft) | 41 |
| Casing Size (in) | 24 |
| Casing Type | |
| Elev. of Casing Top (ft) | 846.5 |
| Outer Casing Depth (ft) | 31 |
| Outer Casing Size (in) | 48 |
| Screen Length (ft) | 10 |
| Screen Size (in) | 24 |
| Static Water Level (ft) | 19 |
| Well Yield (gpm) | |
| Head (ft) | 89 |
| Draw Down (ft) | |
| Pump Test Date (year) | |
| Pump Type | Submersible |
| Pump Manufacturer | |
| Pump Depth (ft) | |
| Pump Capacity (gpm) | 150 |
| Pump Meter (Y/N) | Y |
| VOC Detection (Y/N) | |
| Nitrate Detection (Y/N) | |
| Chlorination (Y/N) | |
| Filtration (Y/N) | |
| GWUDISW (Y/N) | |
| Surface Drainage | |
| State Approved(Y/N) | |
| Date Abandoned (year) | |
| Date Plugged (year) | |

# Cluster GW-9

**Sources adequate**




Cluster GW-9 is supplied by two groundwater wells, which are owned and operated by the City of Salisbury, Missouri. Well #1 has high ammonia content and is not actively used. Well #2 and Well #3 are alternated in use having a routine yield of approximately 300 gpm in the alluvium of the Chariton River. The 2015 average daily normal demand was 0.175 MGD which was produced by the iron removal water treatment plant (MDNR 2016).

Given the proximity to the Chariton River and no known history of declining yield wells, Cluster GW-9 is identified as having adequate sources.

# Salisbury

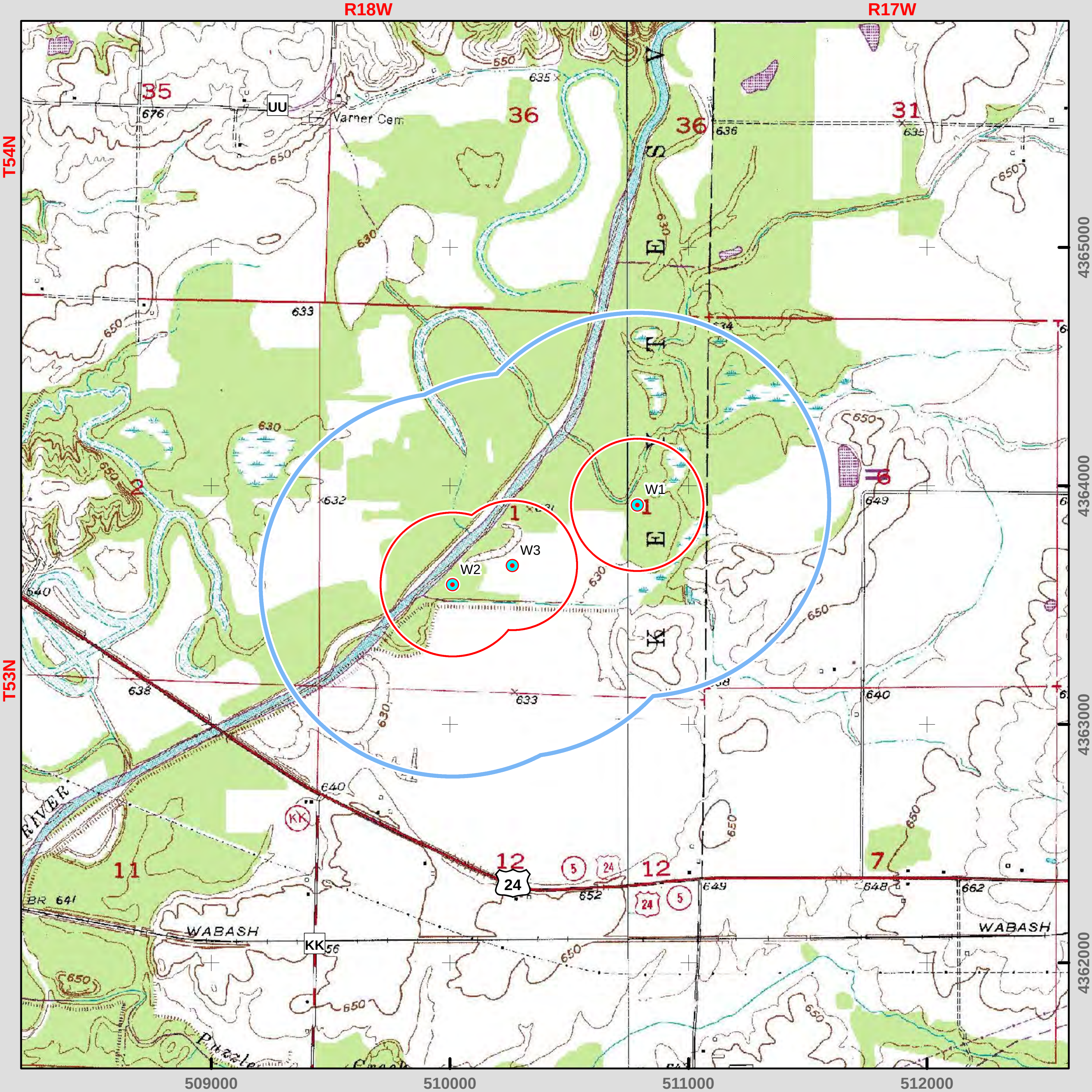
## PWSS No. 2010722

3 Wells, Chariton County

Prepared by: CENTER FOR APPLIED RESEARCH AND ENVIRONMENTAL SYSTEMS, UNIVERSITY OF MISSOURI

Map Update: Jan 22, 2016

Missouri Department of Natural Resources




**Well System**

System Well

**SWAP Delineation Boundary**

20-year time of travel

Half-mile buffer


Feet

0 1,900 3,800

SWAP - Source Water Assessment Plan --
http://drinkingwater.missouri.edu/swap/
For basemap symbols, see the U.S. Geological Survey (USGS) publication: Topographic Map Symbols.

Although all data in this dataset have been used by the Missouri Department of Natural Resources (MoDNR), no warranty, expressed or implied, is made by MoDNR as to the accuracy of the data and related materials. The act of distribution shall not constitute any such warranty, and no responsibility is assumed by MoDNR in the use of these data or related materials. This map is subject to change as additional information is acquired. Additional information at: http://drinkingwater.missouri.edu.

# Salisbury

PWSS No. 2010722

Chariton County

3 wells

Prepared by:

CENTER FOR APPLIED RESEARCH AND ENVIRONMENTAL SYSTEMS UNIVERSITY OF MISSOURI

Sheet Update: Jan 25, 2016

Missouri Department of Natural Resources

| | | | |
|---|---|---|---|
| Well Number | W1 | W2 | W3 |
| Extended PWS # | 2010722101 | 2010722102 | 2010722103 |
| Local Well Name | Well #1 | Well #2 | Well #3 |
| Well ID # | 14628 | 14630 | 14629 |
| DGLS ID # | | | |
| Facility Type | City | City | City |
| Status | Emergency | Active | Active |
| Latitude | 39.42475 | 39.42175 | 39.422472 |
| Longitude | -92.874694 | -92.883694 | -92.880778 |
| Location Method | GPS | GPS | GPS |
| Method Accuracy (ft) | 100 | 100 | 100 |
| USGS 7.5 Quadrangle | Salisbury | Keytesville | Keytesville |
| County | Chariton | Chariton | Chariton |
| MoDNR Region | Northeast | Northeast | Northeast |
| Date Drilled (year) | 1980 | 1981 | 1980 |
| Material (C/U) | Unconsolidated | Unconsolidated | Unconsolidated |
| Base of Casing Formation | Alluvium | Alluvium | Alluvium |
| Total Depth Formation | Alluvium | Alluvium | Alluvium |
| Total Depth | 68 | 60 | 70 |
| Ground Elevation (ft) | 738 | 663 | 613 |
| Top Seal | | | |
| Bottom Seal | | | |
| Casing Depth (ft) | 68 | 60 | 70 |
| Casing Size (in) | 24 | 24 | 24 |
| Casing Type | Steel | Steel | Steel |
| Elev. of Casing Top (ft) | 645 | 648 | 645 |
| Outer Casing Depth (ft) | | | |
| Outer Casing Size (in) | | | |
| Screen Length (ft) | 12 | 12 | 12 |
| Screen Size (in) | 24 | 24 | 24 |
| Static Water Level (ft) | 30 | 28 | 30 |
| Well Yield (gpm) | 250 | 250 | 250 |
| Head (ft) | 42 | 42 | 44 |
| Draw Down (ft) | 36 | 35 | 38 |
| Pump Test Date (year) | 1980 | 1981 | 1980 |
| Pump Type | Vertical Turbine | Vertical Turbine | Vertical Turbine |
| Pump Manufacturer | | | |
| Pump Depth (ft) | 55 | 55 | 55 |
| Pump Capacity (gpm) | 600 | 600 | 600 |
| Pump Meter (Y/N) | Y | Y | Y |
| VOC Detection (Y/N) | N | N | N |
| Nitrate Detection (Y/N) | N | N | N |
| Chlorination (Y/N) | Y | Y | Y |
| Filtration (Y/N) | Y | Y | Y |
| GWUDISW (Y/N) | N | N | N |
| Surface Drainage | | | |
| State Approved(Y/N) | Y | Y | Y |
| Date Abandoned (year) | | | |
| Date Plugged (year) | | | |

## Summary of Groundwater Cluster Evaluations

Approximately 39 percent of Missouri's population is served by groundwater sources (MDNR 2015). In 2015, the groundwater sources of north-central Missouri, accounted for approximately 15.5 percent (2.122 MGD) of the total (13.723 MGD) treated drinking water produced in the 10-county study area. This percentage supports the claims of geologists, well drillers, engineers, and planners that there is a pronounced lack of quality, plentiful groundwater in north-central Missouri. If quality, plentiful groundwater were available in the region, it would be reasonable to assume that comparing the percentage of the total water produced would be similar to that of the state. Additionally, it would be reasonable to assume that there would be more than nine groundwater systems in the four of 10 counties within the region that utilize groundwater as a source of raw water.

Of the 2.122 MGD of groundwater produced in the region, Chillicothe Municipal Utilities (Cluster GW-3) provided nearly 1.30 MGD or 61.3 percent of the total average daily demand supplied by groundwater. This large volume producer also comports with geologic analysis which states: "In general, the most favorable alluvial deposits appear to be those of the lower parts of the Grand and Chariton rivers." (MDNR 1997) The other eight groundwater clusters provided a combined total average of 0.822 MGD. A total of four of the 9 groundwater systems in the study region are located within the alluvium of the Grand and Chariton rivers. They include Chillicothe, Missouri American-Brunswick, Keytesville, and Salisbury.

Other groundwater systems in the study region include: Livingston County PWSD #2, Princeton, Linn County Consolidated PWSD #1, Meadville, and Linn-Livingston PWSD #3 and are located in pre-glacial deposits or smaller stream modern alluvium. The fact that these systems have found enough water, after extensive test hole drilling, to supply their current demand is also explained by Miller as, "pre-glacial alluvial deposits are, unfortunately, limited in areal extent, and are found in rather narrow linear trends, much the same as modern alluvial valleys" (MDNR 1997).

An example of a public water system struggling to find quality and plentiful water is Linn County Consolidated PWSD #1 (Cluster GW-5). A letter explaining the unsuccessful findings from Brotcke Well and Pump from 2003 is included in Appendix B. The embedded map from that letter details the locations of over 30 drilled test wells from 1966-2003. Because of the low average daily demand of 0.085 MGD, the cluster has been able to meet demand with the existing wells, although system staff indicated that Well #2 is virtually unusable due to excessive iron content.

Wells in this region are in decline and losing yield. This has resulted in the closing of 16 groundwater treatment facilities since 1980 and numerous closed/abandoned wells of the current groundwater systems. Appendix C lists the closed systems in the region and Appendix F contains a table of closed wells for active groundwater systems.

Under current demand conditions and the cumulative history of the region, this evaluation has determined that three of the nine ground water clusters might provide an adequate source of dependable quality water for the future. These systems are GW-2 (MO American- Brunswick), GW-3 (Chillicothe Municipal Utilities), and GW-9 (Salisbury). These three systems provided 1.559 MGD (or 73.5 percent) of treated ground water within the study region in 2015. The remaining 0.563 MGD, of treated groundwater, was provided by six systems, ranging in production from 0.033 MGD to 0.168 MGD. The corresponding raw water demand of the six inadequate source clusters, estimating 10 percent treatment losses, totals 0.619 MGD.

A complete listing of the Groundwater Cluster Production and Demand Table from 2015 is located in Appendix K. The impact of inadequate cluster water sources could result in the complete depletion of water in six of nine the existing clusters. Figure 10, below, shows clusters with inadequate sources in red and those with adequate sources, in green. Each segment of the pie corresponds to a groundwater producer within the 10-county region. The size of each segment is proportionate to the average daily demand produced by each system, shown as the value at the end of the labels in MGD.

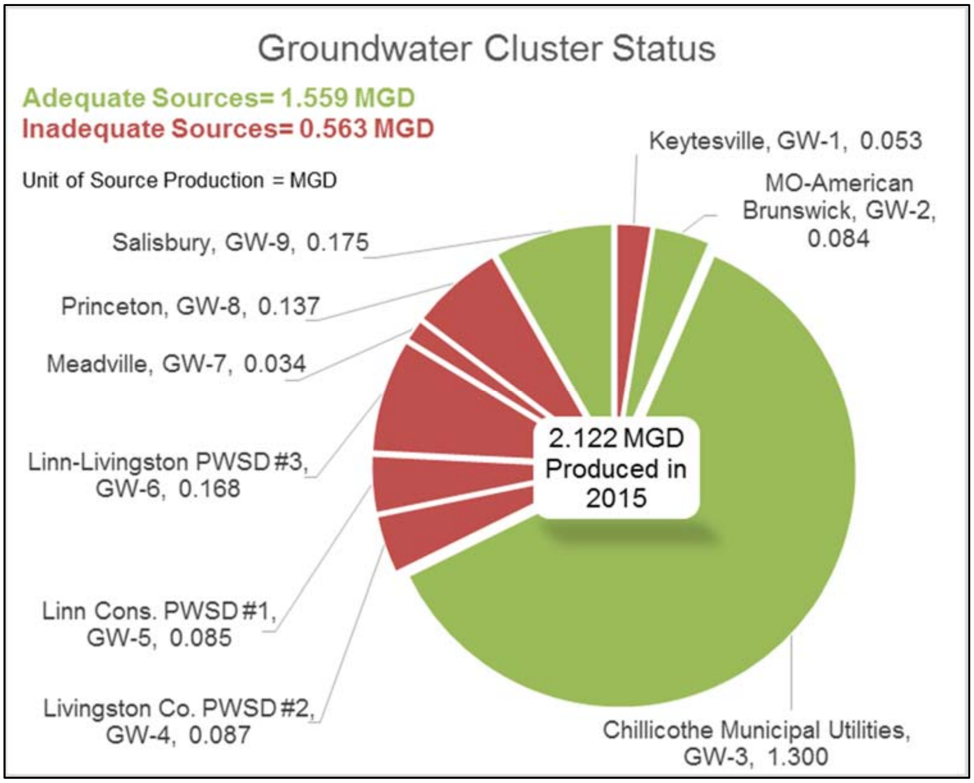



*Figure 10: Groundwater Source Cluster Summary*

## Overview of Out-of-Region Cluster Evaluations

A total of three out-of-region suppliers provided 1.035 MGD of treated water within the 10-county study region in 2015. Both Rathbun Regional Water Association (OR-1) and Clarence Cannon Wholesale Water Commission (OR-2) provide treated surface water via direct wholesale connections. Livingston County PWSD #4 (OR-3) serves customers and is based within the region, but the groundwater wells are located in adjacent Daviess County. Wholesale customers of the Livingston County PWSD#4 are located in Daviess and Caldwell counties, neither of which are within the study region.

Given that the evaluation herein is for sources within the 10-county region of study, analysis of sources outside the region is irrelevant, except that there are communities within the study region depend on those sources for water daily. The underlying assumption is that out-of-region sources will be able to provide the current quantity of water into the future.

Figure 11, below, shows the proximity of the out-of-region surface water sources for OR-1 and OR-2 to the 10-county region.

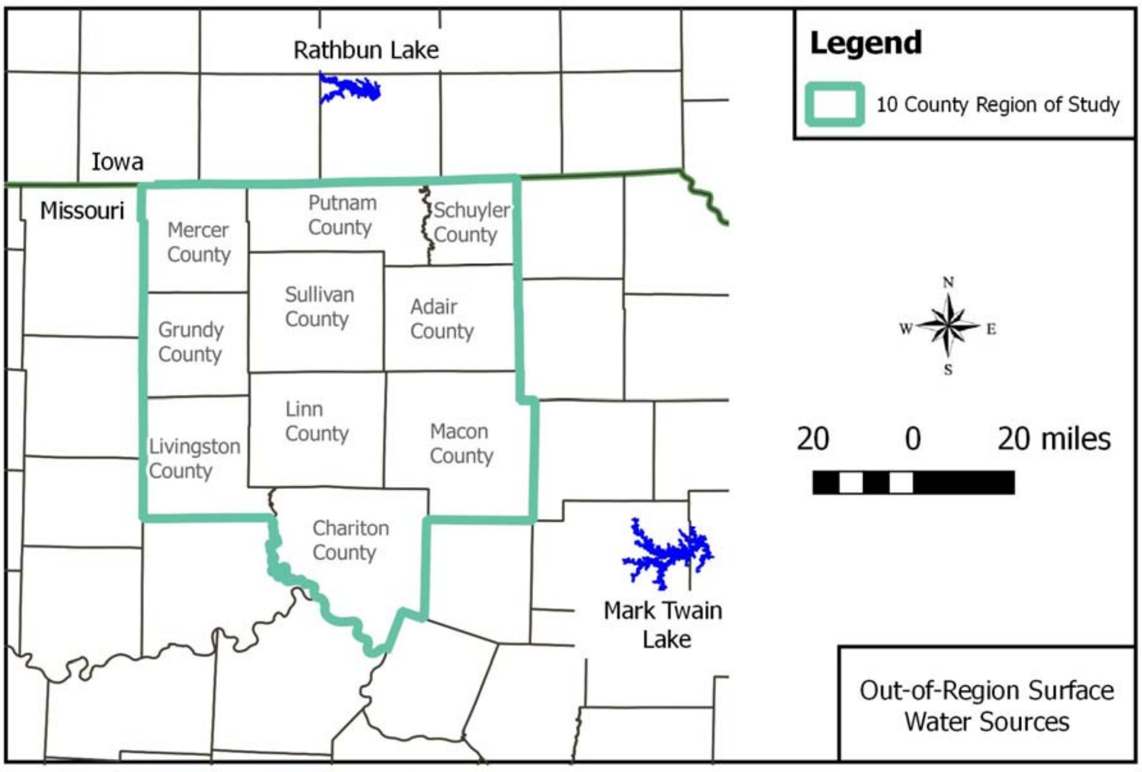


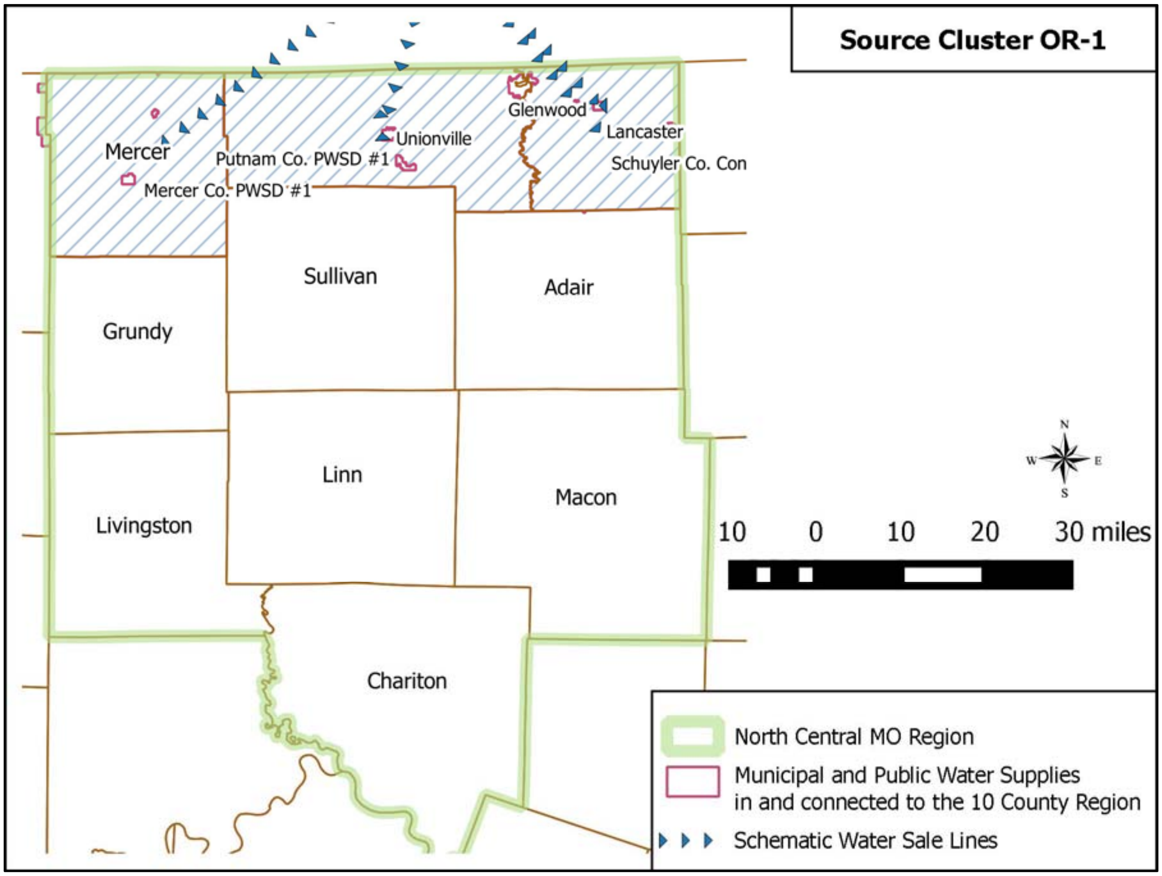

*Figure 11: Out-of-Region Surface Water Sources*

The following out-of-region cluster reports provide information about the systems dependent on the sources from outside of the region. Specific information in regard to drought resistance of those specific sources would have required extensive understanding, cooperation, and research to analyze each regional supply, their demands, and effecting conditions. This was additional research was beyond the scope of this evaluation.

# Out-of-Region Reports OR-1 to OR-3

# Cluster OR-1

**Source Inadequate**




The U.S. Army Corps of Engineers built Rathbun Lake in 1970 as a flood control, recreation, and water supply reservoir. Initially 6,680 acre-feet of the total drinking water allocation of 15,000 acre-feet, was contracted to the Rathbun Regional Water Association who treats the surface water supply. The remaining 8,320 acre-feet were designated as a first right of refusal for Rathbun Regional Water Association, who supplies treated water to over 14 Iowa counties and four Missouri counties.

An important note about OR-1 is that Rathbun Regional Water Association is located in Iowa. Water conveyance across state lines is explicitly listed in 455B.266 Priority Allocation which states:

“2. Notwithstanding a person's possession of a permit or the person's use of water being a nonregulated use, the department may suspend or restrict usage of water by category of use on a local or statewide basis in the following order:

a. Water conveyed across state boundaries.
*b.* Water used primarily for recreational or aesthetic purposes.
*c.* Uses of water for the irrigation of any general crop.
*d.* Uses of water for the irrigation of any specialty crop.
*e.* Uses of water for manufacturing or other industrial processes.
*f.* Uses of water for generation of electrical power for public consumption.
*g.* Uses of water for livestock production.
*h.* Uses of water for human consumption and sanitation supplied by rural water districts, municipal water systems, or other public water supplies. (Iowa 2016)”

Mr. John Glenn of Rathbun Regional Water Association spoke about the drought of 2012 in an April 2013 article of Wallaces Farmer, stating, ”RRWA’s water treatment plant averaged 7.5 million gallons per day last summer with the peak day producing 10.2 mgd, quite a feat considering the plant’s designed capacity is only 8 mgd. Peak demand is strongly tied to livestock use. “Livestock use accounted for up to one-half of RRWA peak water demand last summer," says Glenn. "More than 70 new service connections for livestock were installed in 2012, up from the five-year average of 20 per year (Chester 2013)."

At that time a second water treatment facility was under construction and Glenn was quoted again in the December 2013 Wallace Farmer, saying: "We are now able to supply more than14 million gallons of water daily to customers, almost double our capacity before this project," says Glenn. "This additional supply of drinking water is essential for RRWA to be able to support continued economic and community development efforts across our service territory (Chester 2013b)."

From that same article "Marty Braster, RRWA environmental specialist, says based on previous growth trends and water usage per meter, RRWA is now well prepared to meet the projected demand of peak daily use of 14 million gallons a day by 2035.(Chester 2013b)."

In 2015, Rathbun Regional Water Association provided 0.557 MGD of treated water, or approximately 47 percent of the total 1.175 out-of-region water. Given following list of factors it is reasonable to categorize OR-1 as an inadequate source for Missouri communities:

- Peak demands due to drought were 36 percent above normal demand in 2012
- Rathbun is part of community development and economic growth to over 14 counties in Iowa
- Availability of water during extreme drought depends upon choices made by another state
- Restriction of water conveyance over a state boundary is the first legal priority in allocation

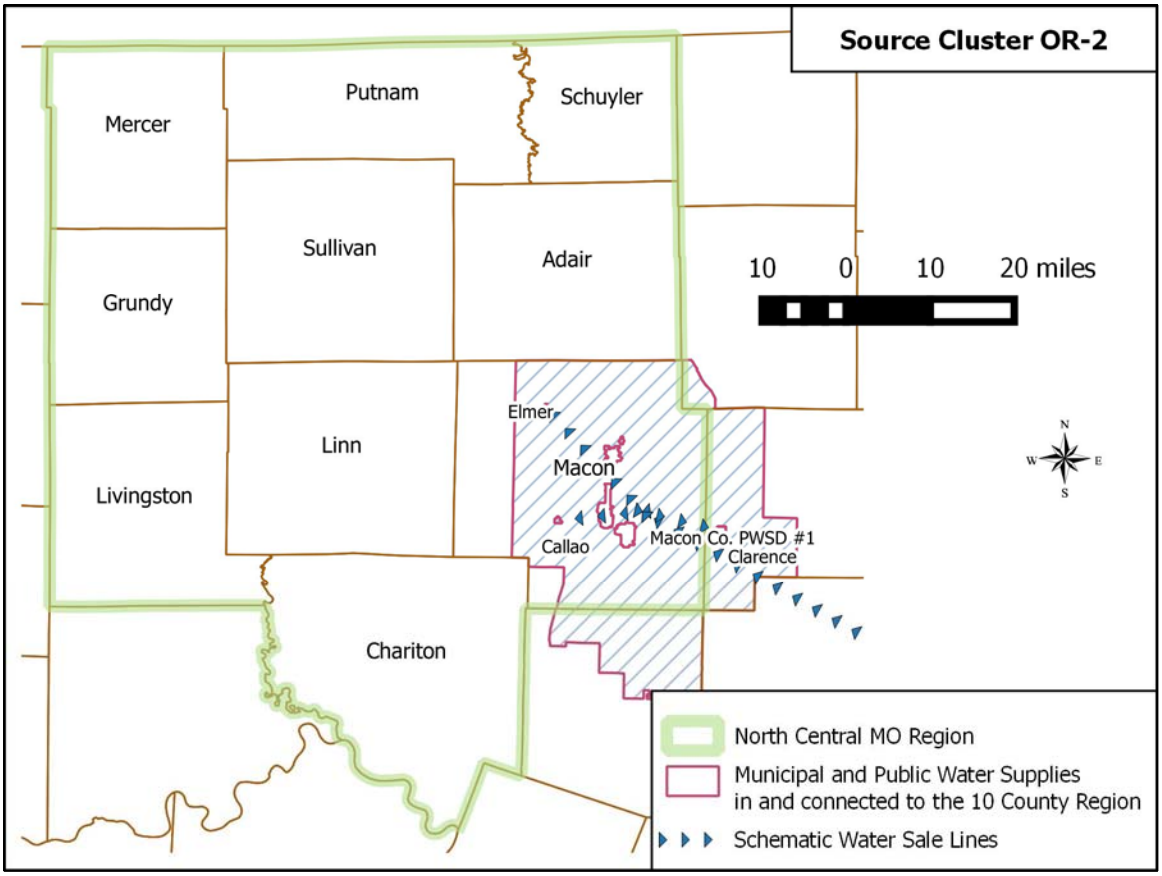
The impact of this inadequate source categorization is that nearly eight second and third tier systems will be without water, at current demand totaling 0.557 MGD. Therefore, Cluster OR-1 is identified as an inadequate source.

The Production and Demand table below details the Missouri communities dependent upon Rathbun for treated water. Note that Adair PWSD #1 is a third tier system to Rathbun and receives 0.25 percent of its total 0.463 MGD (or 0.001 MGD) from Rathbun. The systems listed below Adair PWSD#1 in this table do not receive water from Rathbun and were not included in the Cluster OR-1 map above.

| 2015-2016 Cluster Average Daily Production and Demand (Treated Water Quantities) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Source Cluster | Tier System | | | | | MGD Produced | % purchase from supplier | Total MGD Consumed |
| | 1st | 2nd | 3rd | 4th | 5th | | | |
| OR-1 | Rathbun | | | | | 0.557 | | |
| | | Lancaster | | | | | 100% | 0.065 |
| | | | Glenwood | | | | 100% | 0.013 |
| | | Mercer County PWSD #1 | | | | | 95% | 0.160 |
| | | Putnam County PWSD #1 | | | | | 32% | 0.207 |
| | | | Lake Thunderhead HOA | | | | 100% | 0.021 |
| | | Schuyler County CPWSD #1 | | | | | 100% | 0.266 |
| | | | Downing | | | | 100% | 0.026 |
| | | | Adair PWSD #1 | | | | 0.25% | 0.463 |
| | | | | Brashear | | | 100% | 0.014 |
| | | | | LaPlata | | | 100% | 0.079 |
| | | | | Novinger | | | 100% | 0.026 |
| | | | | Macon County PWSD #1 | | | 1% | 0.014 |
| | | | | | Callao | | 100% | 0.024 |
| | | | | | Clarence | | 100% | 0.065 |
| | | | | | Elmer | | 100% | 0.005 |

# Cluster OR-2

**Source Adequate**




Clarence Cannon Wholesale Water Commission provides treated surface water from Mark Twain Lake in Ralls County Missouri. Mark Twain was constructed by the U.S. Army Corps of Engineers in 1983 on the Salt River to provide flood control, hydroelectricity, public water supply, recreation and navigation. Based on a three-party contract between the U.S. Army Corps of Engineers, the state of Missouri, and the Clarence Cannon Wholesale Water Commission, 20,000 acre-feet of the nearly 400,000 acre-feet within the beneficial use pool, was designated for drinking water supply.

In 2015, the Clarence Cannon Wholesale Water Commission provided 0.278 MGD to the 10-county study region, as detailed in the Production and Demand table below. Cluster OR-2 has an adequate source as determined by this evaluation.

The following excerpt is from the Mark Twain Lake Master Plan 2015 (USACE 2015):

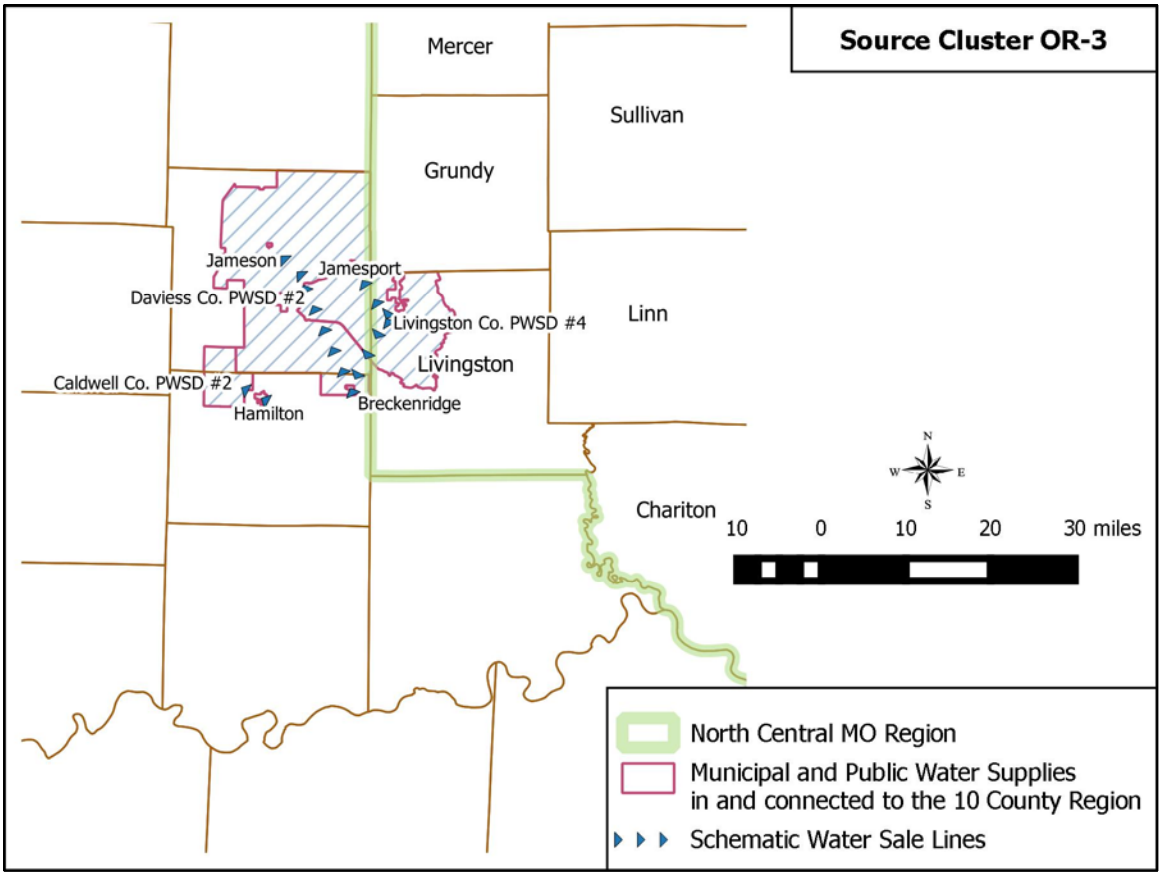
> “Water Treatment Plant, Clarence Cannon Wholesale Water Commission. This regional water treatment plant is located four miles west of Florida, Missouri off of State Highway U. This facility was constructed in 1991and1992. The production and sale of water to members began on June 16, 1992. The Clarence Cannon Wholesale Water Commission (CCWWC) entered into a three party contract with the US Army Corps of Engineers and the State of Missouri to purchase water storage space in Mark Twain Lake. The contract allows for removal of a maximum of 16 million gallons of raw water per day with an allowance for a failure rate of 2 years out of every 100 years for not being able to supply the full 16 million gallons per day. The CCWWC owns the rights to 5.0 million gallons of storage space, while the remaining 11.0 million gallons of water per day are available to them through contract with the State of Missouri. The CCWWC facilities consists of a 4.5 million gallons per day surface water treatment plant, which uses

flocculation, sedimentation, and filtration to purify raw water to acceptable standards for drinking purposes. In addition to the main facilities, the infrastructure consists of 325 miles of transmission mains, four booster pumping stations, a raw water intake structure located on the North Fork Branch of Mark Twain Lake, and daily storage space for 4.5 million gallons of drinking water. The CCWWC currently serves potable water for use by 15 cities, 14 counties, 9 water districts and 72,942 people. Expansion is underway to serve additional customers."

| 2015-2016 Cluster Average Daily Production and Demand (Treated Water Quantities) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Source Cluster | Tier System | | | | | MGD Produced | % purchase from supplier | Total MGD Consumed |
| | 1st | 2nd | 3rd | 4th | 5th | | | |
| OR-2 | Clarence Cannon | | | | | 0.278 | | |
| | | Macon County PWSD #1 | | | | | 18% | 1.523 |
| | | | Callao | | | | 100% | 0.024 |
| | | | Clarence | | | | 100% | 0.080 |
| | | | Elmer | | | | 100% | 0.005 |

# Cluster OR-3

**Sources Adequate**




Livingston County PWSD #4 provides groundwater via three wells located in Daviess County, Missouri. Daviess County is not within the 10-county study region; therefore, this cluster is considered out-of-region. The water district serves customers in both Livingston and Daviess counties, and it also wholesales water to customers in Caldwell and Daviess counties. MDNR well data show that two glacial alluvial wells drilled in the 1970s yielded approximately 200 gpm each of water for the system. In 2010, a new well was located in the nearby Grand River alluvium and is recorded to have a yield of 500 gpm. This new source brought new customers in 2014 when Breckenridge, Missouri and Jamesport, Missouri chose to close their surface water treatment plants. The Production and Demand table below details the 0.340 MGD of treated water produced in 2015 and the communities reliant upon it. Only the 0.200 MGD of the produced water is considered consumption by the district customers within the 10 county region. The other supply goes to communities outside the region and is not included in the summary calculations. Cluster OR-3 is identified as an adequate source given its history and reliability.

| 2015-2016 Cluster Average Daily Production and Demand (Treated Water Quantities) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Source Cluster | Tier System | | | | | MGD Produced | % purchase from supplier | Total MGD Consumed |
| | 1st | 2nd | 3rd | 4th | 5th | | | |
| | Livingston Co. PWSD 4 | | | | | 0.340 | | 0.200 |
| | | Jamesport | | | | | 100% | 0.040 |
| | | Daviess PWSD #2 | | | | | 40% | 0.100 |
| | | | Jameson | | | | 100% | 0.006 |
| | | | Breckenridge | | | | 100% | 0.001 |
| | | | Hamilton | | | | 22% | 0.050 |
| | | | | Caldwell Co. PWSD #2 | | | 100% | |

## Summary of Out-of-Region Cluster Evaluations

An important note about OR-1 is that Rathbun Regional Water Association is located in Iowa and water conveyance across state lines is explicitly listed in Iowa Administrative Code (IAC) 567-subrule 52.10(2) which states:

> “2. Notwithstanding a person's possession of a permit or the person's use of water being a nonregulated use, the department may suspend or restrict usage of water by category of use on a local or statewide basis in the following order: a. Water conveyed across state boundaries.”

Rathbun Regional Water Association provided 0.557 MGD of treated water, or approximately 47 percent of the total 1.035 MGD out-of-region water in 2015. Given that the availability of water during extreme drought depends upon choices made by another state, it is reasonable to categorize OR-1 as an inadequate source. This is explained in the Cluster OR-1 report. The impact of this categorization is that nearly eight second and third-tier systems will be without water, at current demand totaling 0.557 MGD.

A complete listing of the Out-of-Region System Cluster Production & Demand Table from 2015 is located in Appendix L. Figure 12, below, shows clusters with inadequate sources in red and those with adequate sources in green. Each segment of the pie corresponds to a water producer from outside the 10-county region. The size of each segment is proportionate to the average daily demand supplied by each system to the region, shown as the value at the end of the labels in MGD.

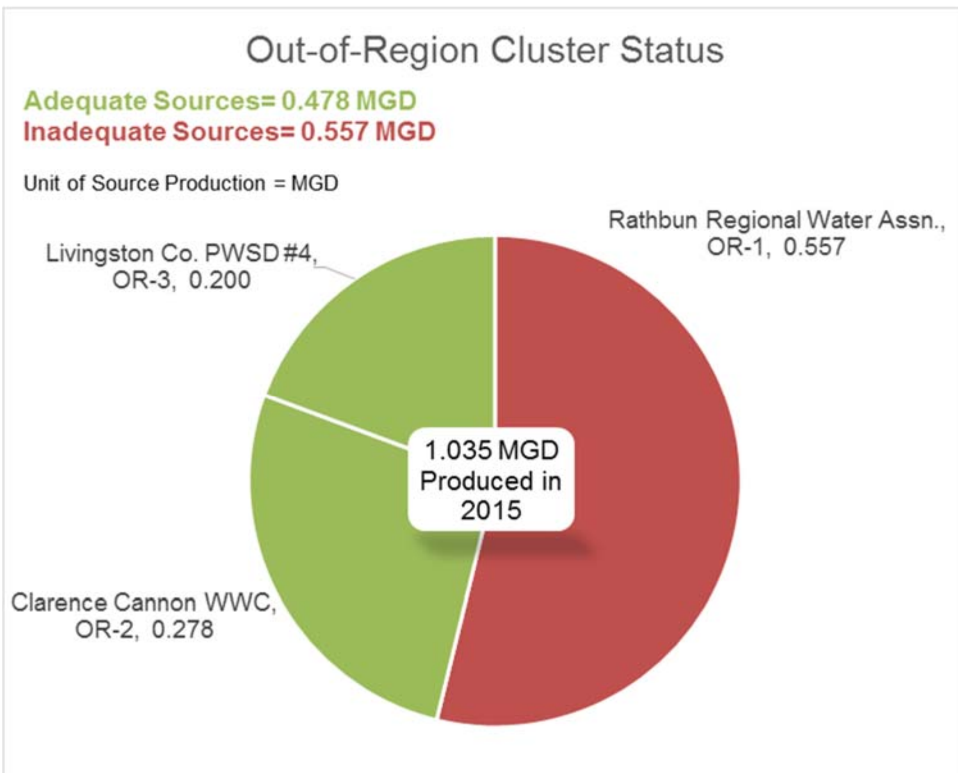



*Figure 12: Out-of-Region Cluster Status*

## Summary of Findings

The evaluation, herein, included surface water and groundwater sources serving communities the in the north-central Missouri 10-county region of study including Adair, Chariton, Grundy, Linn, Livingston, Macon, Mercer, Putnam, Schuyler, and Sullivan counties. By evaluating clusters of drinking water providers and their customers, the determination of sufficient, reliable raw water for the 10 county region, as a whole, was possible. The analysis was based upon the following assumptions:

- Current daily raw water demands remain constant
- DOR recharge conditions
- 50 years of sediment loading for surface water systems
- Water sources are sized according to current MDNR design requirements
- Geologic and hydrogeological evidence
- Local history and information specific to water supply

The clusters were divided into three subsets, surface water clusters (SW-1 through SW-6), groundwater clusters (GW-1 through GW-9) and out-of-region clusters (OR-1 through OR-3). These 18 clusters, comprised of 19 water producers provided 13.723 MGD of treated water within the 10-county region in 2015 (this quantity does not include impending demand from Kraft-Heinz). Figure 13, below, summarizes the production from the individual cluster reports by out-of-region and source water type.

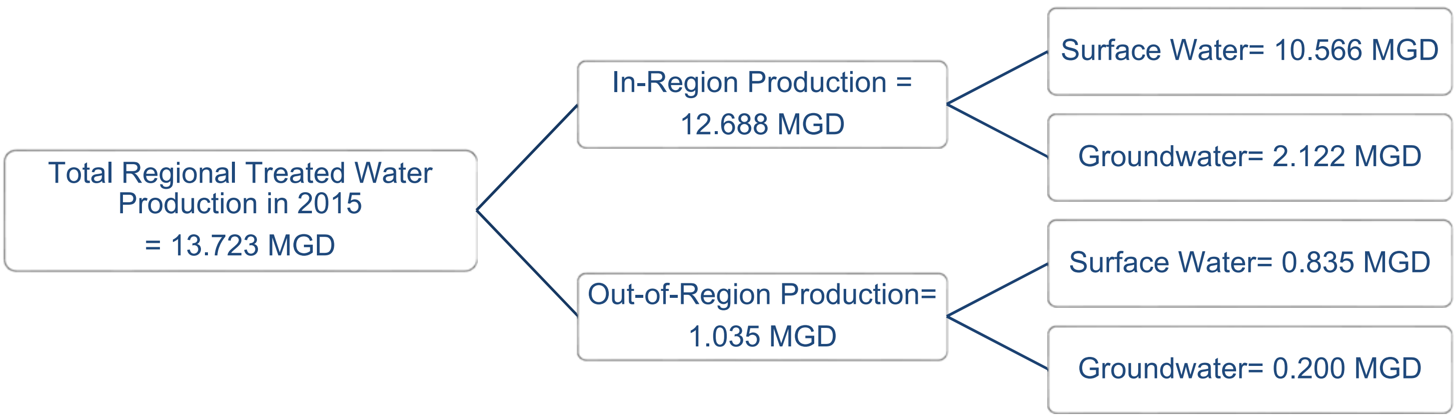
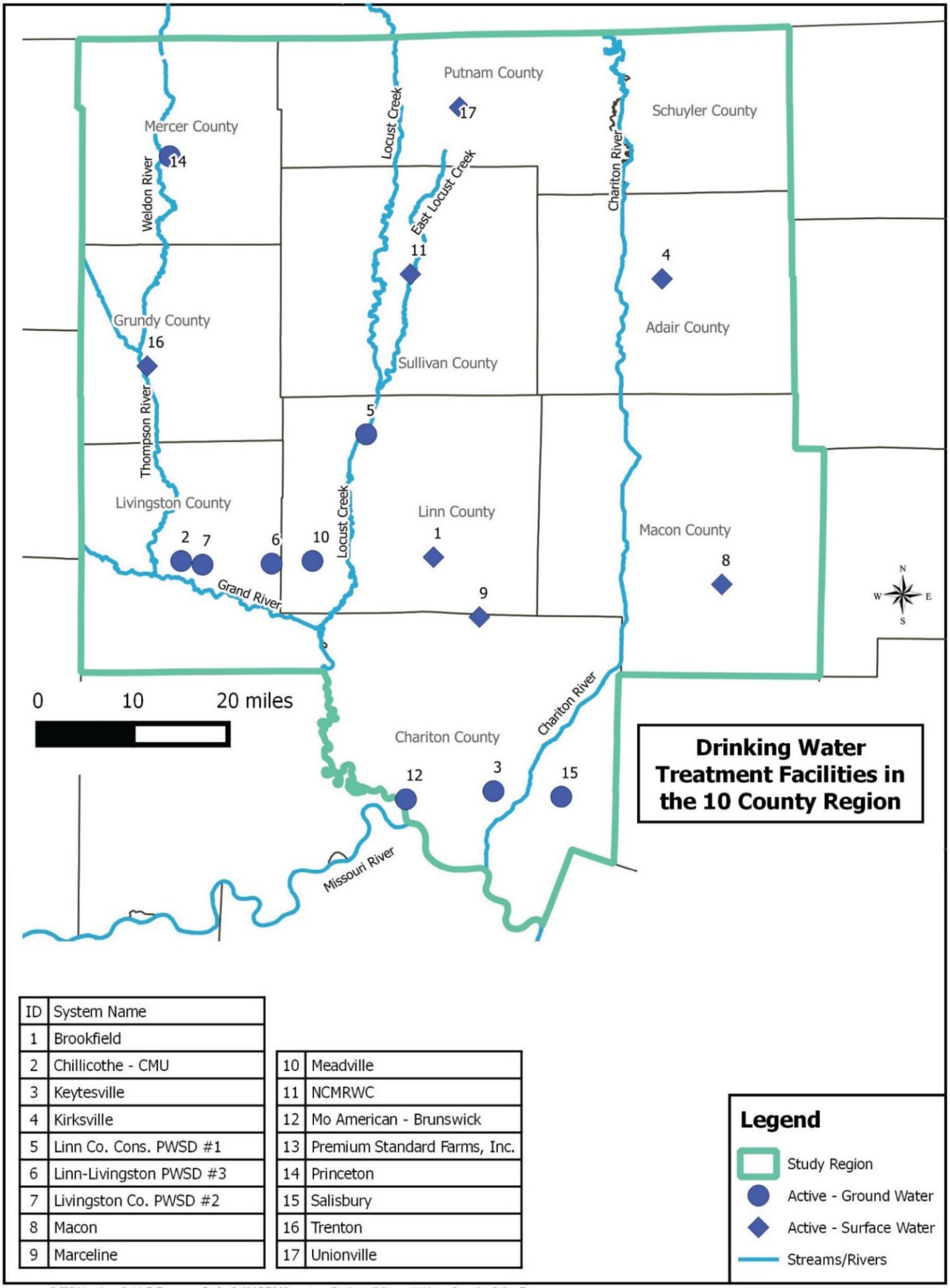



*Figure 13: 2015 Water Provided to 10-county region*

Figure 14, summarizes the type of source water in respect to the total amount of treated water produced for the 10-county region in 2015.


*Figure 14: Total Water Produced in 10-county region in 2015.*

Figure 15, below, details the current location and source water type of the active public water systems in the 10-county region of study. Note that out-of-region sources are not depicted on this figure. Additionally, six of the 10-counties have one source of water and Schuyler County did not have any PWSs produce water in 2015.




| ID | System Name |
|---|---|
| 1 | Brookfield |
| 2 | Chillicothe - CMU |
| 3 | Keytesville |
| 4 | Kirksville |
| 5 | Linn Co. Cons. PWSD #1 |
| 6 | Linn-Livingston PWSD #3 |
| 7 | Livingston Co. PWSD #2 |
| 8 | Macon |
| 9 | Marceline |
| 10 | Meadville |
| 11 | NCMRWC |
| 12 | Mo American - Brunswick |
| 13 | Premium Standard Farms, Inc. |
| 14 | Princeton |
| 15 | Salisbury |
| 16 | Trenton |
| 17 | Unionville |

*Figure 15: Active Public Drinking Water Treatment Facilities in 10 county region.*

As noted in Figure 4 and Appendix C, 28 systems have ceased water treatment activities in the 10-county region since 1980. This regionalization or aggregation of systems is because of reduced source water yield, increasing water quality standards, and expense of maintaining a degrading facility. The reduction in number of water suppliers has placed a strain on more reliable sources within the region, pushing some past a reliability threshold during DOR conditions.

The surface water cluster evaluation determined that five of the six clusters had inadequate sources during a DOR. When these inadequate sources dry up during the drought, they are no longer able to provide any water, until a rainfall event occurs which may allow them to supply a small quantity of water. The cumulative total of treated water demand for these four clusters, given 2015 demands, is 8.406 MGD. This number includes the 0.350 MGD impending demand of the Kraft-Heinz expansion.

The groundwater cluster evaluation determined that 6 of the 9 clusters had inadequate sources based on historical data of wells in the region. In the event of a DOR, their capacity to produce water can be expected to decrease, because they are all based on shallow aquifers. The extent of this decrease is unknown, but once such systems run short of water, they will be inclined to purchase water elsewhere and once they start doing that, it is not likely in their interest to continue producing water once they are connected to larger producers. The cumulative total of treated water demand for these six clusters, given 2015 normal demands, is 0.563 MGD.

The out-of-region cluster evaluation determined that one of the three clusters (a surface water source) had an inadequate source given a dependability question in regards to inter-state conveyance. The total of treated water demand for this cluster is 0.557 MGD.

The cumulative total of inadequate sources serving the 10-county region, based on current treated water normal demand, is 9.526 MGD. The cumulative total was calculated by summing the 2015 treated water demand from those systems determined to have a deficit during the evaluation (including 0.35 MGD from the Kraft-Heinz expansion). Converting this total to raw water requires adding 10 percent or 0.953 MGD, which increases the total regional deficit to 10.479 MGD, based on current demands. Figure 16, below, displays the summary of information from the cluster evaluation sections and displays all of the evaluated clusters proportional to one another. This Regional Source Water Cluster Status graph represents all 18 clusters and 19 water producers in the region.

2015 Treated Water Demand Data and used in Figure 16.

| **2015 Treated Water Demand Data** | Demand on Inadequate Sources (MGD) | Demand on Adequate Sources (MGD) | Total Treated Water Demand in 2015 (MGD) |
|---|---|---|---|
| Surface Water | 8.623 | 2.778 | 11.401 |
| Groundwater | 0.563 | 1.759 | 2.322 |
| Total | 9.186 | 4.537 | 13.723 |

In the 10-county region of study 13 of the 18 clusters, or 14 of the 19 water producers, have inadequate sources of raw water supply. These 13 producers were responsible for 67 percent (9.186 MGD of the 13.723 MGD) of the water supplied to the region in 2015.

In Figure 16, the Surface Water Cluster Status graphic summarizes the five clusters or six producers who have inadequate sources of raw water supply. Overall these producers were responsible for 63 percent (8.623 MGD of the 13.723 MGD) of the total water supplied to the region. In Figure 16, the Groundwater Cluster Status graphic summarizes the six of the 10 clusters which have inadequate sources of raw water supply. Overall these producers were responsible for 13 percent (1.759 MGD of the 13.723 MGD) of the total water supplied to the region.

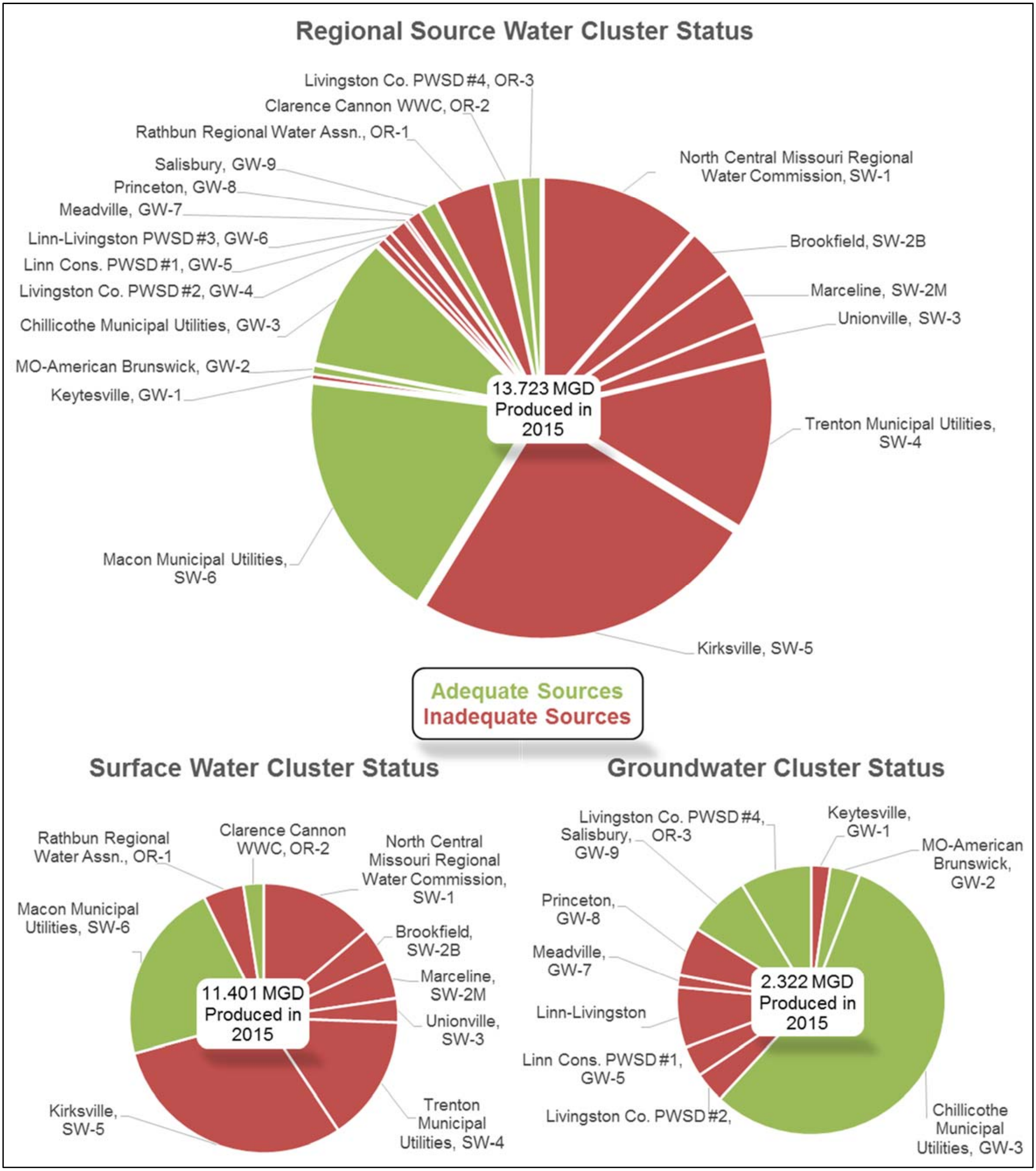
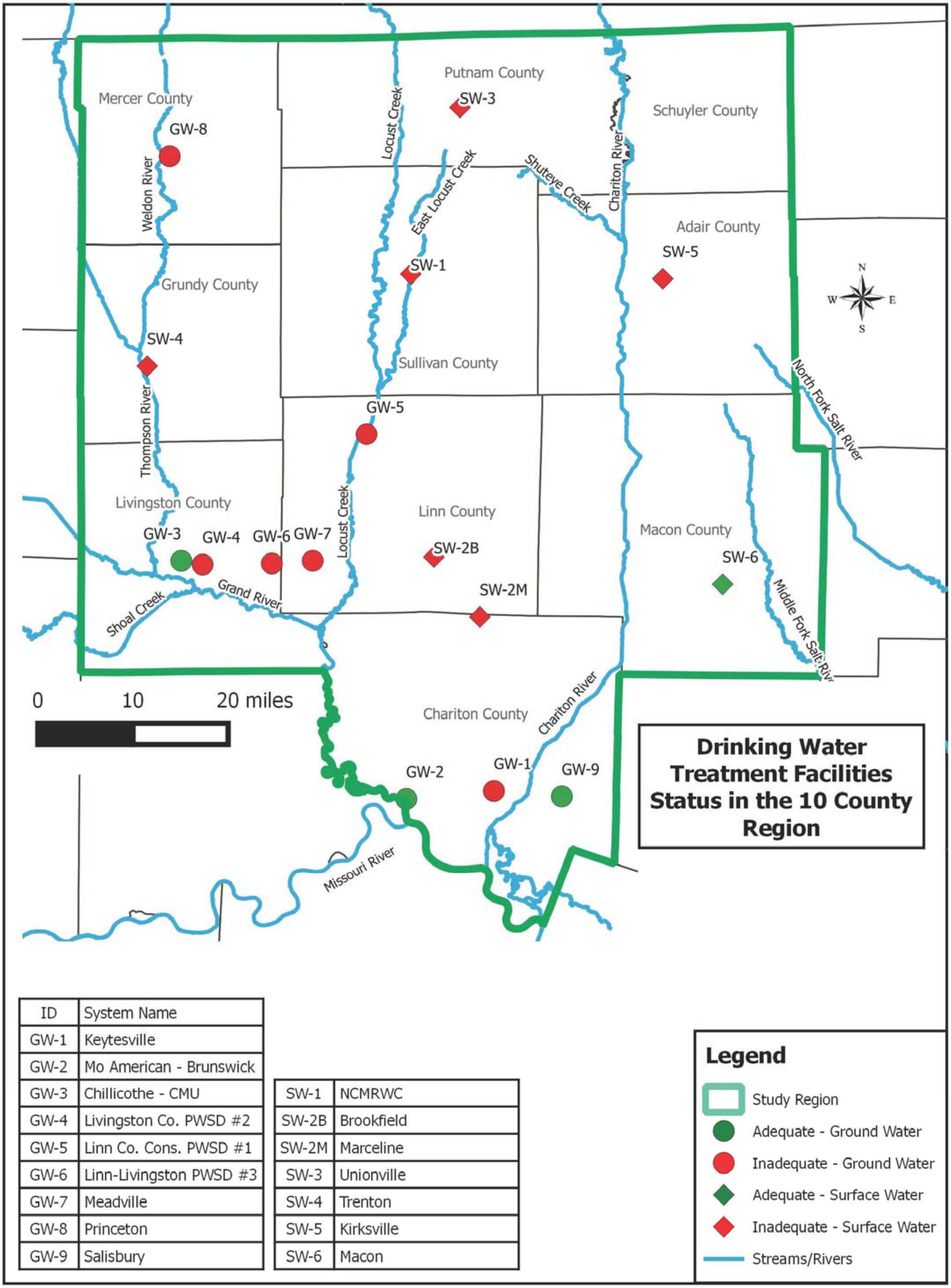



*Figure 16: Summary of Cluster Status and Percent Production*

Figure 17 displays on a map the evaluated clusters and summarizes the determination of their sources as adequate or inadequate.




| ID | System Name |
|---|---|
| GW-1 | Keytesville |
| GW-2 | Mo American - Brunswick |
| GW-3 | Chillicothe - CMU |
| GW-4 | Livingston Co. PWSD #2 |
| GW-5 | Linn Co. Cons. PWSD #1 |
| GW-6 | Linn-Livingston PWSD #3 |
| GW-7 | Meadville |
| GW-8 | Princeton |
| GW-9 | Salisbury |

| | |
|---|---|
| SW-1 | NCMRWC |
| SW-2B | Brookfield |
| SW-2M | Marceline |
| SW-3 | Unionville |
| SW-4 | Trenton |
| SW-5 | Kirksville |
| SW-6 | Macon |

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*Figure 17: Status of Public Drinking Water Treatment Systems in 10-county region.*

## Conclusion

There is a well-documented lack of adequate source water in north-central Missouri. Communities that developed sources, for their own current and future use, are rapidly becoming unintended regional systems as neighboring communities sources continue to deteriorate. The neighboring systems with inadequate sources become dependent upon and place unplanned burden on adequate sources. The result, as shown by the analysis herein, is a 10-county region of north-central Missouri now at risk of running out of water during severe drought conditions. The risk of insufficient water has an impact on community and economic growth.

If a new source(s) is not developed prior to another severe drought event, like that experienced in the 1950s, there will be significant and detrimental impacts made to the communities that call north-central Missouri home. This rural region of Missouri helps provide agri-goods to not only Missouri, but also to surrounding states; therefore, the threat of a no water scenario for 63 percent of users within the region has more broad effect. The impact of wide-spread water shortages on the health and safety of the local population is indisputably negative.

Correcting the 9.186 MGD deficit of inadequate sources by developing new sources will help secure the status quo. New water sources will need to be sized to allow for the support of regional economic growth of existing businesses, as well as for new businesses. Former MDNR Director, Sarah Parker-Pauley, is quoted saying, “Where there is water, there are communities. This is no coincidence” (Pauley 2016).

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# Appendices

A. Regional Map

B. Letter from Well Driller

C. Listing of Closed Systems

D. Map of Closed Systems

E. Map of Treatment Facilities

F. Table of Closed Wells

G. Surface Water Supply Table

H. Stream Low Flow Table

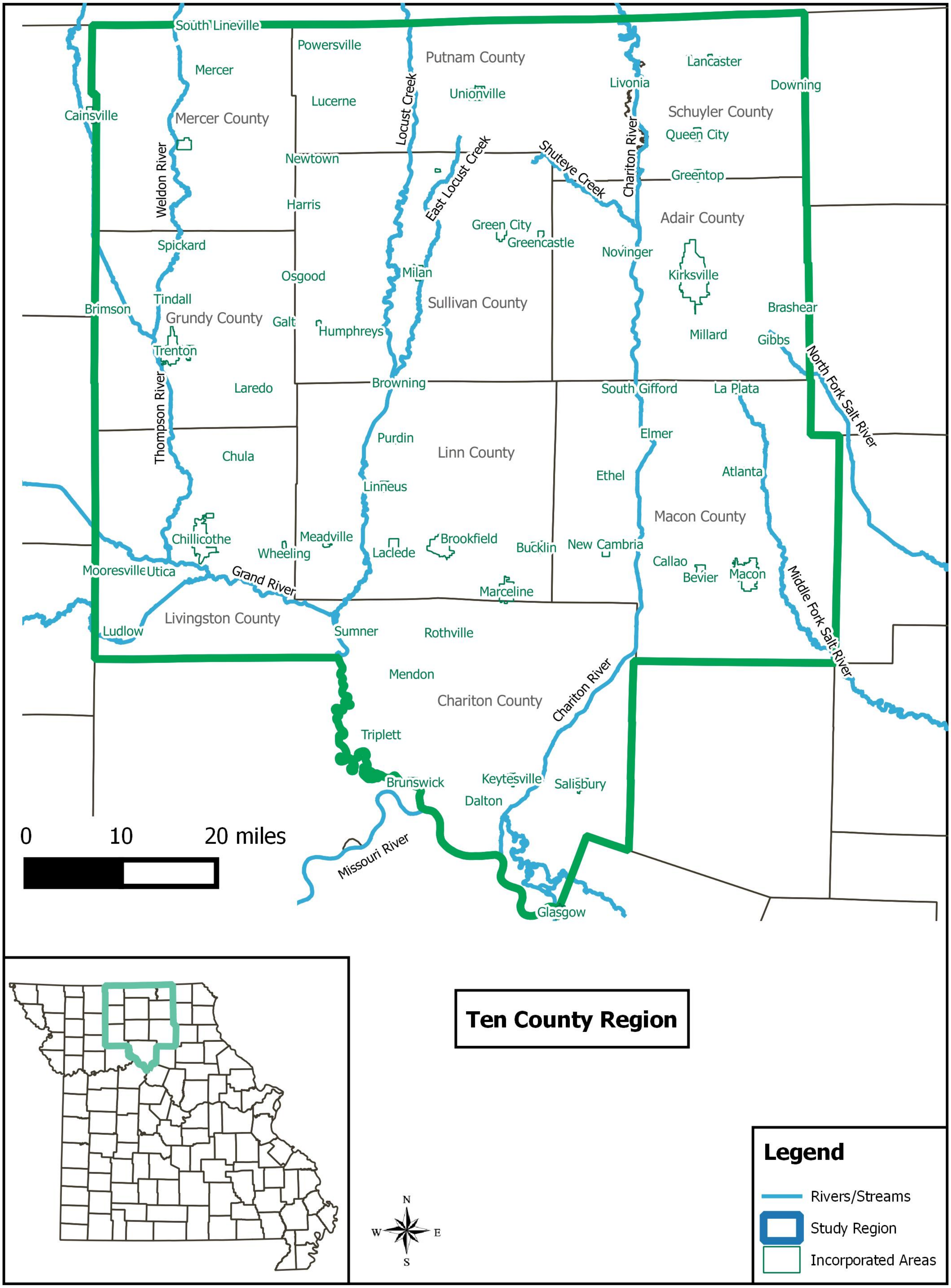
I. Treatment Plant Status

J. Surface Water Cluster Production & Demand Table

K. Groundwater Cluster Production & Demand Table

L. Out-of-Region Cluster Production & Demand Table

# A. Regional Map

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# B. Letter from Well Driller

Brotcke Well & Pump

November 25, 2003

Mr. Don Miller
Linn County PWSD No.1
PO Box 111
Purdin, Missouri 64674

RE: Hydrologic Study

Dear Mr. Miller:

Brotcke Well & Pump is performing a Hydrologic Engineering Study for Linn County CPWSD No. 1. The purpose of the Engineering Study is to locate a well that will have a safe yield of 50 GPM or more. Eleven test holes were completed in this phase of the investigation. They are located along Locust Creek. Presented on the attached map are the locations of the eleven TH. They were located with a hand held GPS device. Therefore their location is approximate. Also presented is our interpretation of the location of previous test-holes. The location and results were obtained from your files.

During test hole drilling soil samples were obtained during the performance of the Standard Penetration Test. This procedure uses a 2-inch split-spoon sampler. Representative samples from the split spoon were placed in glass jars and returned to our laboratory, where the samples were used to edit the Field Boring Logs. Copies of the Boring Logs are enclosed.

We don't feel a suitable formation for a well to produce at least 50 GPM has been encountered. The best TH was TH-9-03. This site at best would be equivalent to your Well No. 3. We do not feel a sustainable 50 GPM well can be constructed at this location.

A summary of previous exploration and current test holes are presented on the enclosed attachment. Where we had ground elevation, the bottom of the aquifer elevation is presented. We understand your best well is located at TH-3-97. As shown, the bottom of the aquifer is about elevation 10 feet. This compares favorably with the Well No. 1 which is at TH-1-66, the bottom elevation is 12 feet. Because of the accuracy in this type work, this elevation should be considered equal. As indicated, the locations are shown on the enclosed site sketch.

After reviewing the TH completed during this phase of study and previous work, we suggest additional exploration be performed. One area which has never been explored is West of Locust Creek. Test hole 4-89 was very poor, but it may be beneficial to explore both North and South of that location.

Brotcke Well & Pump Inc.
Water Supply Services • Geo/Environmental Drilling
750 Merus Court • P.O. Box 1168 • Fenton, Missouri 63026 • (636) 343-3029 • 800-969-3029

A review of the other bottom elevations show all others are about 10 feet to 20 feet higher than the two best Wells, No. 1 and 4. Both are located near the existing water plant. Test Hole 2-97 shows potential for this deeper aquifer. The approximate location is shown on the site map. The test hole report shows 70 feet to the bottom of the aquifer. Depending on the ground elevation, the bottom could be at an elevation in the 10-foot neighborhood.

We recommend that a series of test holes be performed along a line North-South through 2-97. The bedrock valley is apparently very narrow and the TH should be closely spaced to gain the best chance of intersecting the deepest part of the valley.

Brotcke Well & Pump has enjoyed providing these water supply services for the Linn County CPWSD No. 1. For your records we have enclosed the following:

- Field Boring Logs on the eleven test holes.
- Location sketch.
- Test hole summary.

If you have any questions, please do not hesitate to contact us.

Very truly yours,
BROTCKE WELL & PUMP INC.

Mike Thompson
Project Manager

MT/lmv
Enclosure
G:\DIR\Mike\Letters 03\Linn-Miller 11-24-03.doc

Brotcke Well & Pump

# FIELD BORING LOG

**Boring No.** TH-1-03

**Project** LINN CO. PWSD #1 **Job No.** 03286 **Date** 10-20-03

**Location** Purdin, MO **Crew** M. Cox, M. Schaake

**Drilling Method:** ☒ HSA ☒ CFA ☐ Rotary ☐ Rock Coring ☐ Drilling Fluid Bent. Mud

| DEPTH, FT. | | DESCRIPTION | SAMPLE | | | SPT Blows N/6" |
|---|---|---|---|---|---|---|
| FROM | TO | | TYPE | DEPTH, FT. | RECOVERY | |
| 0 | 24 | SILTY CLAY | | | | |
| | | S-1: | SPT | 5-6.5 | 12" | 2-3-4 |
| | | S-2: with some fine sand | SPT | 16-11.5 | 14" | 2-5-5 |
| | | S-3: fine sand layer | SPT | 15-16.5 | 18" | 1-3-3 |
| | | S-4: dark brown | SPT | 20-21.5 | 16" | 1-2-4 |
| | | S-5: gray | SPT | 22.5-24 | 14" | 1-2-3 |
| 24 | 32 | FINE TO MEDIUM SAND | | | | |
| | | S-6: | SPT | 25-26.5 | 12" | 2-6-7 |
| | | S-7: with some coarse sand and few gravels | SPT | 27.5-29 | 6" | 9-6-14 |
| | | S-8: with some coarse sand and gravels | SPT | 30-31.5 | 12" | 6-15-16 |
| 32 | 38 | CLAY/SHALE; gray | | | | |
| | | S-9: | SPT | 32.5-34 | 5" | 4-7-12 |
| | | S-10 | SPT | 35-36.5 | 5" | 12-50-Refusal |
| | | S-11: | SPT | 37.5-39 | 5" | Refusal |
| | 38 | BOTTOM OF HOLE | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

| WATER LEVEL OBSERVATIONS | | | |
|---|---|---|---|
| DURING DRILLING | | | FT. |
| AT COMPLETION | | | FT. |
| AFTER | | HRS | FT. |
| AFTER | | HRS | FT. |
| AFTER | | HRS | FT. |

NOTES

Piezometer Installed ☐ YES ☐ NO

Depth ______ Ft.

39° 58.73N

093° 12.18W

Brotcke Well & Pump

# FIELD BORING LOG

**Boring No.** TH-02-03

**Project** LINN CO. PWSD #1 **Job No.** 03286 **Date** 10-21-03

**Location** Purdin, MO **Crew** M. Cox, M. Schaake

**Drilling Method:** X HSA X CFA ☐ Rotary ☐ Rock Coring ☐ Drilling Fluid Bent. Mud

| DEPTH, FT. | | DESCRIPTION | SAMPLE | | | SPT Blows N/6" |
|---|---|---|---|---|---|---|
| FROM | TO | | TYPE | DEPTH, FT. | RECOVERY | |
| 0 | 22 | SILTY FINE SAND; brown | | | | |
| | | S-1: | SPT | 5-6.5 | 14" | 1-2-2 |
| | | S-2: | SPT | 10-11.5 | 16" | 1-2-2 |
| | | S-3: with some clay | SPT | 15-16.5 | 16" | 1-1-2 |
| | | S-4: Silty Fine Sand to Med. Sand with clay layer | SPT | 18.5-20 | 10" | 2-3-4 |
| 22 | 25 | SANDY GRAY CLAY | SPT | 23.5-25 | 10" | 1-0-4 |
| | | S-5: | | | | |
| 25 | 35 | FINE TO MEDIUM SAND | | | | |
| | | S-6: with coarse sand and trace gravel | SPT | 28.5-30 | 6" | 2-5-5 |
| | | S-7: with trace gravel and clay | SPT | 33.5-35 | 8" | 3-8-10 |
| 35 | 40 | SHALE/CLAY | | | | |
| | | S-8: | SPT | 38.5-40 | 12" | 11-27-34 |
| | 40 | BOTTOM OF HOLE | | | | |
| | | | | | | |
| | | Drilled Through Some Wood @ 20' ± | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

| WATER LEVEL OBSERVATIONS | | | |
|---|---|---|---|
| DURING DRILLING | | | FT. |
| AT COMPLETION | | | FT. |
| AFTER | | HRS | FT. |
| AFTER | | HRS | FT. |
| AFTER | | HRS | FT. |

**NOTES**

**Piezometer Installed** ☐ YES ☒ NO

**Depth** ______ Ft.

39° 58.71N

093° 12.22W

Brotcke Well & Pump

# FIELD BORING LOG

**Boring No.** TH-03-03

**Project** LINN CO. PWSD #1 **Job No.** 03286 **Date** 10-21-03

**Location** Purdin, MO **Crew** M. Cox, M. Schaake

**Drilling Method:** X HSA X CFA ☐ Rotary ☐ Rock Coring ☐ Drilling Fluid Bent. Mud

| DEPTH, FT. | | DESCRIPTION | SAMPLE | | | SPT Blows N/6" |
|---|---|---|---|---|---|---|
| FROM | TO | | TYPE | DEPTH, FT. | RECOVERY | |
| 0 | 11 | SILTY CLAY; brown | | | | |
| | | S-1: | SPT | 5-6.5 | 14" | 2-1-1 |
| | | S-2: with fine sand | SPT | 10-11.5 | 14" | 2-1-1 |
| 11 | 28.5 | FINE SAND | | | | |
| | | S-3: | SPT | 15-16.5 | 14" | 2-3-3 |
| | | S-4: | SPT | 18.5-20 | 6" | 1-2-2 |
| | | S-5: with some medium sand and Clay Layer | SPT | 23.5-25 | 8" | 1-1-2 |
| | | S-6: with some medium sand, Small Clay Layer @ 28.5 | SPT | 28.5-30 | 6" | 3-6-7 |
| 28.5 | 40 | SHALE/CLAY | | | | |
| | | S-7: | SPT | 33.5-35 | 6" | 7-11-11 |
| | | S-8: | SPT | 38.5-40 | 10" | 22-Refusal |
| | 40 | BOTTOM OF HOLE | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | Wood @ 20 ft | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

**WATER LEVEL OBSERVATIONS**

DURING DRILLING ________ FT.
AT COMPLETION ________ FT.
AFTER ____ HRS ____ FT.
AFTER ____ HRS ____ FT.
AFTER ____ HRS ____ FT.

**NOTES** Piezometer Installed ☐ YES ☒ NO
Depth ______ Ft.

39° 58.66N
093° 12.27W



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Brotcke Well & Pump

# FIELD BORING LOG

**Boring No.** TH-04-03

**Project** LINN CO. PWSD #1 **Job No.** 03286 **Date** 10-22-03

**Location** Purdin, MO **Crew** M. Cox, M. Schaake

**Drilling Method:** ☒ HSA ☒ CFA ☐ Rotary ☐ Rock Coring ☐ Drilling Fluid Bent. Mud

| DEPTH, FT. | | DESCRIPTION | SAMPLE | | | SPT Blows N/6" |
|---|---|---|---|---|---|---|
| FROM | TO | | TYPE | DEPTH, FT. | RECOVERY | |
| 0 | 20 | SILTY FINE SAND | | | | |
| | | S-1: | SPT | 5-6.5 | 14" | 3-4-4 |
| | | S-2: | SPT | 10-11.5 | 16" | 1-3-3 |
| | | S-3: with medium sand | SPT | 15-16.5 | 12" | 1-2-2 |
| | | S-4: with some clay | SPT | 18.5-20 | 8" | 1-1-1 |
| 20 | 30 | FINE TO MEDIUM SAND | | | | |
| | | S-5: | SPT | 23.5-25 | 10" | 1-5-6 |
| | | S-6: | SPT | 28.5-30 | 10" | 2-4-4 |
| 30 | 35 | SHALE/CLAY | | | | |
| | | S-7: | SPT | 33.5-35 | 14" | 12-24-Refusal |
| | 35 | BOTTOM OF HOLE | | | | |

**WATER LEVEL OBSERVATIONS**

DURING DRILLING ________ FT.
AT COMPLETION ________ FT.
AFTER ______ HRS ______ FT.
AFTER ______ HRS ______ FT.
AFTER ______ HRS ______ FT.

**NOTES** Piezometer Installed ☐ YES ☐ NO
Depth ______ Ft.

39° 58.62N
093° 12.31W
Medium & Coarse Gravel to 33.5'
Wood @ 25'

Brotcke Well & Pump

# FIELD BORING LOG

**Boring No.** TH-05-03

**Project** LINN CO. PWSD #1 **Job No.** 03286 **Date** 10-22-03

**Location** Purdin, MO **Crew** M. Cox, M. Schaake

**Drilling Method:** X HSA X CFA ☐ Rotary ☐ Rock Coring ☐ Drilling Fluid Bent. Mud

| DEPTH, FT. | | DESCRIPTION | SAMPLE | | | SPT Blows N/6" |
|---|---|---|---|---|---|---|
| FROM | TO | | TYPE | DEPTH, FT. | RECOVERY | |
| 0 | 11 | CLAY | | | | |
| | | S-1: | SPT | 5-6.5 | 14" | 1-1-2 |
| | | S-2: with silty fine sand | SPT | 10-11.5 | 16" | 2-1-1 |
| 11 | 34 | FINE TO MEDIUM SAND | | | | |
| | | S-3: | SPT | 15-16.5 | 16" | 1-1-2 |
| | | S-4: with trace silt | SPT | 18.5-20 | 8" | 1-1-1 |
| | | S-5: with coarse sand | SPT | 23.5-25 | 5" | 2-3-4 |
| | | S-6: with some coarse Sand, 2" Clay Layer | SPT | 28.5-30 | 12" | 4-4-7 |
| 34 | 35 | SHALE/CLAY | | | | |
| | | S-7: | SPT | 33.5-35 | 10" | 8-22-REFUSAL |
| | 35 | BOTTOM OF HOLE | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

| WATER LEVEL OBSERVATIONS | | | |
|---|---|---|---|
| DURING DRILLING | | | FT. |
| AT COMPLETION | | | FT. |
| AFTER | HRS | | FT. |
| AFTER | HRS | | FT. |
| AFTER | HRS | | FT. |

**NOTES** Piezometer Installed ☐ YES ☐ NO

Depth ________ Ft.

39° 58.59N

093° 12.36W

Wood @ 25'

Brotcke Well & Pump

# FIELD BORING LOG

**Boring No.** TH-06-03

**Project** LINN CO. PWSD #1 **Job No.** 03286 **Date** 10-22-03

**Location** Purdin, MO **Crew** M. Cox, M. Schaake

**Drilling Method:** X HSA X CFA ☐ Rotary ☐ Rock Coring ☐ Drilling Fluid Bent. Mud

| DEPTH, FT. | | DESCRIPTION | SAMPLE | | | SPT Blows N/6" |
|---|---|---|---|---|---|---|
| FROM | TO | | TYPE | DEPTH, FT. | RECOVERY | |
| 0 | 11 | SILTY CLAY | | | | |
| | | S-1: | SPT | 5-6.5 | 12" | 3-3-3 |
| | | S-2: | SPT | 10-11.5 | 12" | 2-2-3 |
| 11 | 21 | FINE SILTY SAND | | | | |
| | | S-3: with trace clay | SPT | 15-16.5 | 14" | 2-1-1 |
| | | S-4: | SPT | 18.5-20 | 6" | 1-1-1 |
| 21 | 33 | FINE TO MEDIUM SAND | | | | |
| | | S-5: with some clay and trace gravel | SPT | 23.5-25 | 10" | 2-1-2 |
| | | S-6: with coarse sand | SPT | 28.5-30 | 8" | 3-5-9 |
| 33 | 35 | SHALE/CLAY | | | | |
| | | S-7: | SPT | 33.5-35 | 2" | 23 - |
| | 35 | BOTTOM OF HOLE | | | | |

| WATER LEVEL OBSERVATIONS | | | |
|---|---|---|---|
| DURING DRILLING | | | FT. |
| AT COMPLETION | | | FT. |
| AFTER | | HRS | FT. |
| AFTER | | HRS | FT. |
| AFTER | | HRS | FT. |

**NOTES**

Piezometer Installed ☐ YES ☒ NO

Depth ____ Ft.

39° 58.55N

093° 12.40W

Brotcke Well & Pump

# FIELD BORING LOG

**Boring No.** TH-07-03

**Project** LINN CO. PWSD #1 **Job No.** 03286 **Date** 10-23-03

**Location** Purdin, MO **Crew** M. Cox, M. Schaake

**Drilling Method:** X HSA X CFA ☐ Rotary ☐ Rock Coring ☐ Drilling Fluid Bent. Mud

| DEPTH, FT. FROM | TO | DESCRIPTION | SAMPLE TYPE | SAMPLE DEPTH, FT. | RECOVERY | SPT Blows N/6" |
|---|---|---|---|---|---|---|
| 0 | 11 | SILTY CLAY | | | | |
| | | S-1: | SPT | 5-6.5 | 10" | 3-3-3 |
| | | S-2: | SPT | 10-11.5 | 18" | 2-2-2 |
| 11 | 21 | CLAYEY FINE SAND | | | | |
| | | S-3: | SPT | 15-16.5 | 16" | 1-1-1 |
| | | S-4: | SPT | 18.5-20 | 8" | 3-2-2 |
| 21 | 33 | FINE TO COARSE SAND WITH TRACE GRAVEL | | | | |
| | | S-5: with some clay | SPT | 23.5-25 | 10" | 3-6-7 |
| | | S-6: | SPT | 28.5-30 | 14" | 5-12-14 |
| 33 | 33.5 | SHALE/CLAY | | | | |
| | | S-7: | SPT | 33.5-35 | 6" | Refusal |
| | 33.5 | BOTTOM OF HOLE | | | | |

**WATER LEVEL OBSERVATIONS**

DURING DRILLING ______ FT.
AT COMPLETION ______ FT.
AFTER ______ HRS ______ FT.
AFTER ______ HRS ______ FT.
AFTER ______ HRS ______ FT.

**NOTES** Piezometer Installed ☐ YES ☐ NO
Depth ______ Ft.

39° 58.53N
093° 12.43W

Brotcke Well & Pump

# FIELD BORING LOG

**Boring No.** TH-08-03

**Project** LINN CO. PWSD #1 **Job No.** 03286 **Date** 10-27-03

**Location** Purdin, MO **Crew** M. Cox, M. Schaake

**Drilling Method:** ☒ HSA ☒ CFA ☐ Rotary ☐ Rock Coring ☐ Drilling Fluid Bent. Mud

| DEPTH, FT. | | DESCRIPTION | SAMPLE | | | SPT Blows N/6" |
|---|---|---|---|---|---|---|
| FROM | TO | | TYPE | DEPTH, FT. | RECOVERY | |
| 0 | 11 | SANDY CLAY | | | | |
| | | S-1: | SPT | 5-6.5 | 14" | 3-6-5 |
| | | S-2: | SPT | 10-11.5 | 14" | 3-3-1 |
| 11 | 37 | FINE TO MEDIUM SAND | | | | |
| | | S-3: with some silt | SPT | 15-16.5 | 14" | 1-1-2 |
| | | S-4: with trace silt and gravel | SPT | 18.5-20 | 12" | 3-4-11 |
| | | S-5: | SPT | 23.5-25 | 10" | 2-3-5 |
| | | S-6: with coarse sand and gravel | SPT | 28.5-30 | 4" | 12-8-7 |
| | | S-7: with coarse sand and gravel | SPT | 33.5-35 | 5" | 9-3-3 |
| 37 | 50 | SHALE/CLAY | | | | |
| | | S-8: | SPT | 38.5-40 | 10" | 3-7-8 |
| | | S-9: | SPT | 43.5-45 | 8" | 3-5-7 |
| | | S-10: with some sand | SPT | 48.5-50 | 4" | 3-5-7 |

**WATER LEVEL OBSERVATIONS**

DURING DRILLING ______ FT.
AT COMPLETION ______ FT.
AFTER ______ HRS ______ FT.
AFTER ______ HRS ______ FT.
AFTER ______ HRS ______ FT.

**NOTES** Piezometer Installed ☐ YES ☒ NO
Depth ______ Ft.
39° 59.32N
093° 11.31W

Brotcke Well & Pump

# FIELD BORING LOG

**Boring No.** TH-09-03

**Project** LINN CO. PWSD #1 **Job No.** 03286 **Date** 10-28-03

**Location** Purdin, MO **Crew** M. Cox, M. Schaake

**Drilling Method:** ☒ HSA ☒ CFA ☐ Rotary ☐ Rock Coring ☐ Drilling Fluid Bent. Mud

| DEPTH, FT. | | DESCRIPTION | SAMPLE | | | SPT Blows N/6" |
|---|---|---|---|---|---|---|
| FROM | TO | | TYPE | DEPTH, FT. | RECOVERY | |
| 0 | 17 | CLAY | | | | |
| | | S-1: | SPT | 5-6.5 | 12" | 3-4-4 |
| | | S-2: | SPT | 10-11.5 | 16" | 2-2-2 |
| | | S-3: with fine sand | SPT | 15-16.5 | 16" | 1-2-2 |
| 17 | 10 | FINE TO MEDIUM SAND | | | | |
| | | S-4: with some clay | SPT | 18.5-20 | 14" | 2-2-2 |
| | | S-5: with some clay | SPT | 23.5-25 | 14" | 1-2-3 |
| | | S-6: | SPT | 28.5-30 | 14" | 3-7-9 |
| 31 | 36 | FINE TO COARSE SAND WITH GRAVEL | | | | |
| | | S-7: | SPT | 33.5-35 | 16" | 7-9-12 |
| 36 | 43 | SHALE/CLAY | | | | |
| | | S-8: | SPT | 38.5-40 | | Refusal |
| | 43 | BOTTOM OF HOLE | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

**WATER LEVEL OBSERVATIONS**

DURING DRILLING ______ FT.
AT COMPLETION ______ FT.
AFTER ______ HRS ______ FT.
AFTER ______ HRS ______ FT.
AFTER ______ HRS ______ FT.

**NOTES**

Piezometer Installed ☐ YES ☒ NO
Depth ______ Ft.

39° 58.45N
093° 12.51W

Brotcke Well & Pump

# FIELD BORING LOG

**Boring No.** TH-10-03

**Project** LINN CO. PWSD #1 **Job No.** 03286 **Date** 10-29-03

**Location** Purdin, MO **Crew** M. Cox & M. Schaake

**Drilling Method:** X HSA X CFA ☐ Rotary ☐ Rock Coring ☐ Drilling Fluid Bent. Mud

| DEPTH, FT. | | DESCRIPTION | SAMPLE | | | SPT Blows N/6" |
|---|---|---|---|---|---|---|
| FROM | TO | | TYPE | DEPTH, FT. | RECOVERY | |
| 0 | 21 | CLAY | | | | |
| | | S-1: | SPT | 5-6.5 | 12" | 4-4-4 |
| | | S-2: with fine sand | SPT | 10-11.5 | 16" | 3-3-4 |
| | | S-3: with fine sand | SPT | 15-16.5 | 16" | 3-4-3 |
| | | S-4: with Fine Sand and Wood | SPT | 18.5-20 | 16" | 4-3-2 |
| 21 | 36 | FINE SAND | | | | |
| | | S-5: with traces of Wood | SPT | 23.5-25 | 12" | 3-3-3 |
| | | S-6: with some med sand and trace clay | SPT | 28.5-30 | 8" | 5-8-9 |
| | | S-7: with some med. to coarse sand & Gravel | SPT | 33.5-35 | 6" | 8-13-17 |
| 36 | 40 | SHALE/CLAY | | | | |
| | | S-8: | SPT | 38.5-40 | 14" | 13-17-30 |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

| WATER LEVEL OBSERVATIONS | | | |
|---|---|---|---|
| DURING DRILLING | | | FT. |
| AT COMPLETION | | | FT. |
| AFTER | | HRS | FT. |
| AFTER | | HRS | FT. |
| AFTER | | HRS | FT. |

**NOTES**

**Piezometer Installed** ☐ YES ☒ NO

**Depth** ______ **Ft.**

39° 58.37N

093° 12.57W

Brotcke Well & Pump

# FIELD BORING LOG

**Boring No.** TH-11-03

**Project** LINN CO. PWSD #1 **Job No.** 03286 **Date** 10-29-03

**Location** Purdin, MO **Crew** M. Cox & M. Schaake

**Drilling Method:** ☒ HSA ☒ CFA ☐ Rotary ☐ Rock Coring ☐ Drilling Fluid Bent. Mud

| DEPTH, FT. FROM | DEPTH, FT. TO | DESCRIPTION | SAMPLE TYPE | SAMPLE DEPTH, FT. | SAMPLE RECOVERY | SPT Blows N/6" |
|---|---|---|---|---|---|---|
| 0 | | CLAY | | | | |
| | | S-1: | SPT | 5-6.5 | 12" | 2-2-3 |
| | | S-2: | SPT | 10-11.5 | 14" | 1-1-2 |
| | | S-3: | SPT | 15-16.5 | 20" | 0-1-1 |
| | | S-4: with some fine sand | SPT | 18.5-20 | 16" | 1-3-3 |
| 21 | 33 | FINE TO MEDIUM SAND | | | | |
| | | S-5: with trace clay | SPT | 23.5-25 | 10" | 1-1-3 |
| | | S-6: with trace clay and gravel | SPT | 28.5-30 | 8" | 1-2-4 |
| 33 | 35 | SHALE/CLAY | | | | |
| | | S-7: | SPT | 33.5-35 | 10" | 7-9-13 |
| | 35 | BOTTOM OF HOLE | | | | |

**WATER LEVEL OBSERVATIONS**

DURING DRILLING ______ FT.
AT COMPLETION ______ FT.
AFTER ______ HRS ______ FT.
AFTER ______ HRS ______ FT.
AFTER ______ HRS ______ FT.

**NOTES** Piezometer Installed ☐ YES ☒ NO
Depth ______ Ft.
39° 58.31N
093° 12.60W


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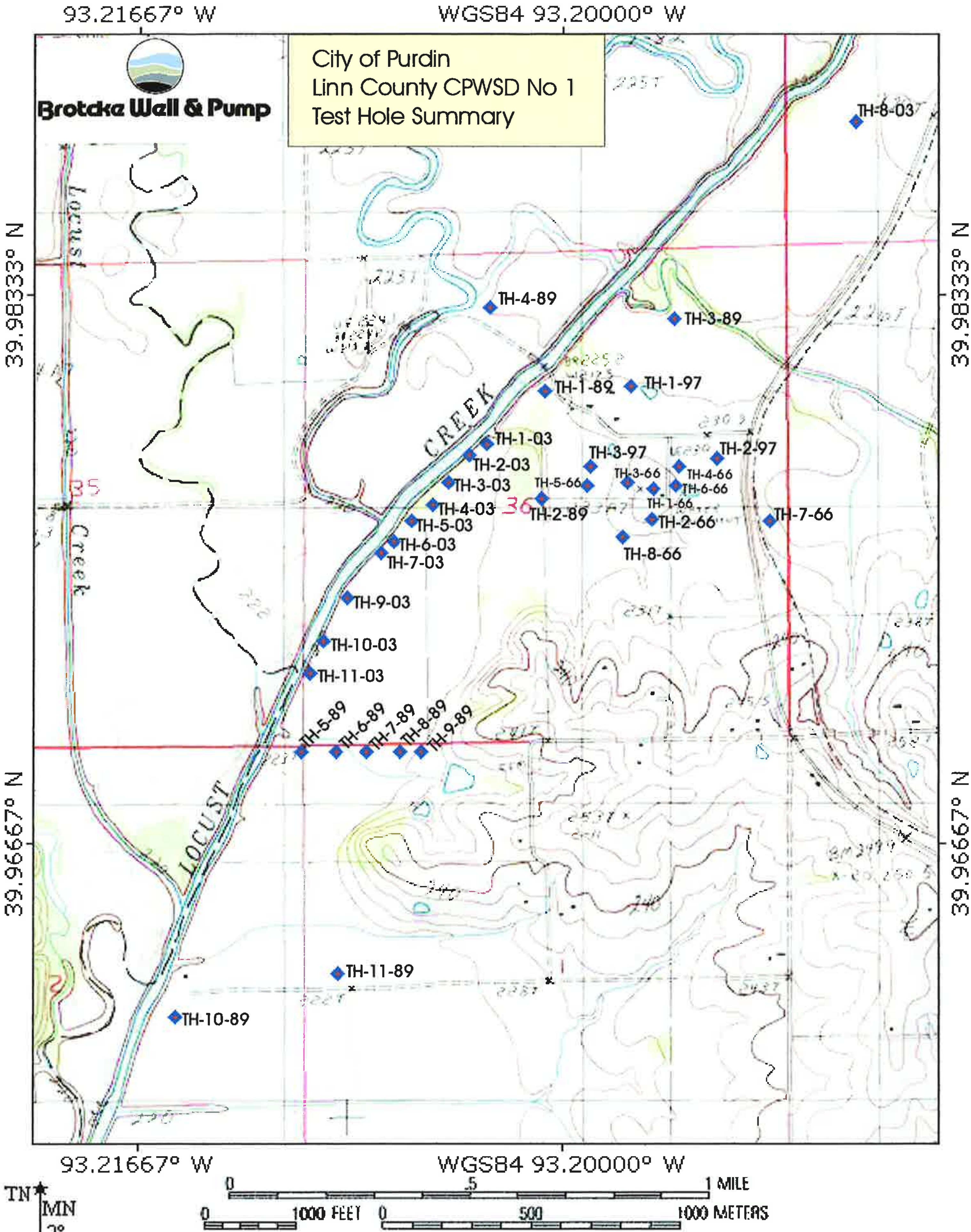
City of Purdin
Linn County CPWSD No 1
Test Hole Summary
Brotcke Well & Pump
93.21667° W
WGS84 93.20000° W
39.98333° N
39.96667° N
LOCUST CREEK
Locust Creek
35
36
TH-8-03
TH-4-89
TH-3-89
TH-1-89
TH-1-97
TH-1-03
TH-2-03
TH-3-03
TH-4-03
TH-5-03
TH-6-03
TH-7-03
TH-9-03
TH-10-03
TH-11-03
TH-3-97
TH-2-97
TH-5-66
TH-3-66
TH-4-66
TH-6-66
TH-1-66
TH-2-89
TH-2-66
TH-7-66
TH-8-66
TH-5-89
TH-6-89
TH-7-89
TH-8-89
TH-9-89
TH-11-89
TH-10-89
TN
MN
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1 MILE
1000 FEET
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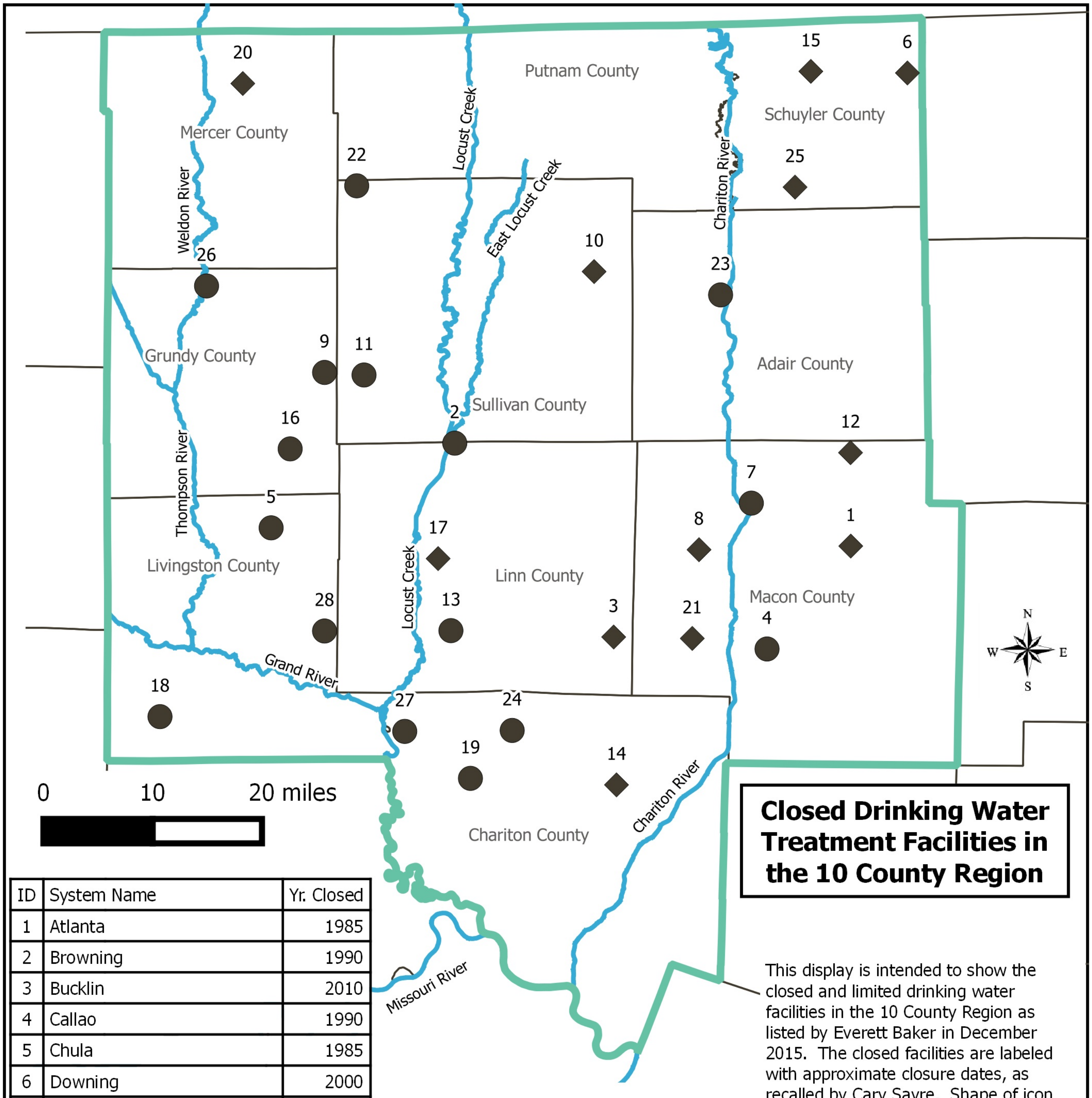
1000 METERS

# C. Listing of Closed Systems

| Inactive Sources Within Clusters | | | | | | |
|---|---|---|---|---|---|---|
| Current Cluster | 2015 Treated Water Demand | Type | System Name | County | Source | Year of Closure |
| GW-3 | 0.077 | Ground Water | Livingston PWSD #1 | Livingston | Failed wells (declining yield, likely due to iron/silt, drilled approx. 28 test wells with low yield); closed plant; now purchase water from Chillicothe | 2005 |
| GW-4 | 0.197 | Ground Water | Chula | Livingston | Failed wells (declining yield, likely due to iron/silt); closed plant; now purchase water from Livingston #2 | 1985 |
| GW-6 | 0.013 | Ground Water | Laredo | Grundy | Failed wells (declining yield, likely due to iron/silt); closed plant; now purchase water from Linn-Livingston #3 | 2000 |
| GW-6 | 0.028 | Surface Water | Linneus | Linn | Inadequate lake (heavily silted, high organic matter, supplemented with Locust Creek when dry); closed plant; now purchase water from Linn-Livingston #3 | 2005 |
| GW-6 | 0.02 | Ground Water | Wheeling | Livingston | Well (declining yield, likely due to iron/silt); closed plant; now purchase water from Linn-Livingston #3 | 1980 |
| GW-8 | 0.024 | Surface Water | Mercer | Mercer | Inadequate lake (shallow and heavily silted); closed plant; now purchase water from Princeton | 1990 |
| OR-1 | 0.026 | Surface Water | Downing | Schuyler | Inadequate lake (shallow and heavily silted); closed plant; now purchase water from Schuyler CPWSD #1 | 2000 |
| OR-1 | 0.065 | Surface Water | Lancaster | Schuyler | Inadequate lake (shallow and heavily silted); closed plant; now purchase water from Rathbun | 2002 |
| OR-1 | 0.24 | Surface Water | Schuyler CPWSD #1 | Schuyler | Inadequate lake and treatment facility; closed plant; now purchase water from Rathbun and Putnam PWSD #1 | 2002 |
| OR-3 | 0.04 | Surface Water | Jamesport | Daviess | Inadequate lake (shallow and heavily silted); closed plant; now purchase water from Livingston #4 | 2010 |
| OR-3 | 0.001 | Surface Water | Breckenridge | Caldwell | Inadequate lake; supplemented from Grand River well; closed inadequate treament plant; now served water from Livingston #4 | 2014 |
| SW-1 | 0.017 | Ground Water | Browning | Sullivan | Failed wells (declining yield, likely due to iron/silt); closed plant; now purchase water from Sullivan PWSD #1 | 1990 |
| SW-1 | 0.122 | Surface Water | Green City | Sullivan | Inadequate lakes to demand; single stage treatment facility became inadequate; closed plant; now purchase water from NCMRWC | 2005 |
| SW-1 | 0.007 | Ground Water | Humphreys | Sullivan | Failed wells (declining yield, likely due to iron/silt); closed plant; now purchase water from Sullivan PWSD #1 | 1990 |
| SW-1 | 0.016 | Ground Water | Newtown | Sullivan | Failed wells (declining yield, likely due to iron/silt); closed plant; now purchase water from Sullivan PWSD #1 | 1995 |
| SW-2 | 0.017 | Surface Water | Bucklin | Linn | Inadequate lake (shallow and heavily silted); struggled with disinfection-by-products; closed plant; now purchase water from | 2010 |
| SW-2 | N/A | Surface Water | Ethel | Macon | Inadequate lake (shallow and heavily silted); closed inadequate treatment plant; adsorbed by Chariton-Linn #3 | 1990 |
| SW-2 | 0.031 | Ground Water | Laclede | Linn | Failed shallow wells (declining yield, likely due to iron/silt); closed plant; now purchase water from Brookfield | 1980 |
| SW-2 | N/A | Surface Water | Lake Nehai Tonkayea | Chariton | Inadequate treatment plant; difficulty maintaining qualified operator; closed plant; adsorbed by Chariton-Linn #3 | 1990 |
| SW-2 | N/A | Ground Water | Mendon | Chariton | Failed shallow wells (declining yield, high in iron); closed plant; now purchase water from Chariton-Linn #3 | 2004 |
| SW-2 | N/A | Surface Water | New Cambria | Macon | Inadequate lake (shallow and heavily silted); closed inadequate treatment plant; adsorbed by Chariton-Linn #3 | 1990 |
| SW-2 | N/A | Ground Water | Rothville | Chariton | Failed shallow wells (declining yield, high in iron); closed plant; adsorbed by Chariton-Linn #3 | 1990 |
| SW-2 | N/A | Ground Water | Sumner | Chariton | Failed shallow wells with declining yield; closed plant; adsorbed by Chariton-Linn #3 | 2008 |
| SW-4 | 0.021 | Ground Water | Galt | Grundy | Failed shallow wells (declining yield, high in iron); closed plant; now purchase water from Grundy PWSD #1 | 1990 |
| SW-4 | 0.028 | Ground Water | Spickard | Grundy | Failed shallow wells (declining yield); closed plant; now purchase water from Linn-Livingston #3 | 1985 |
| SW-5 | 0.079 | Surface Water | La Plata | Macon | Inadequate lakes; closed inadequate treament plant; now purchase water from Adair PWSD #1 | 2000 |
| SW-5 | 0.026 | Ground Water | Novinger | Adair | Failed shallow wells (declining yield); closed plant; now purchase water from Adair PWSD #1 | 2005 |
| SW-6 | 0.02 | Surface Water | Atlanta | Macon | Inadequate lake; struggled with disinfection-by-products; closed plant; now purchase water from Macon | 1985 |
| SW-6 | 0.024 | Ground Water | Callao | Macon | Failed shallow wells (declining yield); closed plant; now purchase water from Macon PWSD #1 | 1990 |
| SW-6 | 0.005 | Ground Water | Elmer | Macon | Failed shallow wells (declining yield, likely due to iron/silt); closed plant; now purchase water from Macon PWSD #1 | 1985 |

# D. Map of Closed Systems




# Closed Drinking Water Treatment Facilities in the 10 County Region

This display is intended to show the closed and limited drinking water facilities in the 10 County Region as listed by Everett Baker in December 2015. The closed facilities are labeled with approximate closure dates, as recalled by Cary Sayre. Shape of icon indicates whether the plant is/was fed by ground or surface water.

| ID | System Name | Yr. Closed |
|---|---|---|
| 1 | Atlanta | 1985 |
| 2 | Browning | 1990 |
| 3 | Bucklin | 2010 |
| 4 | Callao | 1990 |
| 5 | Chula | 1985 |
| 6 | Downing | 2000 |
| 7 | Elmer | 1985 |
| 8 | Ethel | 1990 |
| 9 | Galt | 1990 |
| 10 | Green City | 2005 |
| 11 | Humphreys | 1990 |
| 12 | La Plata | 2000 |
| 13 | Laclede | 1980 |
| 14 | Lake Nehai Tonkayea | 1990 |
| 15 | Lancaster | 2002 |
| 16 | Laredo | 2000 |
| 17 | Linneus | 2005 |
| 18 | Livingston Co. PWSD #1 | 2005 |

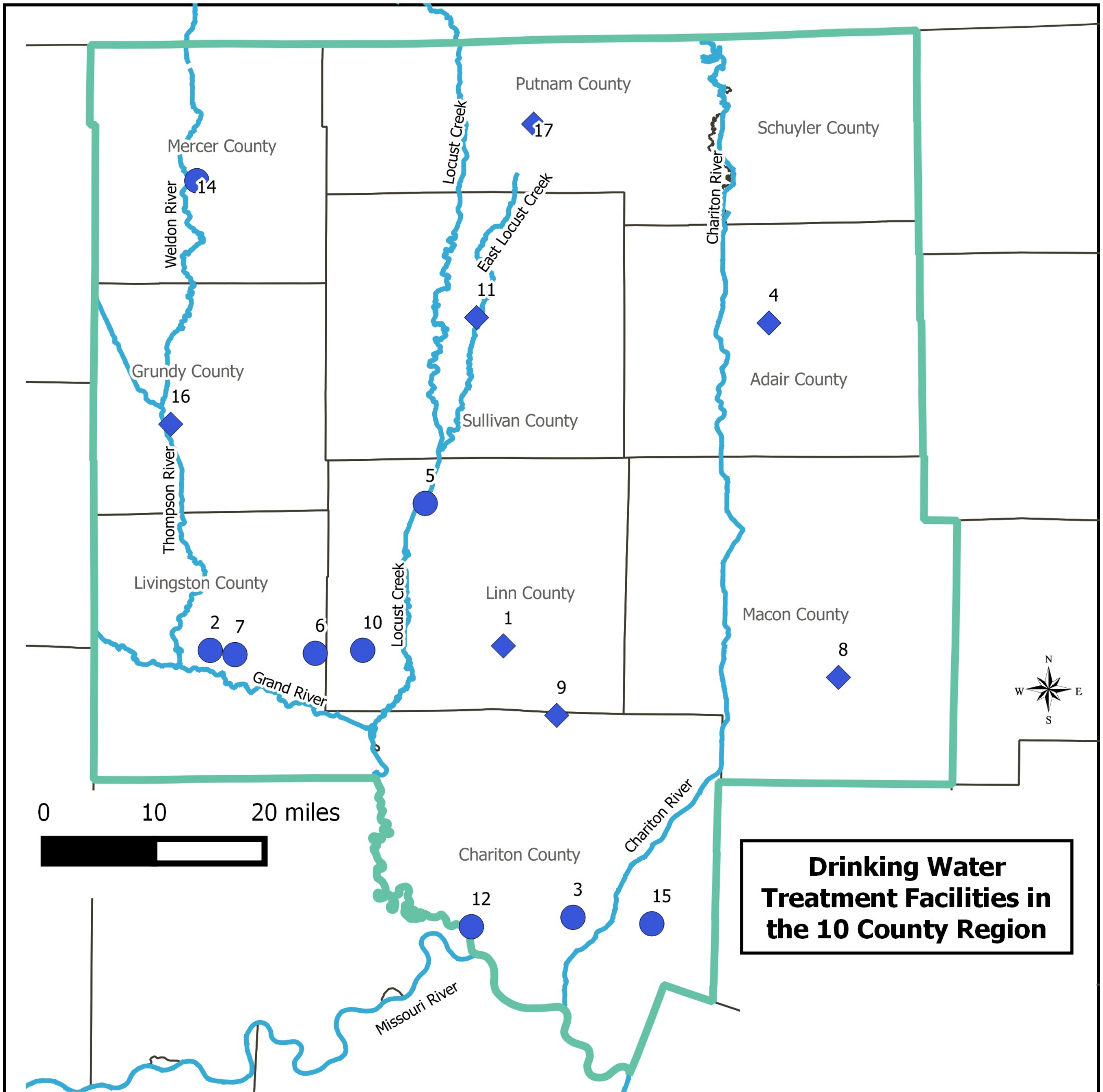
| ID | System Name | Yr. Closed |
|---|---|---|
| 19 | Mendon | 2004 |
| 20 | Mercer | 1990 |
| 21 | New Cambria | 1990 |
| 22 | Newtown | 1995 |
| 23 | Novinger | 2005 |
| 24 | Rothville | 1990 |
| 25 | Schuyler Co. Cons. PWSD #1 | 2002 |
| 26 | Spickard | 1985 |
| 27 | Sumner | 2008 |
| 28 | Wheeling | 1980 |

**Legend**

- Study Region
- Inactive - Ground Water
- Inactive - Surface Water
- Streams/Rivers

QGIS Version: 2.14.5-Essen Path: J:/CARES/Quantum Projects/Missouri Water Supply 2.8noF.qgs

# E. Map of Treatment Facilities




# Drinking Water Treatment Facilities in the 10 County Region

| ID | System Name |
|---|---|
| 1 | Brookfield |
| 2 | Chillicothe - CMU |
| 3 | Keytesville |
| 4 | Kirksville |
| 5 | Linn Co. Cons. PWSD #1 |
| 6 | Linn-Livingston PWSD #3 |
| 7 | Livingston Co. PWSD #2 |
| 8 | Macon |
| 9 | Marceline |

| | |
|---|---|
| 10 | Meadville |
| 11 | NCMRWC |
| 12 | Mo American - Brunswick |
| 13 | Premium Standard Farms, Inc. |
| 14 | Princeton |
| 15 | Salisbury |
| 16 | Trenton |
| 17 | Unionville |

**Legend**

Study Region
Active - Ground Water
Active - Surface Water
Streams/Rivers

QGIS Version: 2.14.5-Essen Path: J:/CARES/Quantum Projects/Missouri Water Supply 2.8noF.qgs

# F. Table of Closed Wells

Closed Wells in the 10 County Study Region
From MDNR Water Well Log Data Set

| PWSSNAME | LOCALNAME | FED_TYPE | STATUS | DRILLDATE | ABAN | PLUG | MATERIAL | Form_TD | TOTDEPTH | STATICLEVE | YIELD | HEAD | DRAWDOWN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Novinger | Well #2, Old Well | C | Plugged | 1977 | 0 | 1999 | Unconsolidated | Alluvium | 43 | 20 | 83 | 0 | 10 |
| Chillicothe Municipal Utilities | Well #6 TEST HOLE | C | Abandoned | 0 | 0 | 0 | Unconsolidated | Glacial Deposits | 135 | 0 | 0 | 158 | 0 |
| Chillicothe Municipal Utilities | Well #7 TEST HOLE | C | Abandoned | 0 | 0 | 0 | Unconsolidated | Glacial Deposits | 135 | 0 | 0 | 158 | 0 |
| Keytesville | Well #2, T53N R18W Chariton (Sec 5) | C | Plugged | 1959 | 0 | 2006 | Unconsolidated | Alluvium | 50 | 20 | 10 | 53 | 1 |
| Keytesville | Well #3 | C | Plugged | 1986 | 0 | 2006 | Unconsolidated | Alluvium | 64 | 16 | 7 | 63 | 1 |
| Keytesville | Well #1, T53N R18W Chariton (Sec 5) | C | Plugged | 1936 | 0 | 2006 | Unconsolidated | Alluvium | 47 | 26 | 11 | 53 | 1 |
| Lake Nehai Tonkayea | Chariton | NP | Inactive | 1970 | 0 | 0 | Unconsolidated | Alluvium | 51 | 6 | 80 | 0 | 14 |
| Linn-Livingston Co. PWSD #3 | Well #2, New Well | C | Inactive | 1982 | 0 | 0 | Unconsolidated | Glacial Deposits | 138 | 60 | 235 | 0 | 16 |
| Livingston Co. PWSD #1 | Well #1 | C | Inactive | 1967 | 0 | 0 | Unconsolidated | NULL | 0 | 24 | 104 | 0 | 22 |
| Livingston Co. PWSD #1 | Well #2 (WRC monitoring well) | C | Observation Well | 1967 | 0 | 0 | Unconsolidated | Glacial Deposits | 79 | 7 | 100 | 0 | 60 |
| Livingston Co. PWSD #1 | Well #3 | C | Inactive | 1989 | 0 | 0 | Unconsolidated | Glacial Deposits | 83 | 27 | 114 | 0 | 0 |
| Livingston Co. PWSD #2 | Well #1 | C | Inactive | 1964 | 0 | 0 | Unconsolidated | Glacial Deposits | 181 | 91 | 94 | 0 | 68 |
| Livingston Co. PWSD #2 | Well #2 | C | Inactive | 1988 | 0 | 0 | Unconsolidated | Glacial Deposits | 139 | 53 | 240 | 0 | 110 |
| Livingston County R-I School | Well #1, School Wellhouse | NTNC | Inactive | 0 | 0 | 0 | Unconsolidated | Glacial Deposits | 65 | 0 | 0 | 0 | 0 |
| Mendon | Well #1 | C | Observation Well | 1955 | 0 | 0 | Unconsolidated | Alluvium | 52 | 0 | 0 | 0 | 0 |
| Mendon | Well #2 | C | Inactive | 1955 | 0 | 0 | Unconsolidated | Alluvium | 54 | 0 | 0 | 0 | 0 |
| Novinger | Well #1 | C | Plugged | 1958 | 1976 | 1986 | Unconsolidated | Alluvium | 44 | 8 | 210 | 125 | 20 |
| Novinger | Well #3, New Well | C | Plugged | 1982 | 0 | 1999 | Unconsolidated | Alluvium | 43 | 29 | 83 | 0 | 8 |
| Princeton | Well #3 | C | Inactive | 1971 | 0 | 0 | Unconsolidated | Alluvium | 38 | 15 | 133 | 132 | 14 |
| Princeton | Well #1 | C | Plugged | 1973 | 0 | 2009 | Unconsolidated | Alluvium | 38 | 15 | 90 | 0 | 8 |
| Princeton | Well #1, Old | C | Plugged | 0 | 1995 | 1995 | Unconsolidated | NULL | 0 | 10 | 0 | 0 | 0 |
| Princeton | Well #12 | C | Plugged | 0 | 1995 | 1995 | Unconsolidated | NULL | 0 | 10 | 0 | 0 | 0 |
| Princeton | Well #13 | C | Plugged | 0 | 1995 | 1995 | Unconsolidated | NULL | 0 | 10 | 0 | 0 | 0 |
| Princeton | Well #5 | C | Plugged | 0 | 0 | 2002 | Unconsolidated | NULL | 0 | 0 | 0 | 0 | 0 |
| Princeton | Well #7 | C | Plugged | 1978 | 0 | 2002 | Unconsolidated | Alluvium | 42 | 13 | 100 | 100 | 13 |
| Princeton | Well #2B | C | Plugged | 1968 | 0 | 2002 | Unconsolidated | Alluvium | 41 | 14 | 100 | 100 | 30 |
| Sumner | Well #1 | C | Inactive | 0 | 0 | 0 | Unconsolidated | Glacial Deposits | 75 | 0 | 0 | 0 | 0 |
| Sumner | Well #2 | C | Inactive | 0 | 0 | 0 | Unconsolidated | Glacial Deposits | 35 | 0 | 0 | 0 | 0 |

This data is from http://drinkingwater.missouri.edu/gisdata/metadata/spwswell.html collected on 8/30/2016 by A. Jones

# G. Surface Water Supply Table

| Surface Water Supply(s) Within Cluster | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Cluster Current Demand | | Raw Water Yield: Without Pumping, With Sediment Loading | | | | | | | | |
| Cluster | Lake/ Reservoir | Normal Treated (MGD) | Normal Raw (MGD) | Source Yield Capacity (MGD) | Cluster Yield Capacity (MGD) | Excess Capacity (Cluster Yield-Cluster Normal Raw Demand) MGD | Lake Purpose (S=water supply, R=recreation, C=flood control) in order of importance | Year Dam Built | Surface Area (acre) | Total Volume (ac.-ft.) | Water Supply Volume (ac.-ft.) |
| SW-1 | Elmwood Reservoir | 1.622 | 1.629 | 0.800 | 0.940 | -0.689 | S, R | 1972 | 194.8 | 2503.2 | 2416.5 |
| SW-1 | Milan Lake (Golf Course) | | | 0.140 | | | S, R | 1940 | 41.0 | 555.21 | 500.27 |
| SW-2 | Brookfield Lake | 1.014 | 1.115 | 0.180 | 0.600 | -0.515 | S, R | 1959 | 107.9 | 2070.3 | 1948.2 |
| SW-2 | Brookfield Reservoir | | | n/a | | | S | | | | |
| SW-2 | Old Marceline Lake | | | n/a | | | S | | | | |
| SW-2 | Marceline Lake (New) | | | 0.420 | | | S, R | 1980 | 172.8 | 1990 | 1812 |
| SW-3 | Unionville Reservoir | 0.33 | 0.363 | 0.200 | 0.200 | -0.163 | S, R | 1941 | 73.5 | 620 | 430 |
| SW-4 | Trenton Lower Reservoir | 1.78 | 1.958 | 0.000 | 0.000 | -1.958 | S | | | | |
| SW-4 | Trenton Upper Reservoir | | | 0.000 | | | S | | | | |
| SW-5 | Forest Lake* | 2.51 | 2.76 | 2.691 | 4.040 | -0.120 | R, S | 1951 | 585.2 | 12500 | 10,380 |
| SW-5 | Hazel Creek Lake* | 1.27 | 1.40 | 1.349 | | | R, S | 1982 | 501.7 | 8680 | 7,230 |
| SW-6 | Long Branch Lake | 2.5 | 2.75 | 3.400 | 3.400 | 0.650 | C, S, R | | | | |

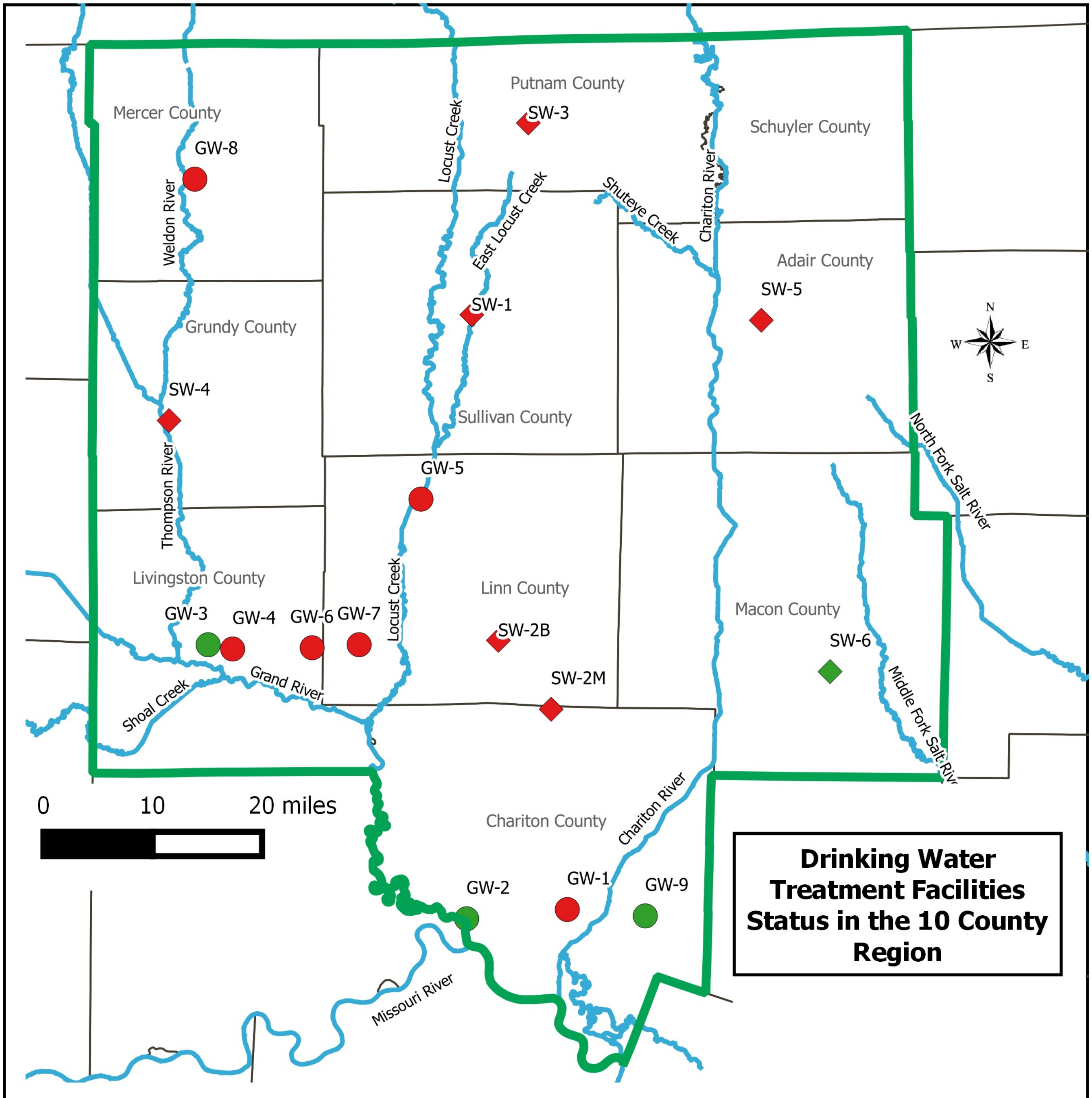
* Normal Treated Demands were proportionaly increased to account for the 0.35 MGD Kraft-Heinz expansion.

# H. Stream Low Flow Table

| Results from USGS Low Flow Equations* for Stream Intakes in 10 County Region | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Inputs | | | Outputs | | |
| Cluster | Supplier | PWSSID | Intake | Drainage Area ($Mi^2$) | Length (mi) | Stream Variable | 7Q10 (MGD) | 30Q10 (MGD) | 60Q10 (MGD) |
| SW-1 | NCMRWC | 2021537 | Locust Creek at Intake | 217.63 | 44.08 | 0.745 | 0.264 | 0.568 | 0.921 |
| SW-2 | Marceline | 2010497 | Mussel Fork at Intake | 146.7 | 55.6 | 0.695 | 0.100 | 0.229 | 0.284 |
| SW-2 | Brookfield | 2010105 | West Yellow Creek at intake | 195.27 | 54.7 | 0.659 | 0.258 | 0.546 | 0.723 |
| SW-4 | Trenton | 2010796 | Thompson River at Intake | 1722.3 | 155.46 | 0.714 | 6.268 | 8.673 | 12.949 |

* Computed Statistics at Streamgages, and Methods for Estimated Low-Flow Frequency Statistics and Development of Regional Regression Equations for Estimating Low Flow Frequency Statistics at Ungaged Locations in Missouri, USGS 2013

# I. Treatment Plant Status




| ID | System Name |
|---|---|
| GW-1 | Keytesville |
| GW-2 | Mo American - Brunswick |
| GW-3 | Chillicothe - CMU |
| GW-4 | Livingston Co. PWSD #2 |
| GW-5 | Linn Co. Cons. PWSD #1 |
| GW-6 | Linn-Livingston PWSD #3 |
| GW-7 | Meadville |
| GW-8 | Princeton |
| GW-9 | Salisbury |

| | |
|---|---|
| SW-1 | NCMRWC |
| SW-2B | Brookfield |
| SW-2M | Marceline |
| SW-3 | Unionville |
| SW-4 | Trenton |
| SW-5 | Kirksville |
| SW-6 | Macon |

QGIS Version: 2.14.5-Essen Path: J:/CARES/Quantum Projects/Missouri Water Supply 2.8noF.qgs

# J. Surface Water Cluster Production & Demand Table

| 2015-2016 Cluster Average Daily Production and Demand (Treated Water Quantities) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Source Cluster | Tier System | | | | | MGD Produced | % purchase from supplier | Total MGD Consumed |
| | 1st | 2nd | 3rd | 4th | 5th | | | |
| SW-1 | North Central Missouri Regional Water Commission | | | | | 1.572 | | n/a |
| | | Green City | | | | | 100% | 0.122 |
| | | | Green Castle | | | | 100% | 0.034 |
| | | Milan | | | | | 100% | 0.180 |
| | | Sullivan County PWSD #1 | | | | | 100% | 0.274 |
| | | | Browning | | | | 100% | 0.017 |
| | | | Humphreys | | | | 100% | 0.007 |
| | | | Newtown | | | | 100% | 0.016 |
| | | Premium Standard Farms (RAW Supply) | | | | | | 0.923 |
| SW-2 | Brookfield | | | | | 0.494 | | 0.376 |
| | | Laclede | | | | | 100% | 0.031 |
| | | Chariton-Linn PWSD #3 | | | | | 25% | 0.351 |
| | | | Bucklin | | | | 100% | 0.017 |
| | | | Mendon | | | | 100% | 0.018 |
| | | | Chariton PSWD #2 | | | | 35% | 0.049 |
| | Marceline | | | | | 0.52 | | 0.257 |
| | | Chariton-Linn PWSD #3 | | | | | 75% | 0.351 |
| | | | Bucklin | | | | 100% | 0.017 |
| | | | Mendon | | | | 100% | 0.018 |
| | | | Chariton PSWD #2 | | | | 35% | 0.049 |
| SW-3 | Unionville | | | | | 0.33 | | 0.150 |
| | | Putnam County PWSD #1 | | | | | 68% | 0.207 |
| | | | Lake Thunderhead HOA | | | | 100% | 0.021 |
| | | | Adair PWSD #1 | | | | 0.75% | 0.463 |
| | | | | Brashear | | | 100% | 0.014 |
| | | | | LaPlata | | | 100% | 0.079 |
| | | | | Novinger | | | 100% | 0.026 |
| | | | | Macon County PWSD #1 | | | 1% | 0.014 |
| | | | | | Callao | | 100% | 0.024 |
| | | | | | Clarence | | 100% | 0.065 |
| | | | | | Elmer | | 100% | 0.005 |
| SW-4 | Trenton Municipal Utilies | | | | | 1.718 | | 1.477 |
| | | Grundy County PWSD #1 | | | | | 100% | 0.241 |
| | | | Galt | | | | 100% | 0.021 |
| | | | Spickard | | | | 100% | 0.028 |
| SW-5 | Kirksville | | | | | 3.432 | | 2.969 |
| | | Adair PWSD #1 | | | | | 99% | 0.463 |
| | | | Brashear | | | | 100% | 0.014 |
| | | | LaPlata | | | | 100% | 0.079 |
| | | | Novinger | | | | 100% | 0.026 |
| | | | Macon County PWSD #1 | | | | 1% | 0.014 |
| | | | | Callao | | | 100% | 0.024 |
| | | | | Clarence | | | 100% | 0.065 |
| | | | | Elmer | | | 100% | 0.005 |
| SW-6 | Macon | | | | | 2.5 | | |
| | | Atlanta | | | | | 100% | 0.020 |
| | | Bevier | | | | | 100% | 0.056 |
| | | Macon County PWSD #1 | | | | | 81% | 1.232 |
| | | | Callao | | | | 100% | 0.024 |
| | | | Clarence | | | | 100% | 0.065 |
| | | | Elmer | | | | 100% | 0.005 |

# K. Groundwater Cluster Production & Demand Table

| 2015-2016 Cluster Average Daily Production and Demand (Treated Water Quantities) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Source Cluster | Tier System | | | | | MGD Produced | % purchase from supplier | Total MGD Consumed |
| | 1st | 2nd | 3rd | 4th | 5th | | | |
| GW-1 | Keytesville | | | | | 0.0530 | | 0.031 |
| | | Chariton PWSD #2 | | | | | 45% | 0.049 |
| GW-2 | Mo American Brunswick | | | | | 0.0841 | | 0.057 |
| | | Chariton PWSD #2 | | | | | 55% | 0.049 |
| GW-3 | Chillicothe Municipal Utilities | | | | | 1.3 | | 0.893 |
| | | Livingston Co. PWSD #1 | | | | | 100% | 0.077 |
| | | Livingston Co. PWSD #2 | | | | | 49% | 0.151 |
| | | | Chula | | | | 100% | 0.016 |
| | | Livingston Co. PWSD #3 East | | | | | 100% | 0.197 |
| | | | Hale | | | | 100% | 0.043 |
| GW-4 | Livingston Co. PWSD #2 | | | | | 0.0865 | 51% | 0.151 |
| | | Chula | | | | | 100% | 0.016 |
| GW-5 | Linn Consolidated PWSD #1 | | | | | 0.085 | | 0.085 |
| GW-6 | Linn-Livingston PWSD #3 | | | | | 0.168062 | | 0.107 |
| | | Laredo | | | | | 100% | 0.013 |
| | | Linneus | | | | | 100% | 0.028 |
| | | Wheeling | | | | | 100% | 0.020 |
| GW-7 | Meadville | | | | | 0.0335 | | 0.034 |
| GW-8 | Princeton | | | | | 0.137 | | 0.080 |
| | | Mercer | | | | | 100% | 0.024 |
| | | Mercer County PWSD #1 | | | | | 5% | 0.033 |
| GW-9 | Salisbury | | | | | 0.1750 | | 0.175 |

# L. Out-of-Region Cluster Production & Demand Table

| 2015-2016 Cluster Average Daily Production and Demand (Treated Water Quantities) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Source Cluster | Tier System | | | | | MGD Produced | % purchase from supplier | Total MGD Consumed |
| | 1st | 2nd | 3rd | 4th | 5th | | | |
| OR-1 | Rathbun | | | | | 0.557 | | |
| | | Lancaster | | | | | 100% | 0.065 |
| | | | Glenwood | | | | 100% | 0.133 |
| | | Mercer County PWSD #1 | | | | | 95% | 0.160 |
| | | Putnam County PWSD #1 | | | | | 32% | 0.207 |
| | | | Lake Thunderhead HOA | | | | 100% | 0.021 |
| | | Schuyler County CPWSD #1 | | | | | 100% | 0.266 |
| | | | Downing | | | | 100% | 0.026 |
| | | | Adair PWSD #1 | | | | 0.25% | 0.463 |
| | | | | Brashear | | | 100% | 0.014 |
| | | | | LaPlata | | | 100% | 0.079 |
| | | | | Novinger | | | 100% | 0.026 |
| | | | | Macon County PWSD #1 | | | 1% | 0.014 |
| | | | | | Callao | | 100% | 0.024 |
| | | | | | Clarence | | 100% | 0.065 |
| | | | | | Elmer | | 100% | 0.005 |
| OR-2 | Clarence Cannon | | | | | 0.278 | | |
| | | Macon County PWSD #1 | | | | | 18% | 1.523 |
| | | | Callao | | | | 100% | 0.024 |
| | | | Clarence | | | | 100% | 0.080 |
| | | | Elmer | | | | 100% | 0.005 |
| OR-3 | Livingston Co. PWSD 4 | | | | | 0.34 | | 0.200 |
| | | Jamesport | | | | | 100% | 0.040 |
| | | Daviess PWSD #2 | | | | | 40% | 0.100 |
| | | | Jameson | | | | 100% | 0.006 |
| | | | Breckenridge | | | | 100% | 0.001 |
| | | | Hamilton | | | | 22% | 0.050 |
| | | | | Caldwell County PWSD #2 | | | 100% | |